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Modelling coaching practice: the role of instruction and demonstration

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In this paper, we review the empirical literature pertaining to the effectiveness of instructions and movement demonstrations. Initially, we examine existing theories and approaches that try to explain the process of skill acquisition so as to determine implications of these theories for instructional provision. This is followed by an evaluation of studies in the motor learning literature in which pre-practice information has been manipulated. Explicit learning strategies are contrasted to implicit and discovery learning methods, and current explanations for instructional effects are discussed in terms of such mechanisms as effects-related attentional focus and movement variability. In the final sections, we review data from our own laboratory where pre-practice information has been manipulated during the learning of a novel bimanual coordination task. From these studies, proposals are made to try and explain how pre-practice information works to effect the process of skill acquisition, including the selection and execution of a response and the processing of associated feedback. An important role is given to the existing skills of the learner in understanding the instructions and performing the desired movement. Finally, we suggest some practical implications of this empirical evidence for the teaching of motor skills.

Keywords: augmented information, motor learning, skill acquisition.

Introduction

Performance analysis of sport has been used primarily to inform the coaching process. Objective information about an athlete's performance is used by the coach to design the practice environment and, subsequently, aid in the modification of athlete behaviour. Therefore, the 'practice session' itself can be considered a critical element in the development of skilled athletic performance. During this 'practice session', effective instruction may be crucial to the pursuit of optimal sporting performance, as the more effective the instruction, the more the instructor's role will benefit athlete performance. Such instruction requires the application of skills that range from the planning and organization of learning experiences to the presentation of instructional and feedback information. Hence, one of the defining roles of the coach is that of instructor. As an instructor, the coach is responsible for teaching the athlete what to do, how to do it and, hopefully, how to do it well. This may involve providing instruction about optimal movement patterns or feedback on errors relating to specific task goals. Instruction can be provided in various modalities and at particular times. For example, the coach may provide a visual demonstration to the learner before any experience with the to-be-learned skill, provide instruction verbally during or after execution, possibly relating to performance of the whole skill, or home in on specific aspects of the skill. Here, we investigate the role that pre-practice information plays in learning a motor skill. We operationally define instruction and demonstration as information given to athletes by the coach at the start of practice (i.e. before physical practice begins) or during practice but independently of performance. Information provided during or after performance is considered feedback and will not be dealt with in detail here.

Although there is considerable empirical evidence of the correct methods for coaches and teachers in providing feedback to athletes and learners generally (More and Franks, 1996; Franks, 1997; Hughes and Franks, 1997), less is known about the effectiveness of

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instruction and demonstration. Despite the shortage of unequivocal empirical evidence to support the provision of pre-practice information, most coaching education programmes sanction its use and consider it to be a key factor in teaching motor skills. A physical education (PE) researcher specialist commented: 'It would be a strange PE lesson, indeed it would be a rare PE lesson, if some form of physical demonstration was not shown to some or all of the pupils' (Blake, 1998: 59).

In fact, little scientific consensus exists about the role pre-practice information plays in the learning process, beyond the sometimes necessary role of relaying to the learner the goals of the task. This gap in knowledge is particularly interesting given that augmented feedback during and after skill execution has received marked attention in the motor learning literature. In their most recent motor control and learning textbook, Schmidt and Lee (1998) echo these sentiments by concluding their section on pre-practice conditions with the following statement: 'few investigations have been carried out on the nature of instructions, and much work remains to be done in assessing their value in learning' (p. 289).

In this paper, we review research that has focused on the effectiveness of pre-practice information for learning motor skills and suggest some guidelines for 'best practice' coaching behaviour that is based on this empirical evidence. First, we discuss the theory underlying these research findings and the implications of these theories for providing pre-practice information. We include a discussion of traditional motor learning theories (e.g. Adams, 1971; Schmidt, 1976) and other approaches that posit a primary role for movement representations (e.g. Fitts and Posner, 1967; Bandura, 1986). Additionally, we discuss less prescriptive approaches with an emphasis on the constraints in the motor system that are responsible for the emerging movement.

We then review empirical findings and contrast explicit learning strategies with more implicit discovery learning environments. Different performance goals are examined, such as criterion templates, demonstrations and verbal instructions, and we try to determine the mechanisms underlying these various instructional methods, including focus of attention and movement variability. These various performance goals, how they influence the emerging movement and, in turn, are influenced by pre-existing skills and the results of the movement, are subsequently illustrated in a flow diagram (see Fig. 1). In the final sections, we present a series of experiments from our laboratory in which we examined the effects of different instructional variables on the learning of novel bi-manual coordination movements. We discuss how various performance goals affect the selection of a movement response and the subsequent processing of feedback. We end with a table that outlines some of the practical implications of the research reviewed for the teaching of motor skills.

Motor learning theory and implications for instruction and demonstration

Classic theories of skill acquisition

The question of how people acquire novel motor skills has long been a topic of interest. This dates back to the early work of the behaviourists (e.g. Thorndike, 1927; Skinner, 1953), when the outcome of the movement and the determination of environmental contingencies were of primary significance. With the cognitive revolution came an associated interest in the processes responsible for learning new behaviours and concepts related to information processing. In motor behaviour, two theories have received most attention. These are Adams' (1971) closed-loop theory of motor control, highly influenced by the field of cybernetics, and Schmidt's (1975, 1976, 1988) schema theory, whereby motor programs are proposed to be responsible for movement execution, much like software programs in computers.

Schmidt and Adams proposed that learning results in the development of two representations of the movement in memory, either actual memory traces (Adams, 1971) or abstractions called 'schemas' (Schmidt, 1975). These representations are responsible for initiating the movement and evaluating its effectiveness both during and after execution. The perceptual trace or recognition schema is responsible for evaluating the effectiveness of the response and, therefore, acts as a reference mechanism to compare the actual sensory consequences with those desired. After practice, the perceptual trace represents those sensory or feedback characteristics of the correct response, whereas the recognition schema allows the learner to estimate the expected sensory consequences of an action, because general (invariant) features of the movement are stored. Given the importance of the detection and recognition of errors in both Adams' and Schmidt's theories, pre-practice information, which is designed to refine the movement template (trace or schema), should be important in aiding this process. Such information that allows the learner to extract easily and efficiently the expected response, either in verbal or visual form, would arguably aid the development of a reference with which feedback about the movement can be compared (see also Swinnen, 1996). This assumption only holds, however, if a movement template is there to begin.

Pre-practice information might easily influence the response that is evoked or selected in the early stages of skill acquisition, when the learner is unable to perform the desired action. If the learner has an existing general program for the movement, as a result of previous experience with similar skills, then information relating to correct parameter selection would possibly be important (e.g. how much force to apply to the movement to achieve a required distance). Pre-practice demonstrations might also provide elaboration for a movement reference after some practice at the required skill has been attained. If the general motor program has not yet been established, but the response components are relatively simple, then perhaps information concerning invariant features should be emphasized, or made salient (e.g. a demonstration showing the correct order of components). However, when the movement response has not been performed before or is sufficiently novel, it is difficult to know what type of information would be most effective in aiding the development of a new motor program. No explicit mention was made by Schmidt or Adams about how these movement representations become established. Given that response-produced sensory feedback has been central to the development of these models and that this information forms the basis of a movement store, it is unclear how sensory information in the absence of action (i.e. a demonstration) would or could be used (for a discussion of these limitations, see Schmidt, 2001).

Other representational-based accounts of skill acquisition

Variations to representational-based theories and mechanisms have been proposed to underlie skill acquisition. Gentile (1972) proposed that acquisition of a general motor pattern, or what she referred to as 'getting an idea of the movement', preceded either refinement or diversification of the general pattern, depending on the environmental conditions. Whiting and den Brinker (1982) also distinguished two motor images that are acquired through practice. First, the 'image of the act', where the learner is primarily concerned with attaining the task goal and acquiring the form of the movement; secondly, a model of the forces to be overcome called 'the image of achievement'. Franks and Wilberg (1982) found that early learners of a tracking task developed a general image of the required movement – as evidenced by drawings – much like the 'image of the act' proposed by Whiting and den Brinker.

During this early stage of motor skill acquisition, understanding the task is the primary goal. Fitts and Posner (1967) claimed that during this so-called cognitive stage, instructions and movement demonstrations are most important in aiding the development of an executive program. This cognitive stage, which is believed to be primarily verbal, shares similarities with stage models of acquisition proposed by Anderson (1982) and Adams (1971), whereby procedures and rules for performing a task get proceduralized, or become more automatic and less verbal with practice. In the early stage of acquisition, Fitts and Posner (1967) proposed that processing of feedback and attending to important cues is critical for learning. Therefore, instructions that serve to emphasize these cues are recommended, such as attending to the feet when dancing. Although very influential in motor learning, Fitts and Posner's theory has been somewhat limited to observations of individuals learning information-processing skills with primarily cognitive or perceptual demands, such as language skills or reaction time studies, rather than difficult motor components. Additionally, much of the theorizing was based on anecdotes and interviews with instructors. Indeed, some recent research has questioned these earlier speculations as to good practice methods. For example, Wulf *et al.* (1998) found that, during the acquisition of novel whole-body movements – ski-like movements on a simulator – encouraging participants to pay attention to their limbs was detrimental to the acquisition process.

Fitts and Posner (1967) also attributed a primary role to habits in influencing the learning of new skills and proposed that 'The learning of skills is largely a matter of transfer of prior habits to new situations' (p. 19). Subsequently, instructions that serve to elicit previously learned behaviours were proposed to be important in activating the appropriate 'cognitive sets and expectancies' (p. 20) and providing a language for understanding the new task. However, in which circumstances this instruction would be appropriate and benefit acquisition was not elaborated, although they argued that 'These general sets will contain aspects both appropriate to the new learning and inappropriate to it' (p. 20).

Another influential motor skills researcher was Edwin Fleishman. In several studies, primarily directed at aiding training and selection protocols for the military (e.g. Fleishman, 1957; Parker and Fleishman, 1959, 1961), Fleishman and colleagues identified changing patterns of ability as a function of practice. For example, Parker and Fleishman (1959) found that spatial–verbal ability, as assessed by pencil-and-paper tests, was an important predictor of performance early in acquisition of a motor skill, supporting the work of Fitts and Posner. As practice progressed, this cognitive ability was replaced by psychomotor ability; finally, coordination skill accounted for the most variance at the end of practice on a tracking task.

Parker and Fleishman (1961) subsequently went on to manipulate verbal instruction relevant to these basic abilities on a tracking task. Their aim was to devise task-appropriate training strategies in which basic abilities were maximized at different stages throughout practice.

Performance based on this training strategy was found to be better than that of a non-instructed control group, although the differences were not so marked when comparisons were made with a 'common-sense' training group. Based on these findings, it is tempting to conclude that instructions about coordination skills should perhaps be given later in practice and demands on cognitive resources kept to a minimum early in acquisition. Decreasing cognitive demands early in acquisition would enable problem-solving capabilities to be devoted to the task, rather than implementing and understanding instructions and movement demonstrations.

More recently, Ackerman and colleagues (e.g. Ackerman, 1988, 1992; Ackerman and Cianciolo, 2000) expanded on Fleishman's original ideas and provided an integrated theory of individual differences based on the skill acquisition framework of Fitts and Posner (1967) and Shiffrin and Schneider (1977). Shiffrin and Schneider (1977) proposed that shifts in processing demands from controlled or highly cognitive to more automatic as a function of practice only arose when the stimulus–response components of the task were consistent. Using a complex air-traffic control task, which integrated both simple and complex task components, Ackerman (1992) showed that general cognitive abilities were most predictive of performance at the early stages of skill acquisition for task components with consistent information-processing demands. However, for more complex task components, cognitive abilities maintained high performance predictability throughout practice. The implications of this work is that individual differences in general cognitive functioning will play a significant role throughout the acquisition process and that for more complex tasks, or task components, the ability of the learner to translate and use information effectively will be important.

Another highly influential theory of learning, again based on the development of movement representations, is the social learning theory of Bandura (1969, 1977). This cognitive-behavioural theory of learning has been the predominant theory guiding research into learning through observation – so-called modelling. A spatial or imaginal system and a verbal system were proposed to underlie the development of movement representations. Verbal mediation allowed for a representation of the model's behaviour and enabled categorization. The spatial representation was proposed to be most important early in the development stage, when the capacity to verbalize was not available or not well developed. Both visual and verbal instructions and demonstrations were believed to influence learning in similar ways in cognitively developed adults. Bandura (1986) proposed several cognitive processes underlying effective modelling. The learner must selectively attend to the relevant information, retain this information, have the capability for using the information and have the desire or motivation to imitate the behaviour.

In terms of pre-practice information, these proposals have important implications for both attentional focus, specifically the determination of 'relevant' information, and movement capability. Obviously, there must be no apparent physical limitations to modelling the desired movement, although whether this implies that the movement response should already be an existing part of an individual's movement repertoire is questionable. If a person cannot perform the response on the first practice trial, does this mean they will not have the capability to use the information? Perhaps one of the criticisms of Bandura's work is the simplistic nature of the response that has been modelled. Often a response is required that places more demands on the cognitive aspects, such as remembering a specific sequence, rather than learning to perform complex motor components (e.g. Carroll and Bandura, 1982, 1985, 1987). This research will be discussed in more detail in the next section.

Alternative, non-representational accounts of learning and perception

Although motor learning research has been predominately explained by the development and strengthening of movement representations that guide production, there are alternative theories. Dynamical systems theory (see Kelso, 1995, for a review) seeks to explain behaviour by variables that bring about a change in movement; as such, movement is seen as a consequence, or an emergent property, of these variables. In this way, movement solutions are discovered as a result of external variables or constraints, such as feedback from the environment and demands on speed, as well as internal constraints, such as prior learning and the physical structure of the motor system. Newell (1986) emphasized the importance of the task in constraining and shaping the final movement. Task requirements, which may be specified by instructions and demonstrations, act to determine the movement, but only against the backdrop of the internal and external constraints that were previously detailed.

Given the emergent nature of behaviour, a reduced emphasis on movement form as the instructed goal of the action might be expected (see Davids *et al.*, 1994). Less direct methods of teaching, such as changing the physical conditions in the environment, would help bring about change in movement form. Although both the dynamical approach and more representational-based accounts of learning have their own strengths and weaknesses, dynamical systems theory offers new tools to tackle the issues of what is learned and what methods best facilitate this learning process. Through the study of inter-limb coordination, Kelso and colleagues (e.g. Kelso, 1984; Haken *et al.*, 1985; Kelso *et al.*, 1986; Schöner *et al.*, 1992) have identified stable modes of coordination that allow the learning of novel patterns to be examined in comparison to preferences for pre-existing stable movements. Knowledge of these existing behaviours offers a way of understanding how pre-practice information influences the selection of an initial response and the resulting refinement and change in these initial behaviours.

The movement pattern is described or quantified by an order parameter, or collective variable. In inter-limb coordination, this order parameter has been the relative position of one limb in relation to the position of the other limb at predetermined temporal and spatial markers. Two basic patterns dominate bi-manual co-ordination and are produced in a reliable and stable fashion. These are symmetrical in-phase movements, characterized by simultaneous flexion and extension of homologous muscle groups (0° relative phase), and asymmetrical anti-phase movements, which are described by alternating flexion and extension of homologous muscles (180° relative phase).

In several experiments, the stability of these patterns has been demonstrated through manipulation of speed constraints. As movement frequency is increased, the anti-phase pattern becomes less stable than the in-phase pattern. This resulting variability in the observed movement can lead to a transition from, or reorganization of, the anti-phase pattern to in-phase (Kelso, 1984). Given that two people who sat facing each other also showed similar transitions between limbs (Schmidt *et al.*, 1990), the implication is that environmental constraints alone (i.e. vision) are sufficient to elicit this change in behaviour. The instructions given to participants have been shown to play a role in influencing the time and indeed exhibition of these transitions. Instructions to a performer to resist intentionally switching to another movement pattern act as higher-order task constraints influencing the observed movement. Lee *et al.* (1996) showed that, under instructions to resist a switch from anti-phase to in-phase coordination at high movement speeds, participants could indeed avoid any transitions to the in-phase pattern. The difficulty in maintaining the anti-phase pattern, however, was indexed by high variability in the resulting movement. This finding illustrates the importance of taking into consideration the task demands, environmental demands and the existing skills of the individual when explaining and predicting behaviour.

One of the important concepts of dynamical systems theory and associated research into coordination dynamics is the notion of stability and its complement, variability. Dynamic systems need to have the capacity to change and, therefore, some variability in a response is necessary to promote change. Bernstein (1967) proposed that the process of skill acquisition is often accompanied by increased variability in the constituent limbs and joints underlying the movement and that, to discover new patterns of coordination, stability has to be sacrificed. Previously stable configurations of joints are freed to allow a more skilful performance (see Arutyunyan *et al.*, 1968; Vereijken *et al.*, 1992b, who have demonstrated this progression in sport skills). An implication for early instruction is that it is important to encourage initial variability in the movement response, or at least not to discourage it, such that stable adherence to non-desirable movement patterns is avoided.

Given the importance of the environment and, in particular, visual perception in constraining or dictating the movement, there has been a move to examine the influence of demonstrations on motor learning from a constraints-led perspective. This approach has been founded on Gibsonian principles of direct perception (e.g. Gibson, 1979), where perception and action are believed to be integrally coupled. As such, the performer is able to pick-up directly information of functional relevance to the task at hand. This direct pick-up of information is not believed to be mediated by cognitive mechanisms, which enable the learner to translate the observation into action (cf. Bandura, 1986). It has been proposed that certain environmental invariances specify action for the performer and that, with learning, the performer becomes better attuned to this information, rather than particular details of the movement. Therefore, an important component of learning is being able to use adequately this information to 'find' and 'guide' optimal solutions to motor problems (Fowler and Turvey, 1978). An implication for pre-practice behaviour is that the content of a movement demonstration becomes extremely important. There is a greater emphasis on what information is picked up from observing a skilled model, rather than how the information should be presented or how it is used (see Scully and Newell, 1985). To date, however, empirical research has shown limited support for the idea that only invariant features of the movement, such as movement kinematics portrayed only as point lights, are helpful for learning (see McCullagh and Weiss, 2000). Given the strong coupling between perception and action, critical perceptual invariants, which arguably specify the required action, may not become available to performers until a certain mastery has been attained. Both the action constrains the perception and the perception constrains the action. Teaching individuals, therefore, to recognize critical information may prove difficult. Goulet *et al.* (1989) remarked upon perceptual differences in tennis as a result of experience and rejected the idea that these skills can be taught to less skilled players. Additionally, as will be remarked on later, there is evidence that the detection of perceptual invariance is typically acquired implicitly, without conscious awareness of regularities on the part of the learner (e.g. Lewicki *et al.*, 1992).

Empirical evidence from research into the effects of pre–practice information on skill acquisition

Criterion templates and optimal movement patterns

The importance of knowing the task goal was demonstrated in a simple study by Newell *et al.* (1990), who required their participants to produce familiar or unfamiliar drawing shapes. When the task requirement was a familiar pattern (a circle), the participants neither required this goal-related information to produce the correct pattern, nor required detailed performance feedback about how the movement was performed – what has been termed knowledge of performance. Rather, knowledge about the success or outcome of the movement, typically referred to as knowledge of results, was sufficient. However, if the task goal was unfamiliar, this criterion information was required during practice to produce benefits in acquisition and in a no-feedback retention test. Newell *et al.* concluded that, without knowledge of what should be produced (the task goal), no reference would be available to compare movement-related feedback, negating any benefits of such feedback.

Motor skills have often been distinguished by the similarity between the outcome goal and the movement required to attain the goal. Two different classes of movement have been proposed based on this distinction, so-called open and closed skills, although they are commonly viewed to lie on a continuum (see Gentile, 1972). For closed skills, the goal of the task and how the task goal is to be achieved are the same. For example, in diving, achieving a dive in a specified way is the goal of the action. Open skills, in contrast, commonly have conflicting goals, where a solution to a particular task goal may be attained in many ways. For example, apart from the rules of the game that dictate which parts of the body can be used to score a goal, there are no constraints placed on the way a goal is scored in soccer, netball or hockey. Although these distinctions exist, Gentile (1972) proposed that the initial stage of skill acquisition is probably similar across open and closed skills. In both cases, the learner is required to find a way of organizing their motor system to produce a desired outcome and determine the appropriate information for realizing this. Additionally, in many open-type skills, the coach or experimenter may turn the action into a closed skill by making the achievement of a particular movement variable – such as form or movement amplitude – the goal of the task. In this instance, optimal movement templates or criterion movement patterns will become an additional goal for the learner and may take precedence at the expense of task attainment – this has been referred to as goal confusion (see Gentile, 1972; Whiting and den Brinker, 1982). For example, correct positioning of the feet and upper body may be attained during a corner kick, but this may be at the detriment of achieving the required height and distance on the ball.

One of the effects of trying to copy movement templates has been an increase in the consistency of the movement (e.g. Newell *et al.*, 1990). Although this consistency may be desirable for closed skills, where consistent production of the same movement pattern is required, in environments where the task demands are continually changing, this consistency may not be desirable (Gentile, 1972). Given the vast array of possible sensory experiences and changing environmental conditions that may be encountered by a tennis player, for example, varied practice conditions will be necessary for effective performance during match-play. Perhaps more importantly, task consistency is only desirable if the skill is performed correctly. Early in practice, when the individual lacks the skills to perform the movement and is possibly biased towards other, more easily attainable movements (e.g. previously developed habits from practice in other movement skills), this consistency is likely to hinder acquisition. Lee *et al.* (1995) examined the learning of a new bi-manual coordination pattern and found that, early in acquisition, initial variability in the attempted response preceded acquisition of a new coordination pattern. Because of pre-existing stable preferences to undesirable movement patterns, variability in the attempted movement was needed to facilitate the break from these patterns. Lee *et al.* concluded that early in practice high variability might be desirable, indicating exploration of new coordination patterns and the break from old ones.

Whether optimal movement patterns exist and, therefore, should be used to teach new motor skills is still a matter of contention in many sports. Newell *et al.* (1985: 238) claimed that: 'As the optimal co-ordination function for most tasks has never been determined formally, it typically reflects the intuitions of the advisor about what pattern of co-ordination is optimal and/or mimics the co-ordination pattern that other successful performers have utilised'. Given the vast differences between individuals in previous practice experiences, physical stature or fitness, it should not be too surprising that similar performance standards are not achieved in similar ways. What may be optimal for one person with a certain skill may not be optimal for another. Even in very simple skills, such as hammering a nail, considerable intra-individual variability in the movements of the joints compared with the end-point of the movement – the tip of the hammer-head – has been noted even after many years of performing the skill (see Latash, 1996).

In a recent experiment in which participants were required to coincide a movement reversal of the arm with a dynamic stimulus display – somewhat akin to hitting an arriving ball – Brisson and Alain (1996) found no relationship between outcome and kinematic markers (i.e. the way the movement was performed). Furthermore, in a retraining experiment, it made no difference to performance scores, which were calculated based on speed and accuracy, whether participants practised with a best participant's template or their own movement template. In fact, to achieve consistency in performance, an individually based movement template was more beneficial than an optimally determined one. These findings serve to question the underlying effectiveness of optimal movement templates in teaching motor skills and, at the very least, caution against their automatic use when teaching new motor skills.

It has also been argued that expert templates or movement demonstrations cause people to try to replicate the solution without trying to find their own solution. Someone else's solution may not be well understood by learners and they have no supporting knowledge base to make it useful. Higgins (1991) calls this training rather than learning. Bernstein (1996) has also remarked on the importance of repetition without repetition – that is, the repeating of the means of solving a problem, rather than repeating the solution.

In the preceding examples, the main instructional technique has been to provide kinematic movement templates that prescribe a certain way for performing a skill. In the next section, visual demonstrations are discussed in reference to their effects on the acquisition of simple motor skills.

Demonstrations and modelling

The empirical evidence supporting the effectiveness of demonstrations as a teaching tool in motor skill learning has been mixed (Newell, 1981). The results of the research obviously depend somewhat on the types of tasks that have been examined and subsequently the type of learning required. When the task is rather simple, or the learner has some prior knowledge of the criterion information to be conveyed, then demonstrations are not useful. In the words of Newell (1981: 537), 'When the information to be conveyed through demonstration is redundant, there is, by definition, no information transmitted to the learner'. Whether information is redundant will depend on both the task and the skills of the learner. If the task is to make a familiar shape, or to perform a common task such as clapping, it is unlikely that a demonstration or a reference template will provide any new information to the learner. If a certain method of clapping is required, then it is likely that additional visual and verbal information will be helpful or, indeed, necessary for performance and learning.

Despite the cases when the task is relatively simple or the individual has some prior knowledge of the task goal, movement demonstrations often play a critical role in specifying the requirements of the goal to the individual. The importance of this pre-practice information has received most support when tasks have been examined that require the 'stringing together' of movements that are already part of a person's movement repertoire. Remembering a specific sequence of movements when learning a gymnastic routine, for example, is very different to learning a specific gymnastics skill such as a cartwheel. In the laboratory, a common motor learning task has been one of learning a sequence of key-presses on a keyboard. For example, Howard *et al.* (1992) examined whether observing different patterns of key sequences would enhance serial pattern learning compared with a group who responded with actual key-presses during practice. They found no differences in overt responding between the groups as measured by reaction time and prediction of the next key in a sequence. In these tasks, when the learner can already perform the motor skills required of the task but has to learn the correct order in which to produce them, the demands on learning are predominantly cognitive rather than motoric. The learner does not require experience of these simple movements, only cognitive elaboration of the to-be-remembered sequence.

As detailed earlier, Bandura has been influential in directing research into the processes underlying observational learning. A key feature of his theory is that of attention. Attention to the modelled action is necessary for the development of a representation of the movement skill in memory, either visually or verbally, which will serve as a reference of correctness to guide the action when required. However, learning models have been shown to be just as good as expert models, which demonstrate 'correct' performance, and, in some cases, more beneficial for learning (e.g. Lee and White, 1990; McCullagh and Caird, 1990; Lee *et al.*, 1991). These findings lead to the suggestion that something other than how to perform the action correctly is being picked up by observers of motor skills. When watching a learning model, learners are actively involved in the problem-solving process and, therefore, are concerned with goal attainment, not just copying the model. They receive variable information across trials, rather than the repetition of one possible solution. Subsequently, when watching a learning model, observers are not merely trying to copy performance, but rather finding out what does and does not work. Indeed, mental practice – another form of covert rehearsal – has been shown to have similar learning benefits as observational practice (see Feltz and Landers, 1983, for a review), suggesting that cognitive processes are mediating these benefits.

Movement demonstrations have been shown to be useful in a variety of tasks that arguably have a high cognitive component (e.g. Carroll and Bandura, 1982, 1985, 1987; Doody *et al.*, 1985; Ross *et al.*, 1985). In studies of the effectiveness of movement demonstration on learning the correct sequence and spatial requirements of arm movements, Carroll and Bandura (1982, 1985, 1987) found that demonstrations served to enhance the memorial representation of the required sequence. This benefit was shown in both measures of reproduction and recognition accuracy. Another, somewhat different, line of evidence for this conclusion comes from work examining cognitive strategies underlying expert performance. Figure skaters and ballet dancers (Deakin, 1987; Starkes *et al.*, 1987) show very good recall for structured dance sequences acquired by watching a model performing the sequence. Experienced performers typically use hand movements during observation to 'mark' the steps, which serve to act as a marker for the whole-body position later in recall. The strategy of marking the steps and, therefore, memory for the correct sequence is enhanced by a demonstration, not the acquisition of the individual moves that make up the sequence, although this was not examined by Deakin and co-workers.

Observational learning studies have typically not required the learner to acquire a new movement pattern, but rather refine an existing movement. Vogt (1996) has referred to the reproduction of tasks already within a person's behavioural repertoire as 'imitation learning', in contrast to 'observational learning', which is the learning of newly acquired skills. Despite this definition, observational learning studies have typically not involved learning new skills. Often learning has been a case of refining old ones, by scaling to a new task parameter.

It has also been shown that movement demonstrations can aid the learner in adopting strategies that are associated with skilled performance (e.g. Martens *et al.*, 1976; Kohl and Shea, 1992). Kohl and Shea (1992) found that merely observing a group perform a tracking task led to the development of a control strategy similar to that of a physical practice group. That is, these individuals showed a strategy characterized by rapid responding, not waiting for response-produced feedback to initiate the next response. However, the accuracy of responding was poorer than that of groups who received physical practice. Subsequently, the strategy acquired was arguably not appropriate for the skill of the observers, who were not able to plan and anticipate their movements to efficiently perform the tracking task. Kohl and Shea (1992) suggested a hierarchical control model to explain these findings, whereby observational learning facilitates acquisition at a higher mental level but not at a muscle level. These levels are somewhat similar to explicit and implicit motor learning processes recently described by Gentile (1998) and also to Bernstein's (1996) higher (mental) level of action plans and lower level of sensory corrections (or synergies). These lower muscular levels are necessary to ensure quality in the movement response, whereas the higher level is required to shape, plan and guide the movement.

Verbal instruction and implicit and explicit learning

Gentile (1998) differentiated two learning processes that are involved in the acquisition of motor skills. These processes were termed 'explicit' and 'implicit', reflecting their differential accessibility to conscious awareness. Although these terms have frequently been used in the cognitive literature to explain both memory and learning processes, Gentile has provided a definition of these terms that is specific to motor learning. Explicit processes are directed towards goal attainment and developing the appropriate mapping between the learner and the task. Implicit processes concern the acquisition of the appropriate force-generation patterns that enable efficient movement production. Pre-practice information focuses the learner on being explicitly aware of certain aspects of the task. These aspects may relate to the movement response characteristics, or to key markers necessary for successful goal attainment. During the high jump, the key marker is the end of the foot, given that toe clearance is a requisite for a successful jump. When performing a free-throw shot, the trajectory of the ball is the key marker and the point about which the performer should be most concerned (see Latash, 1996).

Implicit and explicit processes are proposed to be interdependent, yet develop at different rates. The explicit process is expected to show a much faster rate of development than the implicit process. Instructions and demonstrations would be expected to influence the development of the movement's shape structure – the explicit process. At this level, the learner has an appreciation of the task requirements and a crude reference of the required behaviour. Without experience of the task, however, this explicit process may be insufficient to yield correct performance and learning. Implicit appreciation of the underlying sensory experience of the movement will be needed. Both processes need to be taken into account when assessing the benefits of pre-practice information. An explicit representation of the task possibly develops in parallel with practice experience and does not need to precede correct production (cf. Anderson, 1992). Based on these proposals, it is likely that tasks which place more emphasis on the perceptual–motor demands and have complex response requirements will benefit less from explicit instruction about the details of the movement, at least early in acquisition.

The results of several cognitive studies have also shown that an explicit representation or understanding of the task is not necessary for learning to take place. Participants have been shown to be able to learn to control complex, interactive systems without an awareness of the rules or regularities governing performance, with learning proceeding primarily in an implicit manner (e.g. Reber, 1967; Berry and Broadbent, 1984; Broadbent *et al.*, 1986). Similarly, there is evidence that some motor tasks may also be acquired implicitly. Pew (1974) showed that individuals improved on a repeated segment of a stimulus trace during a tracking task, yet in post-task testing showed little awareness that a segment of the stimulus pattern had been repeated. Lewicki *et al.* (1992) have also shown that perceptual invariances can be used to facilitate performance on simple key-response tasks (e.g. reaction times to repeated stimuli), without knowledge of these regularities. Also, in a computerized, visual–motor coordination task requiring joystick responses to predictable and unpredictable stimuli, Green and Flowers (1991) reported fewer errors for predictable stimuli in the absence of instruction about this regularity. When knowledge of stimulus cues was provided, this explicit knowledge resulted in poorer performance for participants who practised the task under these conditions.

The results of these studies show that, where a strong perceptual component is present, the detection of invariance or regularities in the stimulus array can be detected, even though the learner is not made aware of these regularities. Indeed, there is some suggestion – especially when the stimulus–response regularities are not provided on every trial (see Magill and Clark, 1997) – that explicitly directing individuals to search out this invariance might be detrimental for performance. The importance of attention in mediating learning is critical, yet the complexity of attentional effects has to be appreciated. Just because a variable or certain piece of information might be related to task success, explicitly directing participants to this information may hinder the processing of additional important information or interfere with the cognitive demands of the task.

Not only have instructions been withheld during the acquisition of novel motor skills, but implicit motor learning has been examined by dividing attention between the primary task and a cognitively demanding secondary task. This manipulation is believed to prevent the acquisition of verbalizable rules and thus prevent an explicit mode of learning. Masters (1992) and Hardy *et al.* (1996) compared the performance of an implicit learning group, a non-instructed control group and an explicit learning group in a golf-putting task. The explicit learning group received specific instructions on how to putt a golf ball. These instructions were provided in between practice blocks and the participants were encouraged to follow them as specifically as possible. The implicit learning group showed improvement on the task as a result of practice, although they did not improve at the same rate as the explicit learning and control groups. An interesting finding to emerge from these studies was that, under conditions of stress only, the implicit learning group continued to improve on the task. In fact, the control participants and those who learned under explicit learning conditions showed decrements in performance.

Masters (1992) compared the three groups after practice to assess the number of explicit rules acquired about golf putting. He found that the control group acquired more rules than the implicit learning group. This led him to propose that the acquisition of explicit knowledge was the reason behind performance plateaus, or regressions under pressure. More specifically, Masters proposed that when performance is assessed under pressure, automatically produced actions or procedures that are normally governed by lower-level systems get up-regulated to higher-order controlled subsystems. As such, performance breaks down when 'reinvested with explicit knowledge' (p. 344).

More recently, Maxwell *et al.* (1999) found that the number of explicit rules acquired by the control group in a similar golf-putting study correlated with scores on a reinvestment scale (Masters *et al.*, 1993). This scale assessed a person's predisposition to internalize actions and focus on the mechanics of the movement. The scale proved to be a good predictor of performance, such that participants who scored highly performed poorly on a golf-putting task and were more likely to be rated as 'chokers' (i.e. to perform poorly under pressure) among a group of university athletes.

In a recent invited reaction to the implicit learning research of Masters, Beek (2000) argued that implicit learning should not be seen as an exceptional way of learning motor skills (see also Seeger, 1994). Rather, for the learning of perceptual–motor skills, explicit learning – as defined by the acquisition of verbalizable rules and knowledge about the task – was proposed to play a less significant role than implicit learning. As briefly remarked on earlier, Bernstein (1996) also suggested that the motor system could be conceptualized by four different levels with various control responsibilities. It is only at the highest level of control (i.e. the action plans) that movement planning is critical and thus explicit rules or knowledge are used. Beek proposed that sequencing skills involved in learning to dance or play music draw primarily on this high-level control, whereas skills such as learning to ride a bike may be the function of lower levels.

Discovery learning

Attentional focus. Although demonstrations are useful in learning relatively simple motor tasks with high cognitive components, little evidence shows that pre-practice information facilitates the acquisition of more complex movement tasks, which place more demands on the motor components of the skill. As with the study of Green and Flowers (1991) in the preceding section, several investigators have shown that, in the early stage of acquisition, it may be best to leave participants to discover for themselves how to attain the required goals of the task. Vereijken and Whiting (1989) and Whiting *et al.* (1987) failed to observe benefits in performing ski-like movements on a simulator after watching an expert model. Rather, discovery learning participants performed as well as, and on some variables better than, a group who watched a skilled model (see also Anderson *et al.*, 1998). It was suggested that a demonstration might have caused the learners to be overly concerned with the details of the movement and the achievement of movement form at the expense of goal attainment. Subsequently, attention was divided between copying the movement and solving the motor task. In the ski-simulator task, discovery learners either had no or just a few preconceptions about the task; their focus was on solving the task and keeping the platform in motion. Although differences in performance measures were observed across these learning groups, Vereijken and Whiting (1989) pointed out that it is unclear whether the discovery learning groups approached the task in similar ways to the instructed groups. We have recently examined this issue in investigations discussed in the final sections of this paper (e.g. Hodges and Lee, 1999).

Even though Bandura proposed that selectively attending to key features of a movement was critical for effective modelling, in more complex movement response tasks, directing attention to one of several sources of information, or components of the task, might actually be detrimental to learning. Den Brinker *et al.* (1986) provided learners with instructions and feedback about one performance variable that related to performance on the ski-simulator task that required frequent, fluent and wide oscillating movements. Improvement on the attended variable was observed at the expense of performance on other variables; for example, improvement in frequency of the movements at the expense of movement amplitude. No discovery learning control group was examined in this study. Subsequently, van Emmerik *et al.* (1989) conducted a follow-up experiment. They found that discovery learning was equally as effective as amplitude instruction and even better than instruction and feedback about frequency and fluency parameters. Similar trade-offs in performance on one variable due to attention to other variables have been demonstrated by others (e.g. Solley, 1952; Maraj *et al.*, 1998).

In a more recent study, rather than providing instruction about a specific performance variable, Wulf and Weigelt (1997) gave learners expert strategy instruction concerning the appropriate time to exert force on the ski-apparatus. This variable was identified in earlier studies to be an important predictor of success (e.g. Vereijken *et al.*, 1992a). Therefore, knowledge of what had to be learned – that is, exploiting the reactive forces of the system by varying phase lag – informed as to the content for instructions, without supposedly limiting attention to an isolated performance variable. Despite the relationship of this variable with success, discovery learners showed better acquisition and retention.

Given the lack of practice for these learners before instruction was received, Wulf and Weigelt (1997) suggested that the expert strategy may have been inappropriate until greater understanding and familiarity with the task had been achieved. However, even after 3 days of practice in a second experiment, participants were still unable to use this information effectively to facilitate performance. Rather, almost all the participants showed detriments when it was received as reduced movement frequency, smaller amplitude movements or increased jerkiness (i.e. more inhibited movements). The authors suggested that these detriments were due to a misdirection of attention prompted by the instructions. This proposal has received considerable support (see below). These findings also concur with those of Masters (1992), who suggested that reinvesting well-practised actions with explicit knowledge changes the way a skill is performed.

Wulf *et al.* (1998, 1999) have shown that instructions that direct attention to the limbs (e.g. the feet on a ski-apparatus, the arms during a golf putt), rather than the external effects of the action (e.g. the wheels on the ski-apparatus, the golf club), are detrimental to acquisition. The implication is that, if movement demonstrations or instructions directly or indirectly encourage attention to the limbs, learning is likely to suffer. Recently, research has been conducted to try and provide precise definitions of external and internal focus such that the theoretical nature of these effects can be determined, as well as their practical implications. Wulf *et al.* (2000) found evidence to support the proposition that attention should be directed to an effects-relevant cue – that is, the ball leaving rather than coming towards the racket in tennis. Park *et al.* (2000) found that a focus on a far cue when learning to balance on a stabiliometer was more beneficial to retention performance than a focus on a near, yet external, cue. No control groups were examined in either of these studies, however, so it is difficult to establish whether external-focus instructions provide a benefit beyond discovery learning conditions.

The role of movement variability. Similar to Wulf and Weigelt's (1997) finding of more inhibited movements as a result of attention-directing instructions, Green and Flowers (1991) observed that participants who received instruction throughout practice showed reduced joystick motion in all sessions compared with non-instructed participants. Given that reduction in the motion of the joystick occurred early in the trial sequence when predictive cues could occur, Green and Flowers argued that a different movement strategy was encouraged by the cognitive demands placed on individuals in the instruction group. These demands, such as recall and implementation of the probability instructions, subsequently inhibited performance. Therefore, one of the effects of movement-related instructions or demonstrations may be a reduction in early movement attempts at the desired action – or, at least, inhibited movements – and a reduced exploration of the task environment. Early in skill acquisition, these jerky-type movements are common observations in skills such as skiing, gymnastics and dance. Thinking too much about aspects of the movement, such as the appropriate time to bend the legs when performing a turn when skiing, is likely to make performance more broken and stuttered (see also Wulf and Weigelt, 1997). A reduction in movement experience would be a particular disadvantage if a novel movement was required that was not already part of an existing movement repertoire. Without experience of the task dynamics and varied stimulus–response pairings, the learner would experience difficulties discovering the required co-ordination pattern.

Vereijken (1991) argued that discovery learning could work positively, compared with instructional learning, by encouraging the discovery of optimal solutions specifically suited for the individual. Allowing the individual to gain experience of other less than optimal solutions was proposed to enhance the learner's experience of their environment and become aware of the constraints acting upon them. Instructions or performance models may serve to constrain this search for optimal solutions that may be specifically suited to the individual.

For complex motor tasks, it has been shown that early in learning performers 'freeze' seemingly redundant degrees of freedom in the motor apparatus to ease the process of acquisition. For example, in learning to perform on the ski-apparatus, Vereijken *et al.* (1992b) showed that the movements of the joints in the legs were highly coupled in the early stages of acquisition. After practice, the couplings of these joints, especially those of the ankle, decreased. Trying to copy the movements of an expert model may hinder learning, because performers may not have sufficient control over their degrees of freedom to master the task in the same way as an expert model. Rather than solving the motor problem by imposing their own constraints, then gradually releasing them as control improves, learners will try to copy the skilled model and might fail to bring together adequately the degrees of freedom in the same way as the expert. Paradoxically, the instructions or demonstrations would fail to constrain the motor system, possibly by overwhelming the learner with information about the optimal control of many joints, yet constrain the search for solutions to the motor problem that might be optimal for the learner at that particular time.

Withholding movement instructions and demonstrations is only likely to be beneficial if the learner tries to produce new movements. Langley and Simon (1981) argued that the learning mechanism must be able to generate alternative behaviours if a teacher does not provide them. Trial-and-error learning can only be beneficial to learning if new behaviours are then attempted. This is where either intrinsic or extrinsic feedback about the movement response plays a critical role in alerting the learner to incorrect performance and encouraging change on the next attempt. Swinnen *et al.* (1993) required participants to perform a three-part reversal movement with one arm and a simple flexion movement with the other, yet start and end the movement of each arm simultaneously. This task is difficult to perform because of a preference to synchronize the limbs. Swinnen *et al.* found that outcome information was equally as effective as more detailed knowledge of performance specifying the exact displacements of the limbs. Because both types of feedback alerted participants to a problem in coupling and, therefore, encouraged the generation of new solutions, the amount of detail or information supplied in the feedback was unimportant.

Recent learning experiments and pre-practice information

In several experiments, we have examined the acquisition of novel bi-manual coordination movements under various instructional manipulations. As detailed earlier, in bi-manual coordination, two stable coordination patterns have been identified – in-phase and anti-phase. Some researchers (e.g. Swinnen *et al.*, 1991; Zanone and Kelso, 1992, 1997; Lee *et al.*, 1995; Fontaine *et al.*, 1997) have shown that trying to acquire a new relative phase pattern, such as 90° relative phase, is very difficult, because of competition from these pre-existing behaviours. It is as though individuals get stuck in the early stage of acquisition and need to engage in a process that allows them to break away from the attraction of competing behaviours. Lee *et al.* (1995) showed that the early stage of acquisition was characterized by initial stability in observed relative phase, because early learners showed a strong and stable bias towards the anti-phase and in-phase patterns. After practice trials, however, this stability was sacrificed and variability increased due to within-trial switching between these two stable patterns. The authors argued that this increase in variability was indicative of the search to discover the newly required movement pattern.

Although learning novel bi-manual movements is still relatively simple compared with more real-world tasks, such as learning a backward somersault, these bi-manual tasks require both spatial and temporal coupling and manifest themselves in a wide variety of leisure pursuits (e.g. catching, juggling and playing a musical instrument). From a methodological standpoint, they allow performance to be examined in a controlled laboratory setting and permit quantification of learning in comparison to existing behaviours. Because most individuals cannot perform patterns other than in- and anti-phase pre-practice, it is possible to examine the early stage of skill acquisition where pre-practice information in the form of instructions and movement demonstrations would be expected to have most influence.

In one study (Hodges and Lee, 1999), we manipulated instructions that informed individuals, either generally or specifically, how to move their limbs to produce the required 90° pattern. One group received a step-by-step specific guide as to the positioning of the hands every quarter of a cycle. The general instruction group received instructions specifying the start positions of the hands (i.e. the spatial relationship between the limbs) and the general rule that one hand should always lag the other by a quarter of a cycle. All participants received feedback at the end of each trial in the form of a relative motion plot that depicted a circle pattern when the arms moved in the desired way. In this way, it was possible to manipulate information about how to achieve the movement goal, yet at the same time providing individuals with a task goal and associated feedback.

No benefits for this type of instruction were found. Rather, both instruction groups showed detriments in acquisition, retention or both. The no-instruction group, who received only feedback about circle production, consistently showed the best performance. As predicted, this performance was associated with high within- and between-trial variability in relative phase early in practice, enabling participants to break from pre-existing stable movements. Additionally, a group who learned under secondary-task conditions failed to learn the new movement and showed low within-trial variability in relative phase because of consistent adherence to pre-existing movement patterns. In retention, only the instructed participants were affected by the secondary-task conditions. Arguably, the cognitive demands of the secondary task interfered with the processes required to perform the newly acquired coordination pattern. However, that the instructed participants generally showed more variability in performance of the newly practised pattern (and, therefore, the acquired pattern was not as stable) could also account for these regressions.

In follow-up experiments (Hodges and Franks, 2000, 2001), visual demonstrations were also provided pre-practice and presented at both slow and regular speeds. Again this pre-practice information failed to facilitate learning and, in some instances, showed negative effects on measures of performance. However, manipulation of attentional focus instructions, coupled with movement demonstrations, mediated the effects of pre-practice information in a similar way to that discussed earlier by Wulf and colleagues. Directing participants to focus on the feedback – the external effects of the action – when watching the demonstration and performing the movement reduced the negative effects associated with instructional provision (Hodges and Franks, 2000). Repeated attention-directing instructions during acquisition were also useful later in no-feedback retention tests. Arguably, these instructions promoted attention to other sources of information during practice, or at least encouraged effortful practice once the general form of the movement had been acquired.

We also found that the type of on-line feedback was particularly important in mediating the learning effects (Hodges and Franks, 2001). Simple information, which was indirectly related to the relationship between the limbs – the circle pattern – helped constrain the two limbs to act as a coordinated unit. Providing feedback about the position of both limbs, even though more detailed and arguably more informative, was detrimental to learning. Similar results were reported by Swinnen *et al.* (1993). It was our contention that increasing the compatibility between the demonstrations and the feedback would facilitate acquisition and this limb feedback should have helped. However, the feedback we provided was arguably too complex. Video feedback or perhaps a mirror would have provided learners with more useful error information about the similarity of their movements to the pre-practice template. We are currently exploring the benefits associated with coupling demonstrations and video feedback and the implications of this method for enhancing error-detection processes.

Most recently, we examined whether individual differences could play a role in mediating the effects of instructions (Hodges and Franks, in press). An additional purpose was to determine whether instructions and demonstrations, which showed how existing movements could be adjusted to produce new movements, would facilitate acquisition. Swinnen (1996) has referred to this type of instruction as 'transitional information', whereby learners are instructed as to what to change to produce a new movement. Although this is a common method of instruction, and there is good reason to suppose that alerting participants to existing biases would help them understand what was required (see Fitts and Posner, 1967), it failed to facilitate performance. This was the case irrespective of initial ability. As in previous studies, the non-instructed participants generally outperformed the instructed groups. The instruction groups showed decreased variability early in acquisition, arguably owing to copying and avoidance behaviour promoted by the instructions. For example, participants who were informed of a bias to the in-phase pattern, and who were shown and instructed how to adjust this pattern to perform the required 90° pattern, performed worst overall. On inspection of the relative phase data, we discovered that participants in this instruction group showed a strong tendency to avoid in-phase movements. Rather, a bias to the anti-phase pattern was seen. This failure to switch between the in- and anti-phase patterns early in acquisition was detrimental to the discovery of the newly required movement.

As a result of these studies, we concluded that movement demonstrations and instructions relating to the movement of the limbs convey little useful information in the early stage of acquisition, if information about goal attainment is available through feedback. Instructions were shown to hinder the break from pre-practice patterns, although there was some suggestion that they may possibly help refine the movement at a later stage of practice.

Without examining all possible types of instruction, it is impossible to make any firm conclusions about their role in acquiring bi-manual skills or, indeed, skill acquisition in general. Despite this limitation, it is still surprising that instructions and demonstrations, which both show and tell people how to perform a novel movement and how to adjust existing movements, fail to aid acquisition beyond that achieved from simple feedback. It is important to consider why this feedback was so easy to use. One reason was that it constrains the two limbs to act as a single unit. If we could identify instruction that also acts to convey the general aspects of the movement, then benefits to skill acquisition might be observed. When we have debriefed participants in the past, we have asked them to think about strategies they used to help them perform. They often report quite abstract strategies, such as 'getting the feel for the movement' or 'imagine being a circle'. These insights were similar to those reported by Franks and Stanley (1991), who found that participants learning to track a stimulus waveform would hum or tap a rhythm to help encode the visual pattern. It is difficult to imagine how these could be used to help new learners. Rather, these intuitions are probably only developed and understood once some expertise is achieved. There is, however, a need to examine more holistic methods of instructions (see also Swinnen, 1996) that help the learner constrain the degrees of freedom involved in the movement and focus on more general aspects of the response. We have considered using the analogy of pulling on an elastic band to help participants incorporate the notion of a slight phase lag in the relation between the limbs, but as yet these ideas await investigation.

Summary

To summarize these research findings and the empirical studies reviewed earlier, we have constructed a flow diagram (see Fig. 1) that illustrates how the process of skill acquisition is influenced by pre-practice information.

As depicted in the flow diagram, the goals of the task are a function of both the instructor and the learner. At different stages of learning, the performer will have a different understanding of these goals and thus the acquisition process will be affected by the interaction of the two. Earlier, we discussed Fitts and Posner's (1967) ideas about transfer of habits and the importance of examining what skills the individual brings to the process. Experience or lack of previous experience in similar tasks will influence how the individual interprets each set of circumstances and deals with the pre-practice information. Masters *et al.* (1993) showed how personality factors could impact on the skill acquisition process and how pre-practice information should be designed to minimize the influence of undesirable thoughts or dispositions. Performance goals that reduce attention to limb positioning and are more implicit may be most suitable for individuals who tend to internalize or reinvest actions.

The goals specified by the instructor will influence what behaviours are exhibited by the learner and thus influence the selection of an initial response. A certain strategy may be adopted as a result of this information, such as avoidance or adoption of a particular movement behaviour. Often demonstrations or limb-related instructions will encourage the learner to seek out specific feedback, or error information, that can be compared with pre-practice information or some sort of

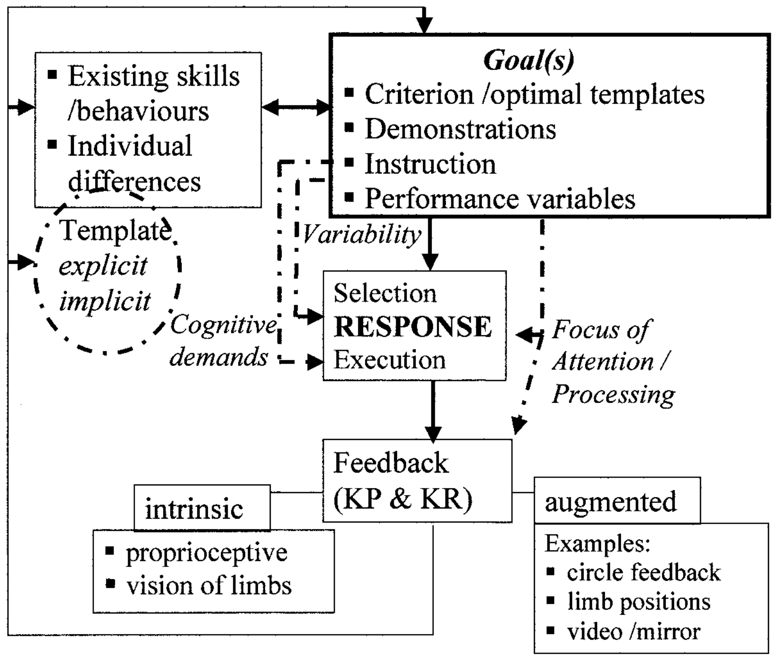

Fig. 1. Flow diagram to illustrate how the process of skill acquisition is influenced by various performance goals that serve to act upon the response, both its selection and execution and associated processing of feedback. The goals, in turn, are influenced by pre-existing movement skills and the results of practice attempts. Postulated mechanisms underlying the effects of various performance goals are suggested (dashed arrows). Both an explicit and implicit representation of the task is believed to develop with practice, with the implicit representation encompassing pre-existing movement habits and skills and the explicit representation having a more direct influence on the choice and perception of the task goal. KP = knowledge of performance, KR = knowledge of results.

explicit transformation of this information. Response-produced feedback may be augmented by the instructor or be a natural consequence of the movement (i.e. intrinsic). This feedback is critical for learning. Without the knowledge that an error has been made, the performer will not be motivated to change their response on the next trial and thus improve performance. If participants are provided with limb information pre-practice, it should not be too surprising that this will be the information they seek out during or after the movement.

If the performance goals are multifaceted, or the instructor provides both outcome goals and movement goals, then some sort of goal confusion could result (Gentile, 1972). This would influence how learners approach the task and, more importantly, where they direct attention during execution. Directing attention to one performance variable may be at the expense of performance on other variables, or focusing on how the movement should be performed may affect attainment (see van Emmerik *et al.*, 1989). As Swinnen (1996) has pointed out, outcome variables such as knowledge of results serve a goal-directing role, helping the learner form a reference-of-correctness. As illustrated in Fig. 1, and demonstrated in our studies, this information will have a strong influence on the performer's subsequent performance goals.

With practice, the skills and knowledge of the learner will change; hence, the proposed template of the movement that develops with practice and forms part of the learner's existing skills will change. The explicit component of this template might be some sort of transformation of the demonstrations, instructions and augmented feedback, at least early in practice. This component would be particularly suited to tasks that place high demands on cognitive or memory processes. The implicit component might reflect more behavioural changes that result from 'getting a feel' for the movement (see Gentile, 1998). Learning to monitor and use effectively proprioceptive input would arguably be most effective for developing a more refined implicit template, which is likely to benefit tasks that place more demands on the motor aspects and subtleties of the movement. These components of the template are similar to the high and low levels of control discussed earlier (see Bernstein, 1996). In Fig. 1, we have represented this template as a circle overlapping with the existing skills. As such, it will influence, and be influenced by, the performance goals and the emerging response.

One of the consequences of trying to implement instructions or copy movement demonstrations is increased consistency in the attempted movement in the early stages of acquisition. This was demonstrated by us in bi-manual coordination studies as well by researchers studying discovery learning (e.g. Vereijken, 1991) and optimal templates (e.g. Newell *et al.*, 1990). Therefore, one of the ways pre-practice information affects the acquisition process is through the encouragement or non-encouragement of variability in the attempted movement from trial to trial. Unless the learner has reason to change what they are doing, new movements will not be attempted. This variability is therefore highly dependent on error information and also the pre-existing skills of the learner.

In our first study (Hodges and Lee, 1999), detailed task instructions affected later performance under cognitively demanding conditions. The suggestion is that it is best to decrease cognitive demands during response execution and that written instructions might inadvertently increase these demands. Bandura (1986) has suggested that children are particularly susceptible to the detrimental effects of high cognitive demands brought about by task instructions. If the attention demands are high, participants could be distracted from processing feedback effectively and breaking from stable, undesirable behaviours. Green and Flowers (1991) and Wulf and Weigelt (1997) also suggested that the effects of movement-related instructions could be related to increased cognitive demands, whereby too much thought about 'what to do' leads to jerky, inhibited movements. In this way, the increased cognitive demands may exert their influence through decreased response variability. Indeed, the members of the secondary-task learning group in our study (Hodges and Lee, 1999) showed little within-trial performance variability and failed to break away from pre-existing behavioural biases even though they received feedback at the end of each trial.

Conclusions

We have shown that the effectiveness of demonstrations and instructions is dependent on the existing skills of the learner and relatedly on the type of tasks or skills that are taught. When the movement response is not an existing part of the learner's movement repertoire, instructions and movement demonstrations, which specify the correct or optimal method for performing a skill, have little learning benefit. Although these conclusions may at first seem somewhat negative, what is important is not that instructions and movement demonstrations should not be used to enhance learning, but rather, when they are used, the instructor and learner should be cautious and consider what information is conveyed. This would require an appreciation of the many, and sometimes conflicting, goals a motor skill may have and how attentional processes might be directed to certain cues as a result of these goals. Additionally, an appreciation of the learner's existing skills and potential limits in understanding the pre-practice information would also help in predicting what behaviours might be tried or, indeed, avoided as a result of instruction.

To highlight some implications of this work for learners and teachers of motor skills generally, and perhaps stimulate future research to verify these conclusions outside traditional laboratory settings, we provide several recommendations for coaching practice. These recommendations are presented and have been broadly categorized based on the specification of the task goal and feedback, skill of the performer, movement variability and focus of attention.

Implications of this research for teaching motor skills

Feedback and specification of the task goal

- Coaches should provide clear pre-practice information about the task goal – whether this is a particular movement pattern or a particular outcome – and provide feedback that is appropriate to the instructed goal.
- Providing error information is vitally important early in skill acquisition. It encourages athletes to try new behaviours on their next attempt. If no new behaviours are attempted on the basis of intrinsic feedback alone, then some directed instruction may be necessary.
- Feedback relating to the movement should be as simple as possible and convey important information about goal attainment. This feedback should be compatible with the pre-practice information, such that error information is easily attainable to determine goal achievement and effective implementation of the pre-practice information.

Skill

- Although there are usually general features of a movement that define skilled performance, optimal movement templates do not always generalize well across individuals. Individually based templates may be more appropriate in refining and achieving consistency in a skill.
- Demonstrations help to highlight the ordering of task components, but not necessarily the teaching of the movement components. If the necessary components to perform the action have already been acquired, then demonstrations, which facilitate the 'stringing

together' of these components, are likely to be useful learning aids.

- Physical limitations as a result of experience or development may limit the ability of the learner to understand and use effectively pre-practice information.
- Coaches should not assume experts and novices are dealing with the same motor problem. Demonstrations and instructions for experts are not necessarily the same as for novices. Skill will affect what information an athlete is able to extract from a demonstration.

Variability

- Coaches should allow (and expect) error and variability early on in learning to facilitate the discovery of new movements.
- Demonstrations that are varied in content are recommended to engage observers in the learning process and to inform them of possible solutions to the motor problem.
- Early in acquisition, experience of the task environment should be encouraged. Withholding detailed pre-practice information at this point may help to encourage this early exploration and hence variability, as long as sufficient error information is available.
- Instructions that build upon stable, pre-existing movement behaviours early in practice do not facilitate the acquisition of skills that are not part of the movement repertoire. This type of instruction can promote avoidance behaviour and decrease early variability necessary to break from undesirable movements.

Attentional focus

- Individuals learn to respond effectively to certain aspects of the skill without being aware of it and without being instructed to learn. Direct instruction or intervention is not always necessary to encourage learning. Additionally, learners may be unable to verbalize the knowledge they have acquired despite showing improved performance on the task.
- Instructions and feedback direct attentional focus. If performance is to be assessed by more than one performance measure, such as amplitude and frequency, or the task is so complex that directing attention to one specific information source may be at the detriment of other important factors, then specific instructions should be avoided.
- When instructions or demonstrations are provided, attention should be directed towards the external effects of the action, rather than the limbs.
- If demonstrations are provided to convey the goal of the task, this pre-practice information should be accompanied by instructions that encourage attention onto the feedback and the effects of the action on the environment. This additional instruction would also promote more effortful practice and attention to information sources that may otherwise go unnoticed or be poorly processed.
- Some individuals may be predisposed to focus attention onto the mechanics of the movement, thus hindering acquisition. For these individuals, the amount of explicit instruction pre-practice should be kept to a minimum.

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