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The University of British Columbia
Vancouver, Canada

Date [March 9th, 2001]
ABSTRACT

Four experiments were conducted to examine how pre-practice information affected the early stage of acquisition when the motor skill was not an existing part of the learner’s movement repertoire. More specifically, the experiments examined why instruction concerning the correct way to perform a motor skill has a negative influence on acquisition and subsequently under what conditions it is useful. In all experiments participants practiced a difficult, bimanual coordination pattern, which resulted in circular shapes on a monitor. In Experiment 1 information prior to and during acquisition was manipulated to examine whether instructions benefited learning when feedback informed as to how they were implemented. No support was found for this prediction, somewhat due to the complexity of the feedback. When only circle feedback was provided pre-practice information hindered acquisition, which supported findings from an initial investigation. In the second experiment focus of attention was manipulated via the instructions to examine whether attention mediated the instructional effects. It was predicted that instructions directing attention onto the effects of the action would facilitate learning. This hypothesis was generally supported, however, non-instructed participants performed as well as an external focus group and all attention-directing instructions decreased the negative effects of feedback withdrawal. The final experiments were designed to examine whether instructions that built upon existing behaviours would facilitate acquisition when only a gradual replacement of an existing behaviour was required (Experiment 4) as compared to a qualitative change (Experiment 3). In Experiment 3, only participants biased to in- and anti-phase movements were studied (bi-stable). In Experiment 4 participants biased to patterns other than these (multi-stable) were examined. Instruction did not benefit learning, irrespective of initial bias. Instructions that built upon in-phase movements were detrimental to acquisition. More permanent changes to the underlying dynamics were manifest in post-practice scanning tasks for the non-instructed participants only. As a result of these studies it was concluded that movement demonstrations and instructions conveyed little useful information in the early stage of acquisition, if information regarding goal attainment was available. Instructions can hinder the break from pre-practice patterns, but may possibly help refine the movement at a later stage.
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4.22 In the top panel, a) the delta RP means (°) are shown for both the continuous and discrete scans pre-practice as a function of attraction (120°-135°, 0° & 135° or 45°-60°). In the lower panel, b) RMSE of goal RP (°) in acquisition and retention for the multi-stable participants as a function of attraction is plotted.

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"As everyone knows, to see how something is done thousands of times and to actually perform it are very different things. Frequently, when you watch the skillful performance of an experienced professional, it is hard to get rid of the feeling that you would do no worse at the first attempt. But if the artisan sees this mute thought in our eyes and lets us take the artisan’s place, the novice experiences a peculiar feeling of awkward dismay that is impossible to forget. Our right hand, which is known to be an obedient and perfectly coordinated servant, becomes clumsy and untamed, as if it were numb or frozen.” Bernstein (1996, p184).

Little is known about the role instructions play in the learning process, beyond a sometimes necessary role of relaying to the learner the task goal(s). This gap in the knowledge base is particularly interesting given that augmented feedback during and after skill execution has been given marked attention in the motor learning literature. In the most recent motor control and learning textbook, Schmidt and Lee (1998) echo these sentiments. They conclude 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” (p289).

It is commonly believed that both instructions and movement demonstrations are critical to learning. They can be used to convey to the learner the goals of the task, how to move, or how not to move and how to perform effectively. They also play a role in specifying boundaries to the movement or the goals of the movement and aid the selection of strategies that are presumed to be useful to acquisition. Pre-practice information is also believed to serve a motivating role and can influence the thought and attentional processes that are directed to acquisition. Despite these beliefs, there is a noticeable lack of research supporting these contentions, due somewhat to the lack of systematic investigations designed to examine if and how pre-practice information affects learning. There are a number of questions that warrant investigation. What type of information contained in the instruction ensures effective instructional provision? Are instructions always needed and how do they interact with other augmented information sources, such as feedback? If instructions and movement demonstrations do have an effect on the learning of novel motor skills, is this effect always positive? How can theory guide instructional strategies? In this thesis the concern was with the role of pre-practice information during the early stage of motor skill acquisition. In particular, the studies were designed to examine how instructions and movement
demonstrations affect the learning of novel motor skills that have complex response requirements.

One of the reasons why instructions have received little attention has been somewhat related to the nature of the tasks that have been examined. Often the tasks have been very simple, with little or no new learning taking place. In this instance, the only role instructions serve is to alert the learner to the task goal. This is partly due to the difficulties inherent in finding sufficiently novel tasks that are not part of an individual’s existing movement repertoire that can be examined in a controlled environment. Appreciation of these problems has led to the examination of more unusual, complex skills (such as juggling), rather than the re-scaling of an already established movement (e.g., learning to hit a target in a certain movement time). The former has been referred to as a problem of coordination, which of course is highly applicable to learning in the sports’ context (e.g., learning to kick a ball, or perform a back handspring). Whereas the latter has been termed a control problem, where certain parameters of a pre-existing movement require modification (e.g., hitting a target with a certain force, or completing a series of learned movements in a particular order). It is probable that, for most so called novel learning situations that confront the learner, both problems of coordination and control are present.

In this thesis an attempt was made to answer these questions and address some of the aforementioned issues. The task chosen to examine these questions was a novel bimanual coordination movement, which has been shown to be particularly difficult to acquire. The difficulty is mostly due to the competing influence of general movement patterns, or habits, that interfere with acquisition of new skills. A number of experiments are reported that address how instructions affect the learning process. This includes how they interact with feedback, the mechanism underlying instructional provision in terms of focus of attention and subsequent sensory processing, and how differences in underlying capabilities affect the learning process and inform as to instructional provision.

To explain the reasons for studying instructions and movement demonstrations and to give some background to the studies and learning literature, the introduction is divided into three sections. After outlining the different ways instruction can be provided and providing some objective criteria for defining instruction, theoretical rationale is then presented, with respect to how theory can guide the when, where and what of instructional provision. Traditional theories of skill acquisition are examined and predictions generated from these with regards to learning in the very early stages are described. After discussing the implications of these traditional theories for instructional provision an alternative theoretical approach is considered. The knowledge base
and methodological tools of dynamical systems theory is discussed with respect to implications for the study of instructions. Finally, empirical data is reviewed, both in the cognitive and motor skill domains where pre-practice movement instructions and demonstrations have been examined. Following this introduction, the rationale underlying the methodology for the studies is detailed and data is presented from an initial study where the effects of written instructions on the learning of a complex, motor coordination task were examined. Three major studies, which comprise the basis of the thesis, are then presented and in the general discussion the results of these studies are reviewed with respect to the issues and questions raised in the introduction and as a result of experimentation.

1.1 Defining Instruction

One of the defining roles of the coach or teacher in the sports’ or movement context is that of instructor. An instructor is responsible for teaching the learner what to do, how to do it, and hopefully how to do it well. This may involve providing instruction as to optimal movement patterns, or feedback regarding errors in relation to specific task goals. Instruction can be provided in a number of different modalities and in a number of different ways at particular times. For example, the instructor may provide a visual demonstration to the learner before any experience with the to-be-learned behaviour, or provide instruction verbally during or after execution, possibly relating to performance of the whole skill, or homing in on specific aspects of the skill. Physical education specialist, Blake (1998, p59) 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.”

The temporal nature of instructional provision can also vary. Instructions can be provided before any physical practice with the movement skill, or at a later stage of skill acquisition. As well, the instruction can be independent or dependent on the learner’s performance, such as a general demonstration, or instructions relating the learner’s performance to the instructor’s expectations (usually referred to as augmented feedback). The concern of this thesis was with the role of instructions provided prior to the action, when the individual is new to the skill and where the instructions are independent of performance. Instructions and demonstrations are typically given to supplement physical practice by providing the learner with information concerning how to perform a specific action and/or the goal of the action. They can also be provided instead of practice which is typical in studies of observational learning. Demonstrations are usually of a limited number, detailing a supposed correct way of attaining the task goal. This situation of
presenting the same instruction, or the same demonstration regardless of the performance of the individual, is not atypical in coaching. For example, in group settings the coach will often have to refer to a general set of instructions to convey the information to the whole group, or revert to some skilled performer to illustrate what the action looks like when it is performed correctly.

In this thesis instructions and demonstrations were examined under the same heading of information provided prior to performance and were not afforded differential treatment. Although verbal and visual instruction may have different effects on learning (the old adage that a picture is worth a thousand words), the majority of studies that have demonstrated this have been within the developmental literature (e.g., Minas, 1977). Subsequently, any differences as a function of mode of presentation have been proposed to be related to differences in memory across age groups and within special populations. In this thesis learning was examined among normal functioning adults. However, there has been evidence to show that the effectiveness of verbal instructions and visual demonstrations may be somewhat dependent on the task requirements. Verbal instructions, or cues have been shown to most directly impact on quantitative aspects of the skill (e.g., the temporal sequence of components), whereas visual demonstrations have been most helpful in improving qualitative aspects, such as movement form (e.g., McCullagh, Stiehl & Weiss, 1990; Weiss & Klint, 1987). For motor skills that require both spatial and temporal coupling, it is not clear whether the different modes of instruction would differentially affect learning.

1.2 Theory

Motor skill acquisition is a dynamic process, characterized by both quantitative and qualitative change in behaviour as a function of practice time and experience. As researchers of motor learning, the questions that are of concern deal with the nature of this change, that is, what has been learnt, what type of practice facilitates this change, and what are the time periods over which change occurs? Although these questions are common to all motor learning theorists and practitioners, the examination and subsequent explanation of the process of skill acquisition has been based upon different theoretical viewpoints.

Learning has been explained as a process of development, refinement and strengthening of movement representations in memory, due to comparisons of the representation with the actual result of the action (both intrinsic and extrinsic feedback). The most commonly cited examples of these representational accounts of motor control and learning are Adams’ (1971) closed-loop theory of motor control and Schmidt’s schema theory (1975, 1976, 1988). Schmidt’s
schema theory was heavily influenced by Adams’ earlier ideas and was developed as a result of limitations in Adams’ theory with respect to such issues as task novelty, error detection and feedback dependency. Subsequently, Schmidt’s theory is the most frequently cited and has played a fundamental role in the motor learning literature for the past twenty or so years.

Common to these models is the notion that some sort of representation of the movement is necessary a priori to execute a movement, either a memory trace (Adams) or schema (Schmidt) and that with learning this memory is responsible for the production of the skill. Learning, therefore, is a covert process inferred from changes in chosen observable variables with practice.

In contrast to this representational view of learning, proponents of the dynamical systems approach to motor skill acquisition, claim that movement is an emergent property of the motor system, which encompasses the person, or animal, interacting in their environment. Subsequently, movement is a function of the task demands that may be specified by visual information (i.e., environmental information), organismic constraints, such as physical capabilities, or preferred movement skills and intentions. Learning is defined by the evolution of preferred movements or states, which are referred to as behavioural attractors. In contrast to representational accounts, there is no specification of some form of the movement prior to its evolution, although memory and intention can act on existing capabilities to influence behaviour. Zanone and Kelso (1992) defined learning as “a relatively permanent change in behaviour in the direction of a to-be-learned pattern specified by the environment.” (p404). Learning is therefore examined in relation to the acquisition of a specified pattern. However, rather than only local change there are compensatory changes in the whole motor system. For example, there are changes due to preference for certain states within the system and an overall coupling of the action system with the task environment. These two approaches are discussed in more detail below.

1.2.1 Classic Theories of Skill Acquisition

1.2.1.1 Adams’ Closed Loop Theory and Schmidt’s Schema Theory

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., Skinner, 1953; Thorndike, 1927), where 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. The incremental or quantitative nature of learning, which was characteristic of
behaviourists accounts, was also maintained by information processing theorists (see Lee & Swinnen, 1993). 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 servo-control mechanisms 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. The traditional information processing notion that is germane to both these theories is that "...learning is facilitated, up to some level, by the provision of more information to the subject." (Newell, 1981, p538).

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 traces or schemas are responsible for both initiating the movement and evaluating its effectiveness both during and after the movement. The recall schema or memory trace is responsible for initiating and selecting the response. They both function as motor programs, although in Adams's theory the memory trace plays only a small role in the unfolding of the movement. Rather, control of the movement is attributed primarily to the perceptual trace. 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, due to the fact that general features of the movement are stored. This estimation is performed on the basis of previous experience with similar tasks under various initial conditions. Therefore both the perceptual trace and the expected sensory consequences are compared to the actual feedback to enable on-line and off-line error detection and correction.

In the case of schema theory, the movement can be executed without the need to compare and utilize response-produced feedback. In this manner the movement is said to comprise open-loop processes, to account for fast, ballistic type movements and closed-loop processes to explain the slow, linear positioning movements that have been germane to the development of Adams' theory. An additional feature of schema theory that has implications for practice is the general and abstract nature of the movement representations that are developed. As a function of experience the individual is proposed to briefly store information pertaining to the movement in terms of the initial conditions, the movement parameters, the outcome and the sensory consequences of the action. For example, after taking a penalty kick in soccer the learner will
temporarily store such information as the size or weight of the ball, the ground conditions, how much force was applied to the ball, whether the ball hit the intended target and how the kick felt and looked. After a number of practice attempts, perhaps under various ground conditions, or to various targets the learner is then able to form relationships between the various information sources to enable response selection when either the same, or novel yet similar movements are required (i.e., various kicking motions). Based on knowledge of the initial conditions and the intended outcome, the learner is able to abstract knowledge about the correct parameter to select (i.e., how much force to apply to the ball). This same information also allows the learner to predict the sensory consequences, which, as explained above can then be used to evaluate performance.

Given the proposed nature of these representations, experience of different movement parameters (such as speed, force, or even different muscles) is expected to facilitate the formulation of this general abstraction of the movement in memory. This feature enables more effective transfer across similar movements that have the same invariant features, such as relative force, phasing, or ordering of elements. This abstraction, or rule pertaining to a particular class of actions, has been referred to in the literature as a generalized motor program. Some of the most convincing evidence in support of schema theory and the associated ideas of general movement templates has been obtained from studies where variability of practice has been manipulated (for a review see Shapiro & Schmidt, 1982). Due to a greater experience of various task parameters such as movement speed, it is predicted that a stronger rule will be developed to enable better parameter selection. Catalano and Kleiner (1984), for example, showed that on a coincident anticipation timer, variable practice conditions did indeed produce superior transfer to new movement speeds as compared to constant practice conditions at one movement speed. This transfer was examined at speeds both close to and far from the ones that had been practiced.

1.2.1.2 Implications of Adams' and Schmidt's Theories for Instruction

Given the importance of detection and correction of errors in both Adams' and Schmidt's theories, pre-practice information, which is designed to refine the movement template (trace or schema), would be important. 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 with. If the movement is sufficiently novel that no template of the required response, or general
class of response, exists then it is not clear how pre-practice information could be used to facilitate production and learning generally.

Pre-practice information may also influence the type of response that is evoked or selected. Using the ideas generated from schema theory and the notion of a generalized motor program, it is possible to speculate as to what information to provide. 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 be important. Such information as how fast, or how wide to make the movement, would be useful. If the generalized 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. For example, a demonstration showing the correct order of components could be provided. 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 concerning how these movement representations become established. The implicit assumption in schema theory was that general programs already exist. One obvious candidate is information about the invariant spatial and temporal features of the movement. However, whether this information would be sufficient to evoke a response that is not an existing part of the learner’s movement repertoire is not clear. In the discussion of the empirical literature that follows, attention-directing strategies are discussed in relation to the effectiveness of knowledge concerning invariant features.

1.2.1.3 Other Representational-Based Accounts of Skill Acquisition

There have been variations of these theories and mechanisms proposed to underlie skill acquisition. Gentile (1972), proposed that early in acquisition a general motor pattern was acquired, or what was referred to as “getting an idea of the movement”. This motor pattern resulted through the organization of the motor system to achieve or solve a particular motor goal or problem. Acquiring this general idea, or pattern of movement preceded either refinement (fixation), or diversification of the general pattern, depending on the environmental conditions. Particular emphasis was placed on motor plans and the formation of an image of the movement to guide and compare the observed motor response to that which was intended. Similar to the ideas of Schmidt and Adams, some sort of comparison process between the expected and observed response enabled selection or refinement of the response on the next attempt.
Whiting and den Brinker (1982) also described acquisition as a process of developing motor images that guide movement production. Two images were proposed. First, the “image of the act”, namely a topological representation of space (Bernstein, 1967), where the learner is primarily concerned with attaining the task goal and acquiring the form of the movement. Second, a model of the forces to be overcome called “the image of achievement”. This image was originally proposed by Pribram (1971), along with the idea that the motor cortex contains a representation of the external forces enabling feed-forward control. Feed-forward control prepares, or readies the motor system for the sensory consequences of the upcoming action. Similar dichotomous processes have more recently been proposed by Gentile (1998) who distinguished explicit processes, like the image of the act, from implicit processes, where external forces are mastered. There is some evidence that a general image or form of the movement is explicitly developed as a result of practice. Franks (1980) for example, found that early in performance with tracking, a generalized image of the form of the required movement was developed, as determined from freehand sketches. In this manner an image of the act may help guide movement production, especially when the response requirements are relatively simple, but the stimulus pattern is more complex. Given that this image was evidenced early in acquisition it is less likely that it was merely a byproduct of practice, but a guiding influence during production.

Fitts and Posner (1967) have also been highly influential in the area of skill acquisition and make explicit statements about the nature of acquisition in the very early stages. However, the development of their theory was limited to observations of individuals learning information processing skills with primarily cognitive, or perceptual demands (i.e., language skills, tracking tasks, reaction time studies), rather than difficult motor components. In addition, much of their theorizing was based on anecdotes and interviews with instructors. It is the common sense appeal of this theory that has probably added to its pervasiveness in the field of motor learning. Fitts and Posner discussed skill acquisition in terms of three stages: A cognitive stage, where the skill is initially acquired; an intermediate or associative phase where early behaviours are tried out, refined and errors eliminated and a final autonomous phase where skills are performed with less conscious control and processing. Support for these learning progressions has primarily been obtained from the cognitive learning literature, whereby rules for solving puzzles and problems become more proceduralized, or automatic with practice (e.g., Anderson, Conrad & Corbett, 1989; Newell, 1991).
In the early stage, understanding of the task is the primary goal. The authors claim that during this stage instructions and movement demonstrations are most important in aiding the development of an executive program. Processing of feedback and attending to cues that later go unnoticed is important to this early stage. Therefore instructions which serve to emphasize these cues and events should be provided early in acquisition (e.g., kinesthetic and visual information about the feet in a dance step, see Fitts & Posner, 1967, p12). However, evidence for these instructional strategies, beyond anecdotal reports, is wanting. Indeed, recent motor learning research (which will be discussed in more detail later) gives reason to question these speculations. For example, Wulf, Höss and Prinz (1998) found that during the acquisition of novel whole body movements, attention to the limbs, which was encouraged by instruction, was actually detrimental to the acquisition process. More recent theories of skill acquisition (e.g., Proteau, 1992) emphasize an increasingly important role for sensory information processing as a result of increased practice at a task, rather than a decreased role. Despite these more recent observations, the three stages proposed by Fitts and Posner have been and still are influential in current theorizing of motor skill acquisition (e.g., Anderson, 1982; Shiffrin & Schneider, 1977).

One of the other defining features of Fitts and Posner’s theory of skill acquisition was the primary role attributed to habits in learning. They claimed that “After the first few years of life, learning an entirely new skill is rare. For the most part new skills are built out of already existing skills” (p19). Instructions that elicit previously learned behaviours were therefore proposed to be important in activating the appropriate “cognitive sets and expectancies” (p20) and providing a language for understanding the new task. However, under what situations this instruction would be appropriate and benefit acquisition was not elaborated upon, although they did propose that “These general sets will contain aspects both appropriate to the new learning and inappropriate to it...” (Fitts & Posner, 1967, p20).

Another influential motor skills researcher around the same time was Fleishman (1960). He defined tasks in terms of the abilities required to perform them and subsequently made predictions about learning progressions in light of these factors, or abilities. In a number of studies, primarily directed at aiding training and selection protocols for the military (e.g., Fleishman 1957, 1972; Fleishman & Hempel 1954, 1955; Parker & Fleishman, 1959, 1960, 1961), Fleishman and colleagues identified changing patterns of ability as a function of practice on a number of different tasks. 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 the acquisition of a motor skill, which supports the work of Fitts and
Posner. As practice progressed, the predictability of cognitive ability was replaced by psychomotor ability and finally coordination skill accounted for the most variance between individuals at the end of practice on a tracking type task.

Parker and Fleishman (1961) then manipulated verbal instruction relevant to these basic abilities, with the aim of devising a task-appropriate training strategy whereby basic abilities were maximized at different stages throughout practice. A control group received no formal training regarding the tracking task. A second group was given “common sense” training, which comprised an initial explanation of the task, followed by a demonstration and guidance during the early trials. A third group was given experimental training based on verbal emphasis of the basic ability at an earlier time point than it was expected to be required in the task. The experimental groups performed better than the control group and there was some support for the fact that this training was superior to common sense training. Based on these findings it might be tempting to conclude that instructions concerning coordination skills should perhaps be given later in practice and demands on cognitive resources decreased early in acquisition.

1.2.2 Dynamical Systems Theory

An alternative theory of motor control and learning, based on natural laws and physical principles, has recently begun to receive considerable attention. This is the dynamic pattern approach, whereby principles of self-organization are evoked to explain the emergence of behaviour, as a function of dynamic forces acting on and within the motor system (see Kelso, 1995 for a review). Rather than evoking concepts such as movement representations, or motor programs to explain the control of movement, motor behaviour is believed to be a consequence of the spontaneous organization of the motor system due to preferred states or patterns of behaviour (i.e., attractors) that arise under certain conditions. Rhythmic movements have typically been used to examine dynamical systems in human movement and motor control. Not only are rhythmic movements pervasive throughout the animal kingdom, but from a methodological standpoint, these movements lend themselves to empirical investigation of the evolution of behaviour.

Kelso and colleagues (e.g., Haken, Kelso & Bunz, 1985; Kelso, Scholz & Schöner, 1986; Scholz, Kelso & Schöner, 1987; Schöner & Kelso, 1988; Schöner, Zanone & Kelso 1992; Tuller & Kelso, 1989) have been responsible for pioneering this approach to the study of rhythmical movements in human motor control. The original task used by Kelso (1984) to examine the spontaneous self-organization of the motor system was a simple two finger wiggling experiment.
Participants were required to move both index fingers in a rhythmical fashion, at roughly the same frequency, in the transverse plane. LEDs attached to the fingertips enabled recording of finger displacements. It was found that two basic patterns could be produced reliably and in a stable fashion. These were symmetrical in-phase movements, characterized by simultaneous flexion and extension of homologous muscle groups and asymmetrical, anti-phase movements, which are described by alternating flexion and extension of homologous muscles, rather like windshield wipers on a car. As a function of the spatial and temporal difference between the limbs at any one point in time, these patterns are also defined in terms of relative phase.

Subsequently, in-phase and anti-phase are quantified as 0° and 180° relative phase, respectively. Both point, or discrete measures of relative phase have been used to capture the phase relations between the limbs, as well as continuous measures. Discrete measures of relative phase provide a representative description of performance at particular markers, for example peak flexion of one limb in comparison to the delay in peak flexion of the other limb, as a function of cycle time. Continuous measures of relative phase, as the name suggests, are based on the trajectory of each limb obtained from continual sampling of displacement and velocity. From this information phase angles for each limb are obtained and the difference between the limbs at any one point in time provides an estimate of relative phase.

During production of these in- and anti-phase movements, Kelso gradually increased the pacing frequency, which was dictated by an auditory metronome, from 1.25 Hz to 3 Hz. He found that at the low movement frequencies the two patterns could be produced equally well, although the anti-phase pattern was somewhat less stable than the in-phase pattern. However, as movement frequency was increased the ability to perform the anti-phase pattern diminished and eventually only in-phase movements were observed. As movement frequency was gradually decreased, no switch back again to anti-phase movements were found. These spontaneous switches to a new movement pattern, at certain critical frequencies (which are somewhat dependent on the individual, the instruction and environmental information), are referred to as phase transitions. Similar observations of phase transitions have been observed in quadruped locomotion, where at higher movement frequencies the pattern of relative movements between the legs changes from a trot, to a gallop. These transitions, rather than being prescribed, are the result of the differential stability of the two movement patterns, particularly at faster movement speeds.

As a result of these observations bimanual control is best described as a bi-stable system at certain values of movement frequency, but may switch to mono-stable (i.e., in-phase only) if
the conditions dictate otherwise. This switch is unidirectional and therefore there is no switch back to a bi-stable system as movement frequency, for example, is decreased. This phenomenon is called hysteresis. Interestingly, switching behaviour from anti-phase to in-phase has also been observed between two people sat facing each other, who were required to move only one limb (Schmidt, Carello & Turvey, 1990), as well as within a limb when flexion and extension of the elbow and wrist were required (Kelso, Buchanen & Wallace, 1991).

Based on these observations of dual finger and wrist movements a model was developed that both describes and predicts real phenomena associated with bimanual movements. This model is referred to as the HKB model after its authors, Haken, Kelso and Bunz (1985). The critical defining feature of this model and dynamical systems generally is the finding that dual limb movements can be adequately described by one macroscopic variable, or order parameter, which in this case is relative phase between the limbs. In it’s simplest form, observed relative phase is a function of the differential stability of the in and anti-phase pattern, which are modeled as cosine functions and by modifications to variables such as frequency, which serve as parameters in the model.

Order parameters describe significant relations (i.e., behavioural patterns) between the system’s components that are dependent on change in specific and non-specific control variables. For example, increasing the speed of movement in quadruped locomotion leads to the spontaneous emergence of a new pattern of behaviour (e.g., the transition from a trot to a gallop). This pattern of behaviour is more cost efficient (Kugler & Turvey, 1987) and more stable at a certain movement frequency and therefore functions as an attractor state, or a preferred pattern of behaviour. Movement frequency is a non-specific control variable, as it contains no prescriptions or “program” for change. Behaviour that results from change in non-specific control variables is referred to as the intrinsic dynamics. In human, bimanual coordination these intrinsic dynamics are in-phase and anti-phase movements.

As explained above, there is only one variable that is responsible for ordering the system, though it is itself determined by lower-level variables. This variable, typically relative phase between two components, allows behavioural change to be explained at a macroscopic level of description. This variable relative phase captures the self-organization of the system, which is responsible for harnessing the large number of interacting components of the lower levels (e.g., muscular and neuronal). The terms coordinative structures and synergies, have also been used to describe the functional coupling of muscles, joints and neurons (e.g., Bernstein, 1967; Tuller & Kelso, 1989). Rather than being ‘hard-wired’, these synergies, like the intrinsic dynamics, are
proposed to be flexible and temporarily assembled to serve task-specific functions. For example, Kelso, Southard and Goodman (1979) showed how bimanual aiming movements were constrained to act as a single unit when both arms were required to hit two targets at different distances, that varied in size. They found that when the movements were performed separately the response times were longer for smaller targets that had greater precision requirements, supporting the extant literature (e.g., Fitts, 1954). However, when both arms aimed to targets of different sizes, the response times were roughly the same. The arm moving to the easier, that is the larger target, slowed down and the arm moving to the more difficult target speeded up a little, as compared to the single response condition. Additionally, the kinematic characteristics of the two movements showed that the two arms were coupled temporally as evidenced by time to peak velocity and acceleration. Presumably this functional coupling served to make the control requirements of the task simpler by reducing the number of variables that required individual control. Although the notion of synergies, coordinative structures and intrinsic dynamics abound in dynamical systems’ research, there has been very little explanation directed towards understanding how these task-specific structures are brought about.

In human movement, this macroscopic level of description is usually at the behavioural level, although small scale or component level analysis (Zanone & Kelso, 1997) have also been described using the same principles. One of the attractive features of dynamical systems theory is this common language of control that can be applied within and between many different levels of task description. Although change can occur at lower levels, these changes may not be relevant for explaining behaviour at the level of observation, even though they play a critical role in the emergence of that behaviour. Without these non-linear interactions within and between levels, the system would be unable to move, adapt, change and display meaningful behaviour. It is in this manner that variability becomes an important component of the learning process, that is, as the engine for change. To acquire new behavioural patterns there is a necessity to break from old attractive states which will require a decrease in the overall stability of the existing motor system dynamics. Variability, therefore, is responsible for change in behaviour and phase transitions to new behavioural states. In this way measures of variability, also referred to as critical fluctuations, are important precursors and indicators of change.

1.2.2.1 Learning from a Dynamical Systems Perspective: Theory and Experiment

Recently it has been shown that intention to switch, or not to switch from anti-phase to in-phase during bimanual movements, can affect the observed patterns of behaviour. Switching
times can be delayed, or prevented as a result of intention (e.g., Lee, Blandin & Proteau, 1996; Scholz & Kelso, 1990). Given the necessity of intention in determining behaviour, and its important role for learning, Schöner et al. (1992) have incorporated this cognitive variable into the HKB model of bimanual coordination so that its influence can be observed in terms of relative phase. Similar to the influence of environmental information on coordination dynamics, to-be-learned attractors, or patterns of behaviour can be specified by intention and interact with the existing intrinsic dynamics of the system. Variables that have a specific influence on the existing dynamics of the motor system are referred to as specific control variables and are modeled as behavioural information. These attractors can then become 'memorized' such that memory too can be considered an example of behavioural information. The importance of perceptual information in the environment acting to constrain the motor system dynamics has already been highlighted by the between person coupling of Schmidt et al. (1990). What is important is that neither intention, or environmental information specifically prescribe the behaviour, rather their dynamics interact with the existing system dynamics formed as a result of intrinsic dynamics, previous learning and current conditions (such as movement frequency).

The following studies serve to illustrate the commonality of these ‘information’ sources. Yamanashi, Kawato and Suzuki (1980) required participants to learn various relative phase requirements in a finger wiggling experiment similar to that adopted by Kelso (1984). In the practice phase of the study, participants were asked to continually flex and extend their index fingers to track two visual metronomes that flashed in various relative phase patterns. These patterns varied from synchrony (i.e., 0° relative phase), such that participants were required to flex their fingers together, the same time the lights flashed, to alternating flexion and extension, as a result of a half cycle lag in the flash times of the metronomes (i.e., 180° relative phase). Feedback was provided when participants deviated from the phase requirements. In the second phase of the experiment participants were required to reproduce all the practiced relative phase patterns from memory, after the visual metronomes first alerted to the required phase and were then turned off.

Yamanashi et al. observed low error (i.e., required − observed relative phase also referred to as delta relative phase) and variability for task requirements at 0° and 180° relative phase only. Phase requirements intermediate to these produced errors in the direction of the in- and anti-phase patterns, accompanied by high variability. Participants had difficulty producing the intermediate relative phase patterns, due to the attracting influence of 0° and 180° relative phase, pulling behaviour towards these states. Tuller and Kelso (1989), who used visual metronomes
throughout to elicit relative phase patterns from 0° (synchrony) to 180° (half cycle lag) and back again to 360° (synchrony) also showed the same pattern of results, which is illustrated in Figure 1.1. In the top panel, negative slopes through the phase requirements at 0°, 180° and 360° are observed when error is plotted as a function of required relative phase. Nearby relative phase values were produced incorrectly as either in-phase, or anti-phase patterns. In the bottom panel, standard deviation of relative phase has been plotted as a function of required relative phase. Again, at the 0°, 180° and 360° phase requirements variability is low, yet increases at values intermediate to these. This pattern of results, due to it’s bird like shape, has been coined the seagull effect (see Kelso, 1995). Common to both these studies was the fact that the same patterns of behaviour were observed regardless of whether the dynamics of the system were scanned using a visual metronome, or whether the required patterns were produced from memory. Two limbs moving relative to one another tend towards states where they are either moving in-phase (0°), or out-of-phase (180°) with each other. Subsequently, these states are defined as attractors.

The scanning procedure adopted by Tuller and Kelso (1989) has been used by other researchers interested in change in coordination dynamics as a function of learning. This procedure allows for a detailed examination of the underlying dynamics and attractive states of the motor system for different values of relative phase. This description of coordination ability is referred to as an individual’s dynamical landscape. Practice on one relative phase pattern not surprisingly leads to improved performance on this pattern, but more interestingly, practice on one pattern can affect performance on a number of non-practiced relative phase patterns. Therefore, general changes to the whole dynamical landscape are observed as a function of practice on one coordination pattern.

Due to the inherent stability of in- and anti-phase, individuals face considerable difficulty learning new coordination movements intermediate to these. If the behavioural information and intrinsic dynamics do not cooperate, then competition between the two emerges and difficulties in skill acquisition are evident. Given that 90° lies half way between the two stable states (0° and 180°) and therefore is subject to the influence of both these patterns, a number of investigators have begun to examine the acquisition of this difficult coordination pattern (i.e., 1/4 of a cycle out-of-phase). As predicted it has been shown that these two stable patterns compete with the acquisition of 90° relative phase, both at the early stages of acquisition and even after considerable practice (e.g., Fontaine, Lee & Swinnen, 1997; Lee, Swinnen & Verschueren, 1995; Swinnen, De Pooter & Delrue, 1991; Zanone & Kelso, 1992, 1997). It is as though individuals
Figure 1.1 Scanning trial data from Tuller and Kelso (1989, adapted from Kelso, 1995). In the top panel the required relative phase as specified by the pacing metronomes is plotted against the difference between the observed and the required relative phase (error). A negative number means that the required relative phase relation was underestimated. In the lower panel standard deviation of the observed relative phase is plotted against the required relative phase.
get stuck in the early stages of skill acquisition and need to engage in a process that allows them to break away from the attraction of the intrinsic patterns. The challenge for motor learning theorists, practitioners and beginner learners, therefore, is to determine ways of decreasing the competition from these pre-practice behaviours so that learning can be optimized. Methods should be adopted that both accelerate the break from these pre-practice behaviours and help resist the influence of these patterns in retention.

As detailed above, scanning procedures are usually adopted to assess the change in a person's dynamical landscape after practice at a new pattern, relative to their dynamical landscape pre-practice. For example, Schöner et al. (1992) required participants to learn how to move their limbs in a 90° relative phase pattern and used a scanning procedure before and after practice to ascertain pre-existing attractors and to determine how they change as a function of practice. Using the model of bimanual coordination (i.e., the refined HKB model), the authors were able to generate predictions as to the effects of learning on the participant's dynamics. One of these predictions, was that the intrinsic dynamics would continue to attract the newly learned pattern after practice, and that 0° would have more of an attracting influence than 180° relative phase, due to the increased stability of the in-phase pattern. Although Schöner et al. found some support for this hypothesis, whereby the attractor at 180° on the scanning task disappeared post-practice (i.e., a negative slope was no longer evident through 180°), more recent studies have failed to provide support for this observation (e.g., Fontaine et al., 1997; Swinnen, Lee, Verschueren, Serrien, & Bogaerds, 1997). However, in these experiments scanning procedures were not used, rather participants were required to produce these movements in isolation, from memory. In the absence of visual information forcing the practiced pattern towards a particular task requirement, the intrinsic dynamics may dominate the observed coordination patterns.

More recently, Zanone and Kelso (1997) have shown that some individuals can produce patterns other than in- and anti-phase before practice, demonstrating a multi-stable dynamical landscape with attractors at 45° or 135° relative phase for example. These abilities are possibly the result of previous practice experiences on other coordination tasks, such as playing musical instruments, video-games, skipping or juggling. Interestingly, these individual differences in coordination ability pre-practice influenced the type of dynamics which emerged after practice at new relative phase patterns. If the system was initially multi-stable, then a gradual, or parametric shift in the dynamical landscape of the individual was evident, that resulted in the replacement of a previous attractive state. In this way learning was characterized by the shifting of previous attractive states to new ones that were relatively 'close by'. For example, an attractor at 45° pre-
practice would gradually be replaced by an attractor at 90° relative phase post-practice if this was the practiced pattern. Given that the dynamics remained multi-stable, no qualitative change to the dynamical landscape occurred, only a quantitative one. This replacement may be due to some limit in the number of attractive states that an individual can simultaneously hold, at least in a specific task environment. If there are too many then the notion of an attractor becomes somewhat meaningless. In contrast, individuals who only show bi-stability and attraction to in- and anti-phase pre-practice, undergo a qualitative change as a function of practice. They may develop an additional attractor, therefore going from a bi-stable to a multi-stable dynamic regime.

Zanone and Kelso (1997) have also observed differences between individuals as to their initial preference for 0° or 180° relative phase. This difference played a role in predicting the strength of intrinsic attractors after practice and the process of learning. In the experiments of Zanone and Kelso participants’ performance was assessed at discrete points in each movement cycle (i.e., at points of peak flexion). After practice at 90° relative phase participants were able to achieve this required pattern at the point required in the cycle. However, on examination of the continuous displacement and velocity of each finger after practice, it was found that participants were not continually performing the newly required relative phase pattern. Rather, performance was quite variable in-between flexion and extension peaks and over half the participants returned to in-phase or anti-phase movements in between peaks. These strategies allowed the individuals to adhere to the task demands, yet at the same time make it easier on themselves when the requirements were less stringent (in between peaks). The type of strategy that was adopted after acquisition was initially evident in the scanning trials prior to acquisition. A pronounced negative slope through 0° relative phase for example was predictive of an in-phase strategy pre-practice. The suggestion, therefore, is that these initial tendencies influence the dynamics that emerge after learning, or may facilitate or hinder the rate of acquisition of the new pattern and its subsequent stability in retention. Although Zanone and Kelso did not examine differences in learning/performance as a function of strategy, probably due to the fact that there were only three participants in each strategy group, they failed to observe any differences between the groups on the scanning trials after practice. For all three strategy groups defined by Zanone and Kelso (1997; the third was termed a sine-like strategy group, whereby participants hovered around the required relative phase), the final dynamics showed a greater attraction to 180° rather than to 0° relative phase (cf., Schöner et al., 1992).
Other researchers who have examined the acquisition of novel bimanual movements have provided continuous feedback to participants during learning such that these composite strategies are not observed. Specifically a Lissajous figure, or relative phase plot has been used to relay, or provide feedback as to task performance, an example of which is illustrated in Figure 1.2. This Lissajous figure is in fact an orthogonal, displacement - displacement plot of the left hand against the right hand. Given this arrangement, positive and negative sloping straight lines are produced for in-phase and anti-phase movements respectively. For patterns in between these two stable states, elliptical (e.g., 45° and 135°) and circular patterns (90°) are produced. These patterns can be used to specify the task goal, independent of specifying how to move the limbs to achieve the required pattern. This type of display enables a relatively simple format for providing relative phase feedback. Swinnen, Lee and colleagues (e.g., Fontaine et al., 1997; Hodges & Lee, 1999; Swinnen, Dounskaia, Walter & Serrien, 1997; Swinnen, Lee, Verschueren, Serrien, & Bogaerds, 1997; Tsutsui, Lee & Hodges, 1998) have successfully used such a task goal to examine learning of new coordination patterns.

Using similar experimental designs, researchers have begun to examine how conditions of practice and augmented information impact on the learning of novel coordination movements (e.g., Swinnen, Schmidt, Nicholson & Shapiro, 1990; Swinnen, Walter, Lee & Serrien, 1993). A number of theoretical and practical issues have been addressed, such as what type of feedback is most beneficial for learning new coordination tasks (based on dynamical principles) and how is performance affected when this information is then removed. For example, Swinnen et al. (1993) provided either KR (knowledge of results) or KP (knowledge of performance) to participants learning a discrete bimanual coordination task. In this task participants were required to perform two different movements simultaneously, either a simple extension movement, or a more complex reversal movement. There was no difference between the groups in either acquisition or retention performance as a function of feedback condition. This led to the conclusion that information relating only to movement outcome was sufficient to bring about change from a constrained pattern of movement.

1.2.2.2 Implications for Pre-Practice Information and Studying Behaviour Change

Given the proposed emergent nature of behaviour and the unfolding of this behaviour in the presence of constraints, concern with current philosophies underlying instructional provision might be raised. Rather than some sort of pre-packaged program being responsible for the production of the act, followed by a strengthening of movement representations, concern should
Figure 1.2 A diagram of Lissajous figure feedback. The circle pattern is illustrated which can be produced by moving the arms 90° out-of-phase, as well as an illustration of the feedback when performing in-phase (0° relative phase) and anti-phase (180° relative phase) movements.
perhaps be directed to the discovering of optimal solutions as a result of interacting with, and exploring the task environment. A reduced emphasis on movement form may be expected and perhaps more indirect methods of movement change may be adopted. For example, Walter and Swinnen (1992) showed how the manipulation of control parameters can decrease the influence of stable intrinsic movement patterns to aid the learning of novel coordination movements. The task for the learner becomes one of discovering the laws of behaviour that constrain performance and learning to use these regularities (such as intrinsic dynamics and environmental information) to acquire new behaviours. The important role of movement variability in effecting change has implications for pre-practice information in encouraging early variability in the movement response, or at least not inhibiting variability.

This theory and the methodology of study have important implications for the study of instructions in learning and identifying variables that bring about change in behaviour. Although task variables, such as movement frequency, have been identified as responsible for change in the two intrinsic patterns, task factors that facilitate learning of new coordination patterns have only received sparse attention. For example, Almeida, Lee and Chua (1998) have examined how the spatial compatibility of the movements and the task goal influence the learning process. Fontaine et al. (1997) and Tsutsui et al. (1998) have examined how acquisition of various coordination patterns are influenced by the stability of existing behaviours and whether order of practice conditions affects the acquisition process responsible for learning continuous, complex motor tasks.

The bimanual coordination methodology is a particularly attractive tool for studying how instructions affect the learning process. Measures of relative phase between the limbs allow quantification of the process of change in addition to quantifying behaviour before a skill has been acquired. In a task such as juggling, for example, measures of skill can only be taken once a person has learned how to juggle. Before acquisition, only a categorical description of the skill is warranted in terms of either being able or not being able to juggle and how many unsuccessful attempts are needed to acquire the skill. This methodology is particularly suited to answering questions with respect to the quality of learning, in terms of such measures as pattern stability under various cognitive and physical demands (see Kelso, 1994). Perhaps most importantly, this methodology allows an examination of learning with respect to existing coordination tendencies and provides a background to examine and compare the learning of novel movements.

Bimanual coordination, although still amenable to controlled, laboratory investigation, is also required in everyday tasks. As well as in the sport environment, bimanual skills are required
in the pursuit of leisure activities such as playing a musical instrument, skipping, or juggling. Individuals are frequently required to learn a new skill or behaviour that requires not only the learning of a new behaviour, but the learning not to do an old one. Inhibition of previously learned habits or intrinsic behaviours that interfere with the learning of the new skill are common observations in a wide variety of movement domains. Therefore, this type of experimental design provides a representative analogue of motor learning situations.

1.3 Empirical Investigations of Instructions and Demonstrations

Despite the enormous amount of research which has examined the role of information provided during or after practice of a motor skill, there has been comparably little research directed at uncovering the role of pre-practice information, such as instructions and movement demonstrations. This is somewhat due to the nature of the tasks that have been examined in controlled laboratory settings. Typically these tasks have not required any new learning as such, that is acquiring new relations between body segments. Only a re-scaling of a previously acquired action has been necessary (e.g., achievement of a specified MT for a sequence of key presses - see Whiting, 1980, 1984; Newell, 1989 & Scully & Newell, 1985 who differentiated novel movement pattern tasks from existing movement pattern tasks). In the latter case, instruction specifying to the individual how to move the limbs to attain the task goal has often been unnecessary. Although some learning situations have required the individual to achieve the task goal in a particular way (i.e., match a movement template, e.g., Newell & McGinnis, 1985), the instruction is then isomorphic with the task goal. In this situation it is difficult to determine whether instruction concerning how to perform an action has a role in motor learning beyond making it clear to the learner the task requirements. Are there benefits to be gleaned from watching a skilled model, or receiving strategy instructions when the task goal is already known? This question has only recently begun to receive attention in the motor learning literature.

Whiting, Bijard and den Brinker (1987) also remarked that very little attention in the motor learning literature has been paid to the early cognitive stage of learning (Fitts & Posner, 1967), where the establishment of movement form is critical (Tyldesley & Whiting, 1975). As discussed in an earlier section, schema theory for example (e.g., Schmidt, 1975), provides no explanation concerning how motor programs exist, or become established, there is just an assumption made as to their prior existence. Similarly, researchers who propose the notion of coordinative structures or synergies (e.g., Kelso et al., 1979; Tuller & Kelso, 1989), offer very little explanation as to how these structures are developed.
In the empirical literature, practice variables have had little effect on the very early stages of skill acquisition. For example, Newell and McDonald (1992) proposed that scheduling of practice manipulations, such as random versus blocked and massed versus distributed practice, have had very little influence, if any, on the early, first stage of skill acquisition and processes involved in figuring what to do. Tsutsui et al. (1998) also found that blocked practice schedules did not effect performance of a continuous bimanual task until the second day of practice. Ingvaldson (1996) failed to show any effects from a number of augmented feedback manipulations applied during the acquisition of a pistol shooting skill. He suggested that KR effects (i.e., knowledge of results) were primarily observed during the attunement phase of a skill (Whiting, 1984), where an already existing behaviour is refined to meet a specific task requirement. This is compared to the initial development of the basic movement pattern.

Subsequently, there is a need to examine how this early stage of skill acquisition is influenced by other practice techniques that are designed specifically to encourage the acquisition of a new movement skill. If movement representations are developed as a result of practice and guide movement production, questions arise as to when they are developed. Indeed, in light of the current research, these representations may not be developed until later in practice, once the skill has been acquired, or perhaps earlier in more simple skills that require only a refinement of an existing movement pattern.

This failure to examine the early stage of motor skill acquisition, particularly the influence of pre-practice information, has been remarked upon by a number of researchers concerned with both the theoretical and practical implications of instructional provision. Lidor (1999, p129), for example, who primarily works within the field of sport psychology claimed that “...more investigations in motor learning and sport psychology should be conducted in order to understand what learners need to think about prior to and during execution of a learning task.” Vickers (1994, p34) made somewhat similar remarks after reviewing the instructional literature for pedagogical reasons. She concluded her review with the following appraisal, “In many studies, instruction was initially given to subjects. How this was done, however, was of no interest to the researchers who concentrated on manipulating practice schedules or feedback frequencies or other variables. It is as though the manner in which the subjects were introduced to the motor skill was not important.”

In a recent motor control text book called “Advances in motor learning and control” a key chapter in the book was written by Swinnen (1996), who has been integral in furthering the understanding of augmented information feedback in a variety of motor tasks. One of the major
issues that is made reference to throughout the chapter is the over-emphasis of research on KR at the expense of other methods for optimizing learning. In particular, Swinnen draws attention to the lack of distinction between the two roles KR plays in influencing the learning process. That is, rather than only providing feedback regarding the completed response, KR often plays an important prescriptive role in defining the task goal. Swinnen (1996, p41) concluded that “The overemphasis on KR manipulations has detracted from other learning aids, such as demonstrations and verbal instructions.” In the following section different types of instructional techniques are discussed in terms of the empirical evidence for and against their usage, including criterion templates, movement demonstrations and verbal instructions.

1.3.1 The Role of Movement / Criterion Templates

The importance of knowledge concerning the goal of the task was recently demonstrated in a simple study by Newell, Carlton and Antoniou (1990), who required participants to produce familiar or unfamiliar drawing shapes. When the task requirement was a familiar pattern (i.e., a circle), goal-related information was not required to produce the correct pattern, nor was detailed performance feedback (i.e., knowledge of performance, referred to as KP). KR, which informed as to absolute error, was sufficient. However, when the task goal was unfamiliar, criterion information was required during practice to produce benefits in acquisition and retention without feedback. This criterion information was necessary for groups who received both KP and KR and only KR. The authors concluded that without knowledge of what should be produced, that is the task goal, no reference would be available to compare movement-related feedback and no benefits of KP would be seen.

It has been common practice in the study of motor skills to differentiate between two different classes of movement; open and closed (although they are commonly viewed to lie on a continuum, see Gentile, 1972). One way in which closed skills are distinguished is by the fact that the goal of the task and the manner with which the task goal is to be achieved are the same. The most typically cited examples are diving or gymnastics. In contrast, open skills commonly have conflicting goals whereby the goal of the task and the way it is to be achieved are not compatible. In these types of skills there may be many ways to reach a particular motor solution, for example, scoring a goal in soccer or putting a ball in golf. In spite of this distinction, it is common practice for sport skill instructors to turn what have been defined as open skills into closed skills, by the provision of optimal movement templates, or criterion movement patterns. In this situation the instructor has to be aware that the goal of the task does not become confused
(see Gentile, 1972; Whiting & denBrinker, 1982), such that achieving the task goal in a specified way gains precedence over attainment. When kicking a ball, for example, the positioning of the hip, leg and feet may be less important than kicking the ball the required distance.

The provision of movement templates has also been shown to increase task consistency (e.g., Newell et al., 1990). Although this is necessary for performance at closed skills, this may be at the expense of developing a response repertoire (Gentile, 1972) necessary for the performance of skills in open, non-predictable and continually changing environments. Increased task consistency is only beneficial to performance if the skill is being performed correctly. During the initial stages of learning, when pre-existing behaviours or bad habits may dominate the action, increased variability in the early movements of the performer may be preferable to facilitate the acquisition of a new movement pattern (see Lee et al., 1995).

In open skill situations, the concept of an optimal performance template is somewhat contentious. Although there appears to be characteristic invariances across skilled performers (e.g., Wulf, Shea & Matschiner, 1998, found that time to peak force on a ski-apparatus differentiated the best performers from the poorest performers), there is often considerable variability in the achievement of even the most simple movement skills (see Latash, 1996). Given the different physiological, morphological and biomechanical differences between individuals, the search for optimal movement templates that apply across individuals of varying skill and physical make-up may not be possible. Even if they are determined, these expert profiles may not be useful learning tools for unskilled individuals.

For example, although Young and Schmidt (1992) found initial evidence suggesting an optimal movement pattern for a simple coincident timing task, on closer examination Brisson and Alain (1996, 1997) failed to verify these findings. They found that compared to a "best" participant's template, an individual's own movement profile was equally useful for task performance, if not more so, especially for maintaining movement consistency. Newell, Morris and Scully (1985, p238) claimed that "As the optimal coordination function for most tasks has never been determined formally, it typically reflects the intuitions of the advisor about what pattern of coordination is optimal and/or mimics the coordination pattern that other successful performers have utilized." These findings lead to the conclusion that, as long as the performer knows what is required in terms of the task goal, additional information specifying the optimal way to achieve this goal may be redundant, or at least not as beneficial as feedback or instruction relating to one's own performance. It has also been argued that interventions of this nature cause people to try and replicate the solution without trying to find their own solution. Someone else's
solution may not be well understood by the learner, due to the fact that he or she has no supporting knowledge base to make it useful. Higgins (1991) calls this training rather than learning. Bernstein (1996) also made similar remarks when he discussed the importance of repetition without repetition, that is repeating the means of solving a problem, rather than repeating the solution. In the studies reported in this section the primary mode of instruction has been kinematic movement templates that prescribe a certain way for performing a skill. In the next section visual demonstrations are discussed with reference to their effects on the acquisition of simple motor skills.

1.3.2 Demonstrations and Modeling: Learning Movement Sequences and Cognitive Strategies

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 have obviously been somewhat dependent on the types of tasks examined and 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 unlikely to be useful. In the words of Newell (1981, p537) “When the information to be conveyed through demonstration is redundant, there is, by definition, no information transmitted to the learner.” Despite these instances, when no new information is being transmitted, movement demonstrations are often critical in specifying to the individual the task goal requirements. The importance of this pre-practice information has received most support when the task has required the stringing together of movements that are already part of a person’s movement repertoire. For example, performing a specific sequence of key presses in a laboratory task, or a series of gymnastic moves in a floor routine. This can be contrasted with learning a skill such as a cartwheel, where the individual learns to do something they could not perform previously and as such acquires a novel movement pattern. If the necessary motor components to perform the action have already been acquired, then demonstrations facilitating the stringing together of these components are likely to be helpful to acquisition.

One of the most influential researchers in learning research over the past three or four decades has been Bandura. He has been responsible for developing a cognitive-behavioural theory of learning called social learning theory (1969). In the original formulations of this theory two systems were proposed to be involved in modeling behaviour. These were a spatial, or imaginal system, and a verbal system. Verbal mediation was proposed to allow for a representation of the model’s behaviour and enable 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. Bandura (1986) also proposed a number of specific cognitive processes underlying effective modeling whereby the learner must selectively attend to the relevant information, retain this information, have the capability for using the information and have the desire (motivation) to imitate the behaviour.

These cognitive processes have important implications for pre-practice information. Undoubtedly motivation to learn is a critical variable in the learning process and much early research by animal learning theorists was concerned with processes such as reward and punishment that encourage, or inhibit certain behaviours. There is little doubt that instructions which encourage early learners with praise, for example, play an important motivating role.

The key feature of Bandura’s social learning theory was that of attention. Attention to the modeled action was proposed to be necessary for the development of a representation of the act in memory (in either visual or verbal form) to serve as a reference of correctness to guide the action when required. However, learning models have been shown to be just as beneficial as expert models and in some cases more beneficial for learning (e.g., Lee, Swanson, & Hall, 1991; Lee & White, 1990; McCullagh & Caird, 1990) which leads to the suggestion that there is something other than how to correctly perform an action that is being picked up through observation. Any internal representations of the act must be more complex than simply a correct movement template.

The observer, when watching a learning model, is actively involved in the problem solving process and therefore concerned with both goal attainment, not just copying the model. They receive variable information across trials, rather than the repetition of one possible solution. When watching a learning model, the observer is not merely trying to copy performance, but is finding out what does and does not work, which is an important component for learning. Indeed, mental practice (another form of covert rehearsal) has been shown to have similar learning benefits as observational practice, suggesting that cognitive processes are mediating these benefits. However, Adams (1990) claimed that mental practice helps the learner determine what follows what, but not necessarily the subtleties of the movement. Instructions and/or movement demonstrations can encourage attentional focus, yet knowing what information is the most appropriate and relevant is not easy to determine. This is especially true when the task goals are complex or numerous and in light of the finding that learning models can be more beneficial than correct models.
The capability of the learner is another particularly interesting characteristic proposed to underlie successful modeling. Children may have difficulty understanding verbal instructions such that developmental characteristics play a role in determining the effectiveness of modeling. Additionally, there must be no apparent physical limitations to modeling the desired movement. Whether this implies that the movement response should already be an existing part of an individual's movement repertoire is not clear however. If the individual cannot perform the response on the first practice trial, does that mean they will not have the capability to use the information? If the learner does not have the capability to use the information then questions as to how this information can be retained also arise. Perhaps one of the criticisms of Bandura's work (at least in the motor domain), is the simplistic nature of the response that has required modeling. Often a response is required that places more demands on the cognitive aspects, such as a specific sequence, rather than complex motor components. The results from some of these studies are detailed below.

Carroll and Bandura (1982, 1985, 1987), showed benefits for groups learning a sequence of actions using hand-held paddles when they had been able to watch demonstrations of the actions prior to practice. Arguably these demonstrations served to enhance the memorial representation of the required sequence of movements. In addition, Howard, Mutter and Howard (1992) showed that serial pattern knowledge could be acquired from observing a skilled performer respond in a key-pressing task, where certain visual stimuli were presented in invariant sequences. Participants who watched a person performing key pressing segments before practice also showed considerably more explicit knowledge as to these invariant sequences than participants who physically practiced the task. Again these findings lead to the suggestion that observational learning most directly impacts on cognitive processes that are open to conscious awareness.

Similarly, Ross, Bird, Doody and Zoeller (1985) and Doody, Bird and Ross (1985) examined the learning of a barrier knock down task under various information manipulations including auditory and visual models, and videotape feedback. Again, modeling was found to facilitate performance when measured in delayed retention and this was suggested to be due to the development of a stronger template of the required movement sequence. As suggested, these types of tasks may create more of a cognitive, memory problem for the individual, rather than a motor problem where the learner has to figure out how to coordinate their limbs to perform a movement. Similar conclusions were reached by Scully and Newell (1985) who, on reviewing the early modeling literature, proposed that systematic benefits for demonstrations were only
found for tasks using existing movement patterns, as compared to tasks requiring the learning of novel movement patterns. McCullagh (1993, p108) more recently questioned “...whether subjects can learn complex movement skills [from demonstrations] when both spatial and temporal aspects need to be coordinated to produce a desired outcome (words in brackets added)”.

Another somewhat different line of evidence for this conclusion comes from work where cognitive strategies underlying expert performance were examined (Deakin, 1987; Starkes, Deakin, Lindley & Crisp, 1987). Figure skaters and ballet dancers showed high levels of recall for structured dance sequences acquired by watching a model perform the sequence. Experienced performers typically used hand movements during observation to “mark” the steps, which served to act as a cue for the whole-body position later in recall. In this manner, the demonstration highlighted the correct ordering of the task components, not the teaching of the actual components themselves. Vogt (1996) referred to the reproduction of tasks already within a person’s behavioural repertoire as imitation learning, as contrasted to observational learning, which is the learning of newly acquired skills. Despite this definition, observational learning studies have typically not involved the learning of new skills. Often learning has been a case of refining old skills, by scaling to a new task parameter. Vogt (1996, p120) alluded to learning as a possible re-scaling of an already acquired movement skill, by referring to observational learning as “repeated demonstrations of patterns which either need to be newly acquired or at least refined by the observer/actor (requiring “adaptation” in Whiting’s, 1984, terms)”. This definition highlights the difficulties which may be faced trying to define movement skills strictly in terms of novelty.

Recently Gentile (1998) differentiated two learning processes involved in the acquisition of motor skills, termed explicit and implicit, reflecting their differential accessibility to conscious awareness. The explicit process is directed towards goal attainment and developing the appropriate mapping function between the learner and the task environment. The implicit process is concerned with the acquisition of the appropriate force generation patterns that enables efficient movement production. Given that observational practice most directly impacts on cognitive processes that are open to conscious awareness (e.g., McCullagh, 1993; Scully & Newell, 1985), it is expected that observational practice may benefit the explicit process only. As no physical practice is undertaken, no facilitation of the implicit process will occur. As remarked on earlier, participants in a tracking study by Franks (1980) developed an explicit template of the form of the movement which was evidenced by a sketch of the stimulus pattern early in practice.
Whether this explicit process can be enhanced for more complex motor skills and subsequently serve to facilitate skill acquisition, remains to be tested.

It has also been shown that movement demonstrations can aid the learner in adopting strategies that are associated with skilled performance. For example, Kohl and Shea (1992) found that merely observing a group performing a tracking task led to the development of a control strategy similar to a physical practice group. That is, these individuals showed a more open-loop strategy characterized by rapid response, not waiting for response-produced feedback to initiate the next response. However, the accuracy of response was poor in comparison to the groups who underwent physical practice. It was argued that the strategy acquired was not appropriate for the level of skill of the observers, who were not able to efficiently plan and anticipate their movements to perform the tracking task in an accurate fashion. Kohl and Shea (1992, p257) concluded that, “actual practice experiences may be needed to manage a particular mode of control, but not required to select that control strategy.” A hierarchical control model was developed by the authors to explain these findings, whereby observational learning was proposed to facilitate acquisition at a higher mental level but not at a muscle level. These levels were somewhat similar to the explicit and implicit processes described by Gentile (1998) and also to levels described by Bernstein (1996). Specifically, Bernstein differentiated the level of action plans, at a higher, mental level, from a lower, muscular level of sensory corrections that was presumed to ensure quality in the movement response.

1.3.3 Implicit and Explicit Learning

Despite the advantages that have been observed for the learning of tracking tasks and movement sequences, relatively recent work in the cognitive literature serves to challenge some of the theoretical rationale underlying learning and the provision of pre-practice information. Results from the implicit learning literature challenge the idea that movement representations are developed early in practice, which guide movement production (at least explicit representations). They serve to question the amount of understanding that is required for early learning to occur (cf., Fitts & Posner, 1967) and the supposition that directing attentional focus to regular stimulus features will be the best method for instruction (cf., Bandura, 1986).

Reber (1967) was one of the first to examine the phenomenon of implicit learning. From studying the acquisition of artificial grammars, Reber showed that individuals were able to generalize their learning of letter strings to correctly predict the grammaticality of newly presented sequences. What was interesting about this observation was the fact that participants
were unable to explicitly verbalize how they were able to do this, that is explain the rule or method for judging whether letter strings were grammatically correct. Based on these findings, Reber termed this type of learning as implicit; occurring at an unconscious level and characterized by the acquisition of abstract knowledge.

Broadbent and colleagues (e.g., Berry & Broadbent, 1984; Broadbent, 1977; Broadbent & Aston, 1978; Broadbent, Fitzgerald & Broadbent, 1986) expanded on this work by exploring the learning of computer interactive tasks. These tasks, framed in terms of real-world problems such as the relation between parking spaces and the number of buses, required an operator to predict how a system (e.g., a transport system) would react to an input based on a usually hidden, complex algorithm or rule. Contrary to perhaps more common sense predictions, individuals were able to learn to control these complex systems without any explicit knowledge underlying their regularity and sometimes more effectively if they had not received instruction as to the general rule underlying performance (e.g., Berry & Broadbent, 1988). As before, participants were often quite unaware as to how they had managed to control these complex systems and correctly perform the task. Despite the similarities in findings to the work of Reber, it has been suggested (see Buchner & Wippich, 1998) that control tasks, such as the ones used by Broadbent and colleagues, are not good examples of implicit tasks. In these tasks the participant knows from the outset that they are expected to solve the problem and therefore actively search for the system invariance. In this manner the learning process is not incidental, a characteristic usually deemed necessary for implicit learning. Berry (1994) agreed that explicit processes may play a more significant role in these control tasks than originally believed, whereby participants adopt explicit hypothesis-testing strategies to try to uncover the rules or regularities underlying task attainment. This situation is comparable to most motor learning contexts, where the individual is usually directed to discovering a motor solution that will lead to the production of a certain movement.

Although negative effects have been associated with explicit instructions on these complex tasks, Hayes and Broadbent (1988), for example, showed that instruction was beneficial to learning under certain conditions. Specifically, prescriptive information concerning what to do was useful for acquisition if the task environment was also more explicit and easier to relate to the instructions (i.e., based on the operator’s current response, rather than their previous response). Selectively attending to specific information may be beneficial for learning under these circumstances, whereas under more complex conditions learning may proceed more effectively in a non-selective manner. Trying to search for rules in complex stimuli, where
regularities are not salient or not predictable, may be detrimental to performance. This is due to the high attentional and cognitive resources that would be devoted to finding the rule at the expense of performing the task. Reber (1976, p93) commented that “searching for rules will not work unless you can find them.”

1.3.4 Implicit Learning in Simple Motor Tasks

As with the learning of cognitive tasks in an implicit manner, that is without awareness of the rules or regularities governing performance, there has been evidence that some motor tasks can also be acquired in a similar manner. For example, early work on tracking by Pew (1974) showed that individuals were able to demonstrate improved performance on a regularly repeating segment during a visual-motor tracking task without demonstrating any awareness that this segment had been repeated. Lewicki, Hill and Bizot (1988) and Lewicki, Hill and Czyzeska (1992) have also shown that perceptual invariances in the stimulus array can speed up response times during simple key pressing tasks without the performer showing any knowledge of stimulus regularities. Similar to some of the work discussed in the preceding subsection, providing explicit knowledge of these rules or covariances either provided no learning advantage, in terms of performance on the task, or produced performance decrements (e.g., Green & Flowers, 1991; Magill, 1998; Magill & Clark, 1997; Magill, Sekiya & Clark, 1995; Magill, Schöenfelder-Zohdi & Hall, 1990). In a computerized, visual-motor coordination task requiring joystick responses to predictable and unpredictable stimuli, Green and Flowers (1991) showed a decrease in error for predictable stimuli, in the absence of instruction concerning this regularity. When knowledge of stimulus cues was provided, such as the usual trajectory of a stimulus pattern, this explicit knowledge actually resulted in poorer performance for participants who practiced the task under those conditions.

Although Magill and colleagues also failed to observe any advantages associated with explicit knowledge of a repeated segment on a tracking task, no detrimental effects were observed. In the study by Green and Flowers (1991) the so called regular stimulus-response pairings were not presented invariantly on 100% of the trials (only an 80% probability) which may be in part responsible for the poor performance of the explicit knowledge group. Indeed, when Magill and Clark (1997) showed the repeated segment on 100% of the trials, no detrimental effects of explicit knowledge were observed. These findings led to the suggestion that some degree of variance in the pattern that requires response may hinder the explicit search for rules or regularities.
The results of these studies show that, in tasks where a strong perceptual component is present, the detection of invariance or regularities in the stimulus array may be best when the individual is not made explicitly aware of any patterns and therefore not directed to search for regularities or rules. The importance of attention in mediating learning is obviously critical, yet the complexity of attentional effects should be appreciated. Just because a variable, or certain piece of information may be related to task success, explicitly directing participants to this information may not be beneficial. It possibly hinders the processing of additional, important information, or interferes with the cognitive demands of the task.

1.3.5 Learning of Novel Motor Patterns

Given that motor learning often requires intentional learning of some kind (and is therefore more explicit), it is interesting that a significant number of experiments requiring the learning of complex actions have not shown benefits as a result of explicit instruction, or the provision of skilled models. For example, Vereijken and Whiting (1989) and Whiting et al. (1987) failed to observe benefits for learning ski movements on a ski-simulator task with an expert model. Rather, discovery learning participants, who were left to discover how to perform the movements themselves performed as well and, on some variables, better than a group who watched a skilled model (see also Anderson et al., 1998). It was suggested that detailed instructions, or a movement demonstration might cause the learner to be overly concerned with the details of the movement and the achievement of movement form at the expense of goal attainment. Therefore attention would be divided between copying the movement and solving the motor task. Given that discovery learners have either no or few pre-conceptions about the task, their focus is on solving the task and keeping the platform moving continuously. Although differences in performance measures have been observed across these learning groups, Vereijken and Whiting (1989) point out that it is unclear whether the discovery learning groups approach the task in similar ways to the instructed groups.

Even though attention to key features of the movement has been proposed to be critical to effective modeling by Bandura, in more complex tasks, attention to one specific information source at the expense of others may actually be detrimental to learning. Den Brinker, Stäbler, Whiting and van Wieringen (1986) provided learners with instructions and feedback concerning one performance variable that related to performance on a ski-simulator task which required frequent, fluent and wide oscillating movements. Improvement on the attended variable was observed, although this was somewhat at the expense of performance on others. For example,
improvement in frequency of the movements was observed when participants received feedback regarding this variable, yet this was at the expense of movement amplitude. Attention to amplitude was the most beneficial in terms of positive transfer to other variables, however, no control group was examined in this study. Van Emmerik, den Brinker, Vereijken and Whiting (1989) conducted a follow-up experiment with a group who did not receive either instruction or feedback, so called the discovery learning group. They found that discovery learning was equally as effective as amplitude feedback and superior to instruction and feedback concerning frequency and fluency parameters.

Similar trade-offs in performance on one variable due to attention to other variables have been demonstrated by a number of researchers (e.g., Solley, 1952; Maraj, Allard & Elliott, 1998). Solley (1952), for example, gave instructions concerning a two step lunge emphasizing accuracy, distance, or both. Participants who received accuracy instruction were the most accurate and those who received distance instruction lunged the furthest. These results underscore the attention directing nature of instructions and feedback. They also serve to caution against providing specific instructions if performance is to be assessed by a number of performance measures (such as both amplitude and frequency). Also, if the task is relatively complex, directing attention to one specific information source may be at the detriment of other important factors or variables necessary for effectively performing the task.

In a more recent study, rather than providing instruction concerning 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 from earlier studies as an important predictor of success (e.g., Vereijken, 1991; Vereijken, Whiting & Beek, 1992; Whiting & Vereijken, 1993). Therefore knowledge of what had to be learned 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 who were not provided with any instructions showed better performance in both acquisition and retention, although the instructed participants showed some slight improvement on their ability to delay force onset. This finding is similar to that of Kohl and Shea (1992) who found that strategy could be trained by demonstrations, but that it may be inappropriate for the skill level of the learner. Due to the lack of practice these participants received before instructions were provided a second study was conducted. Wulf and Weigelt suggested that the expert strategy may have been inappropriate until a different level of understanding and familiarity with the task had been reached. Despite this later manipulation of instruction after
three days of practice the participants in the study were still not able to effectively use the information to facilitate performance. Rather, almost all the participants showed detriments when it was received in terms of reduced movement frequency, smaller amplitude movements and/or increased jerkiness (i.e., more inhibited movements) on the ski-apparatus.

A similar inhibitory effect on the produced movement as a result of instructions was observed by Green and Flowers (1991) in their joystick, coordination study detailed earlier. Specifically, they found that the performance of instructed participants was also accompanied by reduced joystick motion early in the trial sequence when predictive cues could occur. They argued that this qualitatively different movement strategy was encouraged by the cognitive demands placed on individuals in the instruction group, which subsequently inhibited performance. Therefore, one of the effects of movement-related instructions or demonstrations may be a reduction in movement. This lack of movement experience may be a particular disadvantage if a novel movement skill is required that is not already part of an existing movement repertoire. Without experience of the task dynamics and varied stimulus-response pairings, the learner may experience difficulties discovering the required coordination pattern and breaking from undesirable, yet preferred movements.

Vereijken (1991) argued that discovery learning works in a positive manner compared to instruction by encouraging the discovery of optimal solutions by allowing the individual to gain experience of other less than optimal solutions. Instructions or performance models may constrain the search for optimal solutions that may be specifically suited to the individual. For example, early in learning, performers may start by freezing degrees of freedom in the motor apparatus (i.e., certain limbs, or movements in joints) to make the solving of the motor problem easier (e.g., McDonald, van Emmerik & Newell, 1989; Vereijken, Whiting, Newell & van Emmerik, 1992). This freezing of degrees of freedom or constraining of motor components is somewhat similar to the functional coupling found in bimanual aiming movements by Kelso et al. (1979). If performers are required to copy an expert model then this may have an adverse effect on the learning process, because the performer may not have sufficient control of his or her degrees of freedom to perform in the same way as an expert. Rather than solving the motor problem by imposing their own constraints, then gradually releasing them as control improves, the learner will attempt to copy the skilled model and may fail to adequately bring together their degrees of freedom in the same way as the expert. Paradoxically, the instructions or demonstrations may fail to constrain the motor system by overwhelming the learner with information concerning the optimal control of many limbs and joints, yet constrain the search for
solutions to the motor problem which may be optimal for the learner at that particular time. Indeed, Southard and Higgins (1987), found that demonstrations were not sufficient to instigate a change in movement form from a pre-practice constrained pattern of movement during the performance of a forehand shot in racquetball. In fact for one of the important outcome variables (i.e., velocity of the racket) practice-only led to better performance than practice plus demonstrations.

This active search of the task-space to acquire new motor behaviours is in line with predictions from dynamical systems theory, whereby an increase in variability (i.e., critical fluctuations) is an important precursor to behaviour change and the discovery of new patterns. The significance of variability in facilitating behaviour change has been an integral part of theoretical reasoning surrounding the benefits of discovery learning over instructed environments (see van Emmerik et al., 1989; Vereijken, 1991; Vereijken & Whiting, 1988). Preliminary findings suggest that this initial variability is a key variable underlying success in acquiring new coordinative actions. For example, Anderson (1997) found that individuals who were more successful at learning a gymnastic move, were those who demonstrated more trial to trial variability early in learning.

Although discovery learning has been a preferable method for learning than more direct, instructional techniques, a caveat in the interpretation of these results is required. Withholding movement instructions and demonstrations is only likely to be beneficial if the learner attempts 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. Although errorful, trial and error learning can be beneficial to learning; errors can only produce learning if new behaviours are then attempted. Swinnen, Walter, Lee and Bogaerds (1993) found that outcome information was equally as effective as more detailed KP during the acquisition of a complex bimanual skill, due to the fact that both types of feedback alerted to a problem and therefore encouraged the generation of new solutions. However, in contexts where the possible solutions are many, or the constraints on movement control are not clear, less informative, instructional methods may hinder acquisition. Vogt (1996, p128), for example, claimed that “observational practice may act as a short-cut in the exploration of task constraints” and went on to show partial evidence in support of this claim. He found that when participants were able to watch a model perform a pendulum-swing task before practice, during practice they adopted a similar strategy, which was somewhat beneficial to performance. However, as was detailed earlier, adopting a
“similar” strategy as a skilled performer, does not ensure that performance will improve (cf., Wulf & Weigelt, 1997; Kohl & Shea, 1992).

A number of investigators have also suggested that differences between individuals before practice may implicate different instructional methods. Walter and Swinnen (1992) observed a great deal of variability between individuals before practice on a discrete movement task that required the acquisition of a difficult temporal and spatial relationship between the two arms. These performance differences remained throughout practice and in retention. However there was some evidence that a strategy devised to decrease the coupling between the limbs, that is a gradual increase in required movement speed as compared to an early and abrupt increase, was more beneficial for participants who showed the greatest difficulty uncoupling their limbs pre-practice. Based on this finding the authors suggested that differences between people in the strength of underlying coordination tendencies might implicate different instructional techniques. For some people, more direct strategies may be necessary to encourage variability in the movement response, or implementation of different problem-solving techniques or movement strategies.

Not only have instructions been withheld during acquisition of novel motor skills, but implicit motor learning has also been examined by dividing attention between the primary task and a cognitively demanding secondary task. Due to the high cognitive demands associated with this manipulation, it is believed to prevent the acquisition of verbalizable rules and thus prevent an explicit mode of learning. Masters (1992) and Hardy, Mullen and Jones (1996) showed that, although implicit learning delayed the acquisition of a golf putting skill, under conditions of pressure the implicit learning groups continued to improve. The explicit learning groups in contrast were negatively affected by this manipulation. The control group (i.e., a discovery learning group) did not continue to show any learning effects when the task was performed under conditions of pressure (yet see Bright & Freedman, 1998). However the control groups in these studies scored the highest number of putts throughout acquisition and retention.

Analysis of verbal protocols after practice showed that participants in the discovery learning groups acquired significantly more explicit rules governing golf putting than the implicit learning group. They proposed that this acquisition of explicit knowledge was the reason behind performance plateaus or regressions under pressure and explained these effects in terms of inappropriate levels of control. Specifically, when performance is assessed under pressure, automatically produced actions, or procedures, which are normally governed by lower level systems get up-graded to higher order, controlled sub-systems. At this higher level, the task
changes somewhat and becomes more cognitive and declarative. As a result, performance breaks down when “...reinvested with explicit knowledge.” (Masters, 1992, p344).

Baumeister (1984), Carver and Scheier (1981) and Wicklund and Duval (1971) also discussed performance regressions in a similar way to Masters (1992). They proposed an important role for self-attention in mediating performance decrements or plateaus, which could be brought about by the presence of an audience, or a consequential evaluation. They argued that in an attempt to concur with correct performance standards and therefore explicit knowledge of performance, the learner may revert to a controlled way of performing the task, leading to increased self consciousness and increased attention to the internal performance process. Baumeister suggested that this misdirected attention to oneself might be at the expense of other information necessary to perform the task. However this distraction hypothesis was recently discounted by Lewis and Linder (1997) who showed that in a golf putting task only self awareness manipulations resulted in performance decrements under pressure.

Recently, Maxwell, Masters, Eves and MacMahon (1999) found that the differences between the implicit and explicit learning groups remained, even after extended practice (i.e., 3000 practice trials) and did not converge as the authors from earlier studies (i.e., Masters, 1992; Hardy et al., 1996) had suggested. Perhaps more interestingly, in terms of the preceding discussion, the number of rules acquired for the discovery learning, control group correlated with scores on a reinvestment scale (Masters, Polman & Hammond, 1993). This scale was designed to assess a person’s pre-disposition to focus attention inwards towards the limbs, or the mechanics of the movement (i.e., internalize actions). Negative correlations were observed between scores on this scale and putting performance under pressure, such that individuals who showed the greatest difficulty performing under pressure also gained the highest scores on the reinvestment scale. These findings led to the suggestion that learning in an explicit, rule-based fashion may be detrimental to motor learning if performance is required in a stressful situation and the learner has a predisposition to focus attention onto the processes responsible for performance.

These results also concord with recent studies by Wulf and colleagues who proposed that an inward attentional focus could be the primary mechanism mediating negative instructional effects. Specifically, Wulf and Weigelt (1997) proposed that the negative effects of instructions in their ski-simulator task may have been the result of an increased focus of attention onto the limbs as a result of trying to exert force at the correct time. This limb focus would be at the expense of a more global focus of attention onto the distal effects of the action. In a number of recent studies, Wulf and colleagues provided considerable support for this interpretation. For
example, Wulf, Höss and Prinz (1998) manipulated instructional information creating either an internal focus of attention onto the participant's limbs (i.e., the feet), or an external focus of attention towards the wheels on the ski-apparatus. As predicted, a focus of attention onto the external effects of the action led to significantly better performance than instructions promoting an internal focus of attention, both during acquisition and retention. The fact that a non-instructed control group was not significantly different from the internal focus of attention group during retention, at least for movement amplitude, led to the conclusion that an external focus of attention is beneficial to learning.

Further evidence for the positive effects of external versus internal focus instructions was demonstrated by Wulf and colleagues in performing a back hand serve in tennis and putting a golf ball (Maddox, Wulf & Wright, 1999; Wulf, Lauterbach & Toole, 1999). Both of these studies, however, failed to provide control conditions, such that the evidence in favour of externally-focused instructions as compared to non-instructed, discovery learning conditions is sparse. It may be that participants who do not receive instructions generally show a tendency to focus on outcome variables and external cues (see Vereijken, 1991), although some individuals, irrespective of instruction condition may be more prone to think about and focus on the actual movements (e.g., Masters et al., 1993).

Recent discussions concerning the definitions of external and internal focus have been the focus of much debate. For example, Wulf et al. (2000) examined whether the external focus of attention had to be directed to the effects of the action, or merely away from the limbs when learning a tennis serve. Some evidence to show that directing attention to an effects relevant cue, that is the ball leaving the racket, was more beneficial to learning, than a focus away from the limbs, that is the ball coming towards the racket, was found. Park, Shea, McNevin and Wulf (2000) also manipulated near and far cues on a stabilometer and found that in retention, a focus on the furthest cue was more beneficial to performance than a focus on the near, yet external cue. Although again no control groups were examined in either of these studies, the results confirm the fact that attentional focus is an important learning variable that may underlie the effectiveness of pre-practice information.

Current theoretical beliefs concerning movement control also accord with these recent findings concerning attentional focus. In particular, Latash (1993, 1996) proposed that the control focus of a performer during a movement task is directed toward the end-point of the action, what has been referred to as the working end-point. This has been defined as the most important point for executing a task and may range from the fingertips when grasping, or the
trajectory of the ball in a basketball free throw (see Latash, 1993). In comparison to other joints that are involved in the movement, the working point demonstrates the greatest invariance across trials. This finding leads to the suggestion that control strategies are somehow related to the working point, not with the details of the rest of the motor system, that is attending to limb position or the actual movement. Similar suggestions have also been made by Prinz (1992), who proposed that actions are best planned in terms of their effects, referred to as the action-effect hypothesis. As well, these proposals have been corroborated from studies of speech production, where the goal of the action is maintained (i.e., to produce a novel speech sound) even though perturbations to the anatomical components involved in the movement, such as depressing the tongue, are given (e.g., Abbs & Gracco, 1983, Kelso & Tuller, 1981).

Lack of awareness of limb positioning has been both anecdotally and experimentally observed in expert athletes. For example, Lee, Lishman and Thompson (1984), observed that long jumpers used information specifying time-to-contact to adjust their final footfall in their run-up, without being aware of this adjustment strategy. Even at the earlier stages of learning, support for this non-awareness type strategy has been shown to be beneficial for learning. For example, Singer, Lidor and Cauraugh (1993) found that acquiring a self-paced motor task using a non-awareness strategy during execution, was a preferable strategy to consciously attending to the act itself. However, a subsequent study by Bouchard and Singer (1998) looking at the acquisition of a more real-world task (i.e., a tennis serve), failed to show advantages for this strategy over a control condition. The authors suggested that this was because a number of participants in the control condition automatically adopted similar strategies to that encouraged by the experimenters. Leaving participants to their own devices when acquiring new motor skills may be just as beneficial to learning (and maybe more so) than providing some sort of explicit instruction, beyond making it clear to the participant the task requirements.

1.4 General Summary of Instructional Theory and the Empirical Studies

In the preceding two sections a review of motor learning theory was provided, in addition to a detailed examination of empirical investigations where pre-practice information was used. Two contrasting approaches to both the study and explanation of motor learning were discussed with reference to their implications for instruction provision. Although the two approaches differ with respect to how motor skill learning is described and examined, both theoretical approaches have important contributions to make to the study and understanding of the early stages of skill acquisition.
Representational accounts were detailed and discussions were centred on how pre-practice information may work to develop movement templates. The important concepts related to error detection and correction and how pre-practice information could help refine these comparative processes. The role of instructions in the selection of a motor response was discussed, although notable omissions with respect to theory were observed. For example, if a motor response is not an already existing part of a person’s movement repertoire and therefore no existing representation of the skill exists, how can pre-practice information play a role in encouraging selection? Similar questions arose from Bandura’s (1969) modeling theory: If the individual lacks the capability to perform a motor response, at least in the first few attempts, how will movement demonstrations affect the learning process? Although discussions were made by Gentile (1972) and Fitts and Posner (1967) with respect to the acquisition of a new motor response or motor program, such as the importance of understanding or getting an idea of the movement, there has generally been very little theoretical speculation about this early stage. Indeed, work on implicit learning has shown that an understanding of the task is not needed for acquisition to take place (at least not a correct, explicit understanding). As such, it is difficult to envisage what information would most likely encourage acquisition of a novel motor response. Although there has been very little research directed to examining this early stage of acquisition, where attempts have been made to manipulate the learning process by changing the order of practice conditions for example, this initial stage has been relatively impervious to these manipulations.

Where these more cognitive, representational accounts are found wanting, dynamical systems theory and knowledge derived from the study of interlimb coordination (e.g., Kelso, 1984) provide both a format for studying the early stage of skill acquisition and enable theoretical predictions to be made, with respect to the process of learning. These predictions were based on the relative stability of existing behaviours and the general repertoire of responses that exist before practice. Armed with this knowledge it is possible to examine what response is selected in the early stage of acquisition, how the selection of this response is affected by instruction and how this response changes as a function of practice. Important concepts such as competition and variability enable predictions as to how behaviour change can be best encouraged. For example, discovery learning formats, at least for tasks with multifaceted goals (i.e., the ski-simulator task), have been shown to promote early variability in the movement response that may subsequently facilitate acquisition of the skill.
The studies reviewed in the discussion of the empirical literature lead to the conclusion that pre-practice information should not be administered liberally and without concern for the type of motor skill that requires learning. Instructions and demonstrations have frequently not provided the learner with any additional information beyond specifying to the participant the goal of the task, whether this requires matching a movement template or criterion, focusing on a particular movement variable, or remembering a movement sequence. Although there is the suggestion that instructions directing attention to the external effects of the action have benefits for learning over contexts that promote an inward focus of attention, the benefits for this type of instruction compared to non-instructed, control conditions is somewhat equivocal.

As a result of these issues and omissions in the learning literature an initial investigation was undertaken. The purpose of this study was to combine the knowledge and methods generated from both dynamical systems theory and representational based accounts of learning, to investigate how instructions affect the process of acquisition. A number of questions were of particular concern: How do instructions play a role in the selection of early and late motor responses and is the role a positive one? How do existing movements interfere with acquisition and is their interference dependent on instructional provision? Are instructions concerning movement form necessary to acquire a motor skill that has complex response requirements? Are the initial stages of skill acquisition cognitively demanding and, if so, do instructions serve to increase this cognitive or attentional load?

1.5 An Initial Investigation

The Role of Augmented Information Prior to Learning a Bimanual, Visual-Motor Coordination Task: Do Instructions of the Movement Pattern Facilitate Learning Relative to Discovery Learning?

To examine how instructions affect learning and to address some of the concerns raised in the above review, an initial study was undertaken to investigate the role of instructions in the learning of a novel bimanual coordination skill. Vereijken and Whiting (1989) remarked on the fact that although differences in performance have been observed across a variety of learning conditions (e.g., discovery learning versus movement-related instruction conditions), it is not clear whether the groups approached the task in similar ways. Using the knowledge and methods provided by interlimb coordination studies it was possible to examine this process in relation to existing behavioural biases.
As detailed earlier, Kelso (1984) identified two stable, preferred patterns of bimanual coordination; 0° relative phase (in-phase) and 180° relative phase (anti-phase). When the speed of performance of these coordination patterns is increased, there is a critical point whereby the anti-phase pattern destabilizes, and a transition to the more stable in-phase pattern is observed. This transitional behaviour is preceded by an increase in the variability of timing between the limbs (i.e., the standard deviation in relative phase) which provides an important measure of pattern stability and pending destabilization of the current coordination pattern. These bi-stable tendencies were proposed to be similar for all individuals and are referred to as the intrinsic dynamics.

Knowledge of these existing coordination preferences provides a background to examine and compare the learning of novel patterns. One pattern that has received considerable attention is the learning of 90° relative phase. This pattern lies half way between the two stable intrinsic states, creating a competitive learning environment between the intrinsic dynamics and the to-be-learned pattern. This is a situation commonly observed in the learning of motor skills, whereby existing habits or behaviours interfere with the learning of new ones. The acquisition of this novel pattern was examined in this initial study, where one limb was required to be offset from the other limb by about a quarter of a full cycle. Movements were made on a bimanual linear slide apparatus, which is shown in Figure 1.3.

Participants were required to grasp two wooden handles, which were attached to the slides. The slides moved horizontally across ball bearings that were enclosed within metal casings. Movements could be made to the right or left of the participant’s mid-line and visual markers on the apparatus dictated the amplitude. Linear potentiometers attached parallel to the linear slide encoded displacement (sampling rate was 200 Hz). Terminal augmented feedback was provided to participants via a computer monitor situated to the left of the participant that displayed a Lissajous figure of the relative displacements. Specifically, the real time displacement of one limb was plotted on the ordinate against the displacement of the other limb on the abscissa. When performing in 90° relative phase the feedback appeared as a circle. This information was then used to specify the task goal and was provided to participants as augmented feedback (see Figure 1.2).

The goal for participants was to produce circular shapes on the computer monitor while moving in time with an auditory metronome. In this way it was possible to manipulate instructions concerning movement form, that is how to produce the required movement, as all participants were aware of the task goal and received feedback relating to this goal. Due to the
Figure 1.3 A diagram of the experimental set-up used in the initial investigation. A bimanual linear slide device was used to perform the movements and potentiometers under the slides recorded displacement. The apparatus was connected to a computer that collected the data and provided feedback to participants.
fact that participants were not made aware of the complex relationship between their movements and the feedback a somewhat implicit learning environment presented itself to participants. No feedback was provided during task execution, only after each trial in the form of a Lissajous figure. Specifically, summary feedback from the last trial overlaying the criterion circle pattern was displayed.

In light of the foregoing discussion it was predicted that initial instruction concerning how to move the limbs to make the circle pattern would not facilitate learning and could even be detrimental. Due to the competition between the required pattern and the intrinsic dynamics, discovery methods of learning were predicted to facilitate greater exploration of the task dynamics and encourage the break from competing stable patterns. This exploration was expected to be evidenced initially by increased variability in relative phase that would decrease substantially on acquisition of the new pattern.

Two instruction groups were examined: One group received a step-by-step specific guide as to the positioning of the hands every quarter of a cycle; a second group received general 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 follow behind the other by a quarter of a cycle. The general-instruction group was included to rule out the possibility that the instructions did not facilitate learning because they were too detailed and confusing, as could possibly be the case for the specific instructions. Step-by-step sequential instructions similar to those provided to the specific-instruction group are frequently given to performers in coaching and teaching environments. It was therefore of interest to examine whether this type of instruction would affect the acquisition process and facilitate learning.

Two other groups did not receive instruction concerning how to make the new pattern; one group was called the no-instruction group and the other group was a secondary-task learning group which was also required to perform a cognitively demanding task, of counting backwards in threes, out loud, during practice. This secondary-task situation is similar to implicit learning manipulations that have been examined in previous motor learning studies, for example, Hardy et al. (1996) and Masters (1992). These authors showed that participants were able to acquire a golf-putting skill under these conditions and in contrast to explicit learning groups showed a resistance to stress-inducing transfer conditions. Since a secondary task condition was provided in transfer, having a group which practised the task this way during acquisition provided a control condition to compare performance. This manipulation made it possible to examine
whether learning could take place under conditions of divided attention, especially since the learner would be required to resist the attraction of pre-existing, stable coordination patterns.

The purpose of the transfer test was two-fold. First, it was hypothesized that adding a cognitive load may serve to stress the current stability of the system and the observed dynamics and therefore provide a window into the quality, or stability of the newly acquired pattern (see Kelso, 1994). Less stable patterns would be more susceptible to the influence of in- and anti-phase and therefore transitions may be observed. Schöner et al. (1992) predicted that the more stable in-phase pattern would have more of an attracting influence than anti-phase on production of a newly practiced pattern. Second, attention demanding tasks have typically been used to infer the type of resources that are allocated to the primary task, with the supposition being that, if the resources of the primary (i.e., performing 90° relative phase) and secondary task (i.e., counting) are dissimilar, then the amount of interference between them will be minimal (e.g., Wickens, 1980). In contrast, if the resources are shared then there will be an increased cost leading to a reduction in performance on the primary task. In this case, a cognitive-verbal task would be expected to interfere more with individuals who perform the task in a more explicit, instructional manner as compared to individuals who have acquired the task in the absence of instructions, or in an implicit manner. Green and Flowers (1991) suggested that increased cognitive demands as a result of explicit instructions were responsible for the poor performance of instructed participants in their visual-motor coordination study.

An additional transfer test of performing a new pattern represented as a rightward slanting elliptical shape (45° relative phase) was also given to explore the generalization of learning as a result of these different instructional manipulations. The question of whether explicit learning conditions and subsequently the knowledge obtained under these conditions promotes more effective transfer than implicit learning conditions is unresolved (see Seeger, 1994). However there is generally more agreement in the literature that learning in an explicit fashion, with instructions, is more beneficial for transfer performance on similar, yet new conditions, as compared to implicit learning (e.g., Karmiloff-Smith, 1992; Senge & Sterman, 1992). To assess the acquisition of explicit knowledge at the end of testing, participants were required to answer questions pertaining to the correct movement of the limbs. These questions were in a similar format to the specific instructions.
1.5.1 Results and Discussion

In general, acquisition performance was independent of whether participants did or did not receive instruction detailing how the hands should be coordinated to make the circle pattern. The acquisition and retention/transfer data for the four groups is illustrated in Figure 1.4 for root mean squared error (RMSE). RMSE provided a composite measure of performance, as it was based on both error in relative phase and within-trial variability. This measure has been used successfully in past experiments to capture group differences in performance as a function of practice (e.g., Fontaine et al., 1997).

The type of instruction did appear to mediate performance, that is the general-instruction group had more difficulty acquiring the task than the specific-instruction group, although the difference between these groups was not significant. This trend for the specific-instruction group to perform better than the general-instruction group suggests that it is not the amount of information provided prior to practice (i.e., too much) that is disruptive to performance. However, the specific-instruction group also moved the slowest during the trials (i.e., produced the fewest cycles) which is shown in Figure 1.5. This may have helped the participants in this group implement the instructions. Indeed, Walter and Swinnen (1992) showed that slowing down the task by reducing the required frequency, facilitated the break from preferred patterns of coordination. In further experiments reported in this thesis the speed constraints were reduced early in acquisition.

The no-instruction and specific-instruction groups were the most accurate in acquisition and demonstrated similar performance in terms of error. Both groups also showed high within-trial variability in relative phase early in acquisition, which is shown on the left side of Figure 1.6. This finding suggests a greater exploration of the task space during practice, which arguably aids the discovery of new coordination patterns. However the process of acquisition was quite different for both groups. Mean relative phase values, which are displayed in Figure 1.7, showed that the instructed participants evidenced an initial preference towards the anti-phase pattern, whereas the non-instructed groups showed a preference towards the in-phase pattern. It was proposed that the instructions alerted participants to the fact that in-phase was definitely not the way to make the circle pattern, thus leading to the initial bias towards anti-phase. This knowledge, however, did not benefit the learning process (especially for the general-instruction group), and may have even been disruptive to learning, possibly by hindering exploration of the task dynamics and avoidance of in-phase type movements. Even though anti-phase is inherently less stable than in-phase, locating within the region of this pattern early in practice (that is,
Figure 1.4  RMSE of goal relative phase (°) for the four groups; specific instruction (SI), general instructions (GI), no-instructions (NI) and the secondary-task learning group (STL) across two days of acquisition, retention (R) and transfer, both secondary task conditions (ST) and a right elliptical shape (EL).
Figure 1.5  Number of cycles produced each 15 s trial for the four groups across the two days of acquisition, retention (R) and transfer, both secondary task conditions (ST) and a right elliptical shape (EL).
Figure 1.6  Within-trial SD of goal relative phase (°) for the four groups across the two days of acquisition, retention (R) and transfer, both secondary task conditions (ST) and a right elliptical shape (EL).
Figure 1.7  Mean relative phase (°) for the four groups across the two days of acquisition, retention (R) and transfer, both secondary task conditions (ST) and a right elliptical shape (EL).
performing anti-phase biased movements) did not provide any benefits to the acquisition process. Due perhaps to its reduced stability, the anti-phase pattern may actually interfere more with the acquisition of new coordination patterns. This point is discussed in more detail below.

The retention and transfer data yield the most interesting findings. The superior performance of the specific-instruction and no-instruction groups was maintained during retention (see right side of Figure 1.4); no difference in error between these two groups was found. However the specific-instruction group was significantly affected by the secondary-task transfer condition (ST), whereas the no-instruction group did not show any detriment in performance on transfer to this condition. Participants in the specific-instruction group showed a regression back in the direction of the previously stable anti-phase attractor. This finding was particularly interesting; it suggested that these two groups, although demonstrating similar performance with regards to outcome measures, were actually performing the primary task in quite different ways.

In terms of the multiple resource model of Wickens (1980), it would appear that whatever resources the no-instruction group was using to perform the primary task, these were not interfered with by the secondary task. In contrast, the specific-instruction group did show interference. Given that the secondary task was highly cognitive and verbal (i.e., counting backwards aloud) the suggestion was made that the specific-instruction group was also drawing on similar cognitive-verbal resources to produce the 90° relative phase pattern. Although it is possible only to speculate as to what this group was actually attending to during production of the circle pattern, one possibility is that they were repeating key aspects of the instructions to themselves. Therefore dividing attention with this secondary task may have been particularly disruptive to performance.

This decrement in performance under secondary-task transfer conditions for the specific-instruction group may have been related to the stability of the newly acquired pattern. Although not significantly different from the other groups, the specific-instruction group demonstrated the highest within-trial variability of relative phase, both in retention (R) and secondary-task (ST) transfer which is shown on the right side of Figure 1.6. This observed instability when performing the newly acquired pattern would make this pattern more susceptible to the competitive influences of the intrinsic dynamics. Subsequently, the addition of a cognitive load would be sufficient to effect a transition to a more stable pattern, which in this case was anti-phase (see Kelso, 1994 who suggests that a cognitive load may affect performance in a similar way to a physical perturbation).
As previously suggested, the anti-phase attractor may have continued to exert a stronger influence on the production of the 90° pattern that became noticeable only under these cognitive load conditions. Due to its inherent instability, as compared to in-phase, this pattern may compete more with the production of 90° (cf., Schöner et al., 1992). Participants may be better able to isolate the in-phase pattern, such that it does not interfere with performance. Indeed, Fontaine et al. (1997) also found that a 45° relative phase pattern was not more difficult to acquire than a 135° relative phase pattern, even though the more stable in-phase pattern was closer in parameter space to 45° and therefore more likely to hinder acquisition. The possibility remains that other information may be responsible for the transition to anti-phase from 90°, such as feedback or instructions. Recently Zanone and Kelso (1997) examined learning of this 90° pattern and found that, although there were differences between individuals as to attractor preference prior to practice, at the end of practice the participants showed greater attraction to the 90° and 180° pattern, as compared to 0°.

All of the groups had difficulty applying their knowledge to the new transfer pattern depicted as an elliptical shape, which could be produced by moving the arms 45° out-of-phase. Performance on this pattern is shown on the far right of each of the Figures (EL). Again the no-instruction and specific-instruction groups demonstrated the lowest error for this new pattern, and the no-instruction group scored the highest on the post-test questionnaire that assessed explicit knowledge of the relative positions of the two hands required to make the ellipse (see Figure 1.8). This questionnaire contained four diagrammatic questions which required participants to mark the correct position of one arm when the position of the other arm was shown. Perhaps not surprisingly however, the two instruction groups who received instruction concerning 90° relative phase scored highest on the questionnaire assessing explicit awareness of the position of the arms.

The findings reviewed above are in general agreement with previous studies that have examined the effects of instructions on motor skill learning (e.g., Vereijken & Whiting, 1989; Wulf & Weigelt, 1997). Providing learners with knowledge concerning how to correctly perform a specific motor skill did not facilitate learning, but were associated with performance decrements. When the learner was provided with additional information that alerted them as to goal attainment instructions concerning movement form failed to provide any additional, useable information. It was suggested that instructions might distract attention from other important information that needs to be attended to during movement execution. Indeed, the poor performance of the secondary-task learning group highlights the importance of allocating the
Figure 1.8  Questionnaire results assessing knowledge of the relative position of the two hands for both the circle pattern (90° RP) and the right ellipse (45° RP), for the four groups.
appropriate cognitive-verbal resources to the coordination task. These resources may be necessary to efficiently process kinesthetic feedback and resist the attraction of more stable coordination patterns. Although participants in the secondary-task learning group showed improvements in performance as a function of practice, suggesting that focused attention to the task itself was not necessary for skill acquisition, attention, or concentration was an important contributor to the learning process, at least in terms of acquisition rate.

1.5.2 Implications of this Initial Investigation for the Thesis Experiments

This initial investigation was conducted to address a number of questions and provided the impetus for the thesis experiments. Perhaps most importantly this study examined whether instructions concerning correct movement form were necessary to acquire a novel coordination movement. Given that the no-instruction group consistently showed the best performance throughout all phases of the experiment, it was concluded that this information was not necessary and indeed not important, as long as additional information relating to goal attainment was available. Even though the feedback was only provided at the end of each trial and was relatively non-prescriptive in nature (i.e., alerting to the fact that a change in performance was needed, but not how to effect this change), this information was sufficient. Arguably, more prescriptive feedback, alerting participants to the actual position of their limbs as a function of time may have allowed the instructed participants the opportunity to judge how the instructions had been implemented, which was not afforded to them with only the circle feedback. Therefore in Experiment 1, the compatibility of instructions and feedback was examined.

Even though the instructions were not helpful to acquisition they did, however, have an effect on acquisition. The general instruction group failed to show the same improvements as the specific instruction and the no-instruction groups on the second practice day and in retention and transfer. Although the specific instruction group did not perform less accurately than the control group in acquisition and retention, under attention-demanding transfer conditions this group showed considerable difficulty in maintaining the newly practised pattern and regressed back to anti-phase biased movements. Given the discrepancies in findings between these two instruction groups, further experiments are needed to examine how the type of instruction influences the learning process, both early in acquisition and later in retention and transfer.

In Experiment 1 manipulations were conducted that related to the detail contained in both the instructions and the feedback. In Experiment 2 instructions were provided that informed participants as to the relationship between the feedback and their movements. This type of
instruction was expected to encourage attention towards the external effects of the action, which, as suggested by Wulf et al (1998), was expected to be beneficial to acquisition. More specifically, in Experiment 2 instructions were manipulated to test the proposition that the negative effects of instructions and movement demonstrations were related to a focus of attention onto the movement and the limbs at the expense of attention towards goal attainment and goal-relevant feedback. Additional instructional manipulations were made in Experiments 3 and 4, where participants were instructed as to pre-existing coordination patterns and were shown how to adjust or refine these to produce the newly required movement pattern. In all the thesis experiments the information medium was changed. Due to the fact that a cognitive-verbal task interfered with retention performance for the specific instruction group, it was proposed that pre-practice information that placed fewer demands on cognitive resources might be more beneficial. In the following experiments visual demonstrations in addition to verbal instructions were provided.

From this preliminary study it was possible to determine how the instructions affected the initial selection of a movement response. Both instruction groups showed a bias to the anti-phase pattern early in acquisition, as compared to the non-instructed groups who showed a bias in the direction of the in-phase pattern. Therefore the discovery learning groups and instruction groups did not approach the task in the same way. The type of response that was evoked early in practice was dependent on the nature of the instructions. When regressions in performance were observed, these were in the direction of the anti-phase pattern. The consequences of residing close to the anti-phase pattern as opposed to the in-phase pattern, or switching between the two was discussed earlier in reference to movement variability and interference from less stable patterns. Given that the pathway to learning is influenced by the nature of the instructions, in Experiment 3 instructions were manipulated to alter the selection of an early motor response. Attention to either the in-phase or anti-phase movement pattern was encouraged. Additionally in Experiment 2 performance as a function of pre-practice bias to either the in- or anti-phase pattern was examined. In Experiments 2, 3 and 4 scanning tasks were used to assess pre-practice performance, to ensure task novelty and allow a more precise description of change in coordination dynamics as a function of practice. Based on ability during this task participants were either excluded from testing, or allocated to different groups in Experiments 3 and 4.

In this initial investigation there was plenty of evidence to support the proposition that the early stage of skill acquisition is cognitively demanding. The secondary task learning group showed particular difficulty learning this new coordination movement, even though they were
only required to count backwards during the actual trial itself and not between trials. Due to the observed stability in the presence of high error for participants within this group it was concluded that attentional resources are required to learn a new coordination pattern and resist the influence of more stable movement patterns. Perhaps the attentional demands placed on participants within this group during practice inhibited or prevented the participant from exploring the task dynamics and attempting new movements. Indeed the two groups who showed the best performance on this task were also the most variable at the start of acquisition. Although this high variability was somewhat maintained for the specific instruction group, the non-instructed participants showed low error and low within-trial variability in retention. This issue of early variability in performance was examined in the following experiments. Given that Zanone and Kelso (1992, 1994) described the learning process in terms of an abrupt change in the coordination dynamics from bi-stability to multi-stability, early variability in performance was presumed to be necessary to bring about this change. In Experiment 4, participants were examined who were not expected to show this abrupt change in their coordination dynamics, but rather more of a gradual replacement (see Zanone & Kelso, 1997). Participants who showed multi-stable dynamics before practice (e.g., attractors at 45° or 135°) were alerted to existing movement biases and shown how to refine these movements to produce the newly required movement pattern. Performance was compared to non-instructed participants and the bi-stable participants in Experiment 3.

In summary the purpose of the following studies was to examine in more detail how pre-practice information affects the early stage of skill acquisition when the motor skill is not an existing part of the learner’s movement repertoire. The experiments were conducted to both examine why instructions and demonstrations that alert the learner as to the correct way to perform a motor skill might have a detrimental effect on acquisition and also to find ways of facilitating acquisition and learning generally.
1.6 Statement of Ethics

All the experiments that follow were conducted in accordance with the ethical guidelines of the University of British Columbia.
II Experiment 1
Learning a Coordination Skill: Interactive Effects of Instruction and Feedback

2.1 Introduction

It is a widely held belief in the teaching of motor skills and in the motor learning literature that “learning is facilitated up to some level, by the provision of more information” (Newell et al., 1990, p538). This proposal is partly the result of traditional theories of skill acquisition, whereby learning results from the acquisition of more appropriate representations of the movement skill (e.g., Adams, 1971; Schmidt, 1988). This belief is also founded on theories that propose a transition in the learning process from an initial declarative or verbal stage, to a more procedural and non-verbal final learning stage (e.g., Anderson, 1982; Fitts & Posner, 1967). It is during the early stages that instructions are believed to be most helpful.

Despite this expectation, recent investigations of movement instructions provided prior to acquisition of a novel motor skill have failed to demonstrate beneficial effects and in fact detriments have been shown. These findings were demonstrated in the initial investigation reported in the introduction (i.e., Hodges & Lee, 1999) and previously by Wulf and Weigelt (1997). In these studies, augmented feedback was either withheld (i.e., Wulf & Weigelt, 1997), or only goal-related feedback was provided after execution (i.e., Hodges & Lee, 1999). It is in these degraded feedback conditions where instructions would be expected to be of most help (see Swinnen, 1996). An alternative hypothesis, however, is that these impoverished feedback environments may be responsible for the lack of instructional benefits and serve to prevent the instructions from being used effectively. In the absence of feedback relating performance errors to the instructions, participants may be unable to judge how these instructions were implemented.

Theoretically, this hypothesis accords with current views regarding the learning process as it relates to instruction. Swinnen (1996), for example, suggested that instructions and movement demonstrations provided pre-practice may help with the development of a reference-of-correctness, or movement template with which later performance can be compared. If this reference is not compatible with the feedback, or the feedback is impoverished in some way, any potential benefits of the instructions would be substantially diminished. Indeed, without the appropriate feedback, the instructions could disrupt regular problem solving activities required to acquire the motor skill, including processing of sensory feedback. The purpose of the following study was to examine the possible interactive effects of instructions and feedback in the learning
of a novel bimanual movement pattern. More specifically, to determine whether instruction that specifies how to move the limbs facilitates learning when feedback is also available that is compatible with the instruction.

In the initial investigation reported in the general introduction, participants were required to learn a difficult bimanual coordination pattern, which was represented as a circular shape on a computer monitor. This movement pattern could be produced by correctly moving the arms in a 90° relative phase pattern of coordination. The circle pattern (see Figure 1.2) was actually an orthogonal, displacement-displacement graph of the left arm’s movements versus the right arm’s movements. Participants were not, however, explicitly aware of this relationship. It was found that movement instructions, which specified how to move the arms to make the circle pattern, failed to benefit either acquisition or retention. This was despite the finding that the instructions alerted participants to the fact that moving the arms symmetrically in-phase was not the way to produce the pattern, as evidenced by an initial anti-phase bias for instructed participants. Post-task feedback relating only to goal attainment, that is production of the circle pattern, was sufficient information to encourage learning. Not only were the instructions redundant, but they actually caused performance decrements, both in acquisition for one group and in retention and transfer for two of the groups. These detrimental effects were proposed to be a result of misdirected attention during task execution.

In this earlier experiment participants in the instruction group were directed to implementing the instructions and focusing on the visual consequences of the arm movements. Given this focus, they may have failed to attend adequately to kinesthetic feedback and the problem solving activities required to understand how the movements of the limbs related to the feedback display and goal attainment. The instructions may not only misdirect attention, but also confuse the participant with respect to the nature of the task, what has been termed goal confusion (Gentile, 1972). When the instructions and the task goal are not explicitly compatible, the goal of the task becomes one of both copying the movement instructions and producing the circle pattern. This demand on cognitive resources was confirmed in transfer tests where participants who received instructions were most affected by the addition of a cognitively demanding secondary task.

In the following study, the interaction of task instructions with feedback was examined, by providing additional feedback that related explicitly to the individual displacements of both limbs. It was predicted that this information would aid the learner in determining whether the instructions had been effectively implemented and if not, how to change their movements in
order to make corrections. Fowler and Turvey (1978) originally stressed the importance of matching the feedback to the instructions or task constraints during movement skill acquisition. More recently, Newell et al. (1990, p537) concluded from examining the production of regular and irregular drawing patterns under various feedback manipulations that “...the task criterion specifies the appropriate information feedback for skill learning, in that the information feedback must match the constraints imposed upon response output”.

To examine this hypothesis, a similar task methodology to the initial investigation was adopted. Feedback was manipulated such that half of the participants received only feedback relating to goal attainment and limb positioning in an implicit fashion (i.e., circle feedback), whereas the other half received limb feedback detailing the actual position of both limbs during the trial. No study has directly compared this holistic, circle feedback to individual, limb displacement feedback. In the latter case the feedback was more detailed with two degrees of freedom relating to the movements of both the left and right arm individually. Therefore the exact position of both limbs as a function of time was explicit. This feedback was rather like watching oneself in a mirror, except that a history plot of the trial emerged as the trial progressed. Participants in this condition were also provided with post-task feedback informing as to the correct position of each limb. In this manner, the limb-feedback contained information as to both the presence of errors and how to correct them. In contrast, the circle feedback specified only the low-dimensional relative phase (i.e. one-degree of freedom of information depicted as a moving cursor) and only informed when errors were made, not how to correct these errors (i.e., departure from a circular shape). Although the feedback contained information about the displacements of the limbs, this information was implicit in the stimulus display. As suggested by Hayes and Broadbent (1988), when the relationship between the stimulus and response is relatively complex, or implicit, participants might not benefit from explicit instructions. However, when this relationship is less complex, explicit instructions might be beneficial for learning.

It was predicted that the circle feedback would constrain the actions of the limbs more effectively than the limb feedback such that achievement of the newly required relative phase pattern would be facilitated. Even though this feedback was not as explicitly informative as the limb feedback, it provided important information about the relative motion of the limbs in a simple way which would be expected to benefit acquisition (see Scully & Newell, 1985). Interestingly, Swinnen, et al. (1993), failed to observe differences in learning a discrete, bimanual skill when feedback was provided that related only to the global outcome, versus
detailed limb kinematics. They concluded that as long as feedback was available that alerted to the degree of coupling between the limbs and subsequently the degree of attraction of existing movement patterns, acquisition would be facilitated. Given that participants were aware that an error had been made in both cases, the learner would be encouraged to search for the problem and eventually its solution. This may increase sensitivity to response-produced feedback and enhance the detection of errors. In light of these findings and the fact that the circle feedback has been sufficient in encouraging movement skill acquisition, this information was expected to facilitate learning more than the limb feedback, at least when instructions were withheld.

To test these predictions, four different groups were compared over two days of practice and in immediate and delayed retention. Two groups received concurrent feedback relating only to the task goal, that is the circle pattern. Two other groups were provided with concurrent feedback relating to the individual displacements of each limb and post-task feedback that specified the correct displacements of each limb. All participants received post-task summary feedback relating to attainment of the task goal (i.e., the circle pattern). These feedback conditions were crossed with instruction condition. One of each of the feedback groups also received limb-related instruction specifying how to correctly move the limbs 90° out-of-phase, accompanied with visual demonstrations. Under the limb feedback conditions, instructions were expected to facilitate both acquisition and retention, due to the more explicit and compatible nature of the two sources of information. Under circle feedback conditions, no benefits for instruction were expected, but rather, based on findings from the initial investigation, instruction was expected to produce decrements in performance. Measures of variability were expected to be particularly sensitive to these manipulations. In the initial investigation high variability early in acquisition was found to be indicative of low error later in practice and in retention. Arguably, this variability facilitates the break from more stable coordination patterns, thus facilitating the production and discovery of new movement patterns (Lee et al., 1995; Zanone & Kelso, 1992).

Two transfer tests were also administered to examine in more detail the stability of the newly acquired pattern and therefore the quality of learning. The first transfer test required performance of the practiced pattern under secondary-task conditions to assess attention demands as a function of the feedback and instruction condition. Given that performance regressions were observed for the specific-instruction group in the initial investigation under these conditions it was suggested that the instructions might serve to keep performance at a cognitively demanding level of attention. Due to the detail in the limb feedback, this information
might also be more cognitively demanding than the circle feedback. As such, the instruction, limb-feedback group would be most affected by the attention-demanding transfer task.

The instruction group in the initial investigation, however, also showed high within-trial variability in relative phase. Therefore, any transitions to more stable patterns, could have been a result of this initial instability, rather than the nature of the transfer task per se. Subsequently, a second transfer task was administered in the following study where participants were required to produce the circle pattern at an increased speed of 1.5 Hz. This manipulation has been shown to probe movement stability and produce transitions in performance to more stable behaviours (e.g., in-phase or anti-phase) and/or increase variability in relative phase (e.g., Kelso, 1984). More recently, Kelso (1994) proposed that physical and cognitive loads might produce similar effects in terms of lowering the threshold for phase transitions to more stable patterns.

2.2 Method

2.2.1 Participants

Thirty-two participants were randomly allocated to one of four groups (8 per group) with the additional constraint that an equal number of men and women were within each group. There were two circle-feedback groups, who practiced the task either in the presence or absence of movement-related instructions. Two limb-feedback groups were also divided based on whether movement-related instructions were provided or withheld. All participants were self-professed right handers, whose ages ranged from 20-32 years.

2.2.2 Apparatus and Task

The task was to produce circle patterns on a computer screen by manipulating two angular manipulanda. The movements required to produce this pattern were continuous flexion and extension movements about the elbow joint in the horizontal plane. An illustration of the criterion circle pattern was displayed earlier in Figure 1.2. Participants were seated at a colour monitor (Daytek, DT-1731) turned on its side such that the length of the screen was 33 cm. A schematic diagram of the experimental set-up is illustrated in Figure 2.1. On either side of the monitor were two identical manipulanda that restricted arm movements to the elbow joint. Participants’ arms were positioned on these, such that the elbow joint was aligned with the axis of rotation and the hands were placed palm down on adjustable metal plates. The middle finger was secured between two vertical pins and Velcro straps secured the forearms and hands.
Figure 2.1 A diagram of the general experimental set-up used across the thesis experiments. Angular manipulanda were used to produce the movements and optical encoders recorded displacement. Feedback was provided on the monitor directly in front of participants. Movement demonstrations were relayed via a VCR and TV set-up to the left of the participant.
Movement amplitude was alerted by the computer feedback and markers on the table, specifying “in”, “mid” and “out” positions for each arm. The required movement amplitude was 40° from the “in” to the “out” markers. Elbow angles were 105° when the participants positioned the manipulandum at the “mid” position. Flexing the arms inwards, towards the body resulted in elbow angles of 85°. Extension movements towards the “out” marker resulted in elbow angles of 125°. A 40° movement translated to a 15 cm movement on the computer screen. Angular positions were recorded using two optical encoders (Dynapar E20-2500-130) attached to the shaft of each manipulandum. Custom made computer interface cards enabled high speed sampling of angular positions (sampling rate was 1000 Hz). All instructions and demonstrations concerning how to produce the circle pattern were shown to the participants on a pre-recorded video played on a video cassette recorder (Panasonic, NV-8500) via a colour video monitor (Panasonic, CT 110 MCA).

2.2.3 Procedure

2.2.3.1 Acquisition

Participants familiarized themselves with the task apparatus and were alerted to the task goal. No feedback of any kind was provided during familiarization. On the computer screen in front of the participants the criterion circle pattern was illustrated and feedback obtained previously from a well-practiced person who had performed a 10 s trial overlaid the criterion. Participants were told that this pattern could be achieved by continuously moving the arms in a to-be-determined relationship between the two amplitude markers. Participants were required to produce 10 full cycles with the arms during each 10 s trial. The criterion for one cycle was explained and then demonstrated to the participants. A full cycle consisted of moving the full distance between the “in” and “out” markers to arrive back in the original position with each of the arms. An auditory metronome signaled the start and end of each cycle, such that it would beep once every second (1 Hz). Participants were told that these “speed constraints” did not need to be rigorously adhered to early in practice, but that they would be continuously reminded to move in time with the metronome. The speed constraints were included to make the task challenging, in addition to ensuring that all participants received the same amount of practice (i.e., roughly 10 attempts per trial). Group assignment determined the provision of the instructions and procedures.

Individuals in the two circle-feedback groups (instruction and no-instruction) received continuous feedback on the computer screen relating to production of the circle pattern.
throughout each trial. This was a continuous trace of their movement pattern in the form of a Lissajous figure. Participants were never made explicitly aware of the relationship between their movements and the feedback and were always encouraged to keep both arms moving. The feedback remained on the screen throughout the trial such that a history plot emerged as the trial progressed. After the first practice trial and every fourth trial following, participants in the circle-feedback groups received a 10 s playback of their previous trial, overlaying the criterion circle template.

Participants in the two limb-feedback groups (i.e., instruction and no-instruction) received continuous feedback of the instantaneous positions of both the right and left arm as a function of time. As with the circle feedback this remained on the screen throughout the trial, producing a history plot as the trial progressed. Before practice, participants were shown a summary trace of the limb feedback from a well-practiced individual who had moved their arms correctly 90° out-of-phase. An illustration of this feedback is provided in Figure 2.2. In this figure the continuous displacements of the right arm (dashed line) and left arm (solid line) have been plotted as a function of time (only 3 s for illustrative purposes). In the actual feedback provided to the participants the displacements of the right arm were displayed in yellow and the displacements of the left arm in red. Movements of the manipulanda to either the left or right produced corresponding mirror movements of the displacement trace on the screen. In this way, moving the arms in anti-phase coordination produced overlapping displacement traces on the screen. It was explained to participants that overlapping traces signified that the arms were moving in the same direction at the same time. Moving the arms in-phase produced displacement traces that mirrored each other in the vertical plane.

Participants were told that the top of the feedback screen signified the start of the movement (i.e., time zero) and that during the trial the displacement traces would scroll down. At the end of the first practice trial and every fourth trial following, participants received a playback of their previous trial (i.e., right and left arm displacements), along with a criterion left arm trace in black. This trace alerted participants to the “correct” position of the left arm relative to the right throughout the 10 s trial. Participants were also reminded of the circle pattern task goal. They were informed that after receiving the limb feedback criterion trace every fourth trial; they would also view a summary of their previous trial, relating to the task goal. This was provided to ensure that all participants had the same outcome goal, even though the concurrent feedback and instructions were different across the groups.
Figure 2.2  A schematic diagram of the limb feedback that would result from correctly moving the arms in 90° relative phase (first 3 seconds only).
One of each of the feedback groups also received verbal instructions and a visual demonstration of a well-practiced model performing the required movement on a pre-recorded video. The demonstration was filmed, such that the camera was positioned above and behind the model. Initially the model demonstrated how to produce one circle. While moving the arms simultaneously, the model talked through the positions at each quarter of a cycle, thus also providing the participant with verbal instruction. Following this demonstration, the model performed a 10 s trial in time with the metronome. Participants were made aware that this was the correct way to perform the task. On-line feedback from the model was not provided on the video, only post-task summary feedback relating to production of the circle pattern. The video was again shown to the instruction groups halfway through acquisition on the first day and at the start and halfway through practice on the second day. No further instructions were administered to the non-instructed participants in each of the feedback groups; during instruction these participants received a two minute rest. All participants were reminded to keep both arms moving throughout each trial and one practice trial was provided along with concurrent and post-task feedback. The feedback was again fully explained to the participants after practice and questions addressed. Two days of acquisition followed, consisting of 40 trials per day, lasting 10 s each (10 blocks of 4 trials per day).

2.2.3.2 Retention and Transfer

At the end of the second day, all participants were given a short rest and then transferred to a four trial, no-feedback (both on-line or summary) immediate retention test. These four trials were repeated one day later. After approximately four months, participants underwent additional retention testing. The first four trials were retention tests in which all feedback was withheld and the following trials were administered with the concurrent feedback available to each group during acquisition. Four retention trials were interspersed with eight transfer trials; half of the transfer trials required participants to subtract in threes out loud, while performing circle patterns (practice at subtraction was given before the first trial). Participants were asked to try and verbalize each number in time with the metronome beat. The remaining trials were performed under increased speed conditions where the metronome beeped at a speed of 1.5 Hz. Participants were required to try and produce circle patterns while moving in time with the metronome.
2.2.4 Dependent Measures and Analyses

Discrete measures of relative phase were calculated at points of peak flexion and extension, that is the relative position of the left arm scaled with respect to the right\textsuperscript{1}. Comparing the data to the Lissajous figure of the circle pattern validated all values. Relative phase (RP) was calculated for each cycle after the speed and position of the limbs had been normalized. The phase angles were calculated using the methods described in Scholz and Kelso (1989)\textsuperscript{2} and were converted to positive values between 0° and 180°. The negative sign was ignored and values greater than 180° were subtracted from 360° to yield values within the required range. Within-trial RP means were used for all analyses to determine the direction of participant's bias (either towards in-phase or anti-phase). Within-trial standard deviation (SD of RP) was also calculated by taking the average of the standard deviations about the mean RP values for flexion and extension peaks. Variability within a trial is an important variable at the start of practice, indexing the exploration of new coordination patterns and the break from old ones, as well as at the end of practice, alerting to the stability and quality of the newly acquired pattern. To determine whether individuals were able to adhere to the speed constraints, at least later in practice and in retention and transfer, the number of cycles produced per trial were calculated for each individual.

Finally, root mean squared error (RMSE) was used as a general measure of error. This value was made up of both within-trial accuracy (i.e., constant error, which was calculated by subtracting 90° from the produced RP) and SD of RP. Specifically, RMSE was obtained from the square root of the sum of constant error squared and within-trial SD of RP squared. This measure provided a representative descriptor of within-trial performance due to the problems inherent in averaging relative phase over a 10 s trial. For example, if a participant switched within a trial between 0° and 180° RP, this would result in a mean value of 90° and performance would be judged correct. Variability would be extremely high, however, such that RMSE values would take account of this variance and modify the individual error score accordingly. Although high RMSE values may be due to either, or both, variability and accuracy, low RMSE is indicative of

\textsuperscript{1} Continuous relative phase data were also calculated. However this data mirrored the findings obtained from discrete measures and as such did not elucidate further on the acquisition process.

\textsuperscript{2} \( \phi = \tan^{-1} \left( \frac{(dX_R/dt)}{X_R} \right) - \tan^{-1} \left( \frac{(dX_L/dt)}{X_L} \right) \), where \( \phi \) = relative phase between the limbs, \( X \) is the position of the limb within a cycle re-scaled to the interval [-1, 1], (dX/dt) refers to normalized instantaneous velocity, and R and L are the right and left limbs (adapted from Scholz & Kelso, 1989, p129).
good performance on this task. This measure has been used successfully to capture group differences in performance (e.g., Fontaine et al., 1997).

The four dependent measures in acquisition were subjected to a 2 (Instruction) × 2 (Feedback) × 2 (Day) × 10 (Block) mixed ANOVA with repeated measures on the last two factors. In retention, the last block of acquisition was compared to retention in a 2 (Instruction) × 2 (Feedback) × 2 or 3 (Test condition) mixed ANOVA, with repeated measures on the last factor. Test condition referred to the time of testing. Specifically, the last block of acquisition was compared to immediate and delayed retention without feedback in one analysis and to delayed retention with feedback in a second analysis. Finally, delayed retention with feedback was compared to the two transfer tasks in a three factor ANOVA similar to the retention data. The Tukey HSD method was used for all post-hoc comparisons. Statistical significance was set at $p < .05$. Preplanned orthogonal contrasts were used to determine linear trends for the repeated measures factors in acquisition.

2.3 Results

2.3.1 Root Mean Squared Error

2.3.1.1 Acquisition

The results for RMSE are shown on the left side of Figure 2.3. A significant main effect for feedback-group was observed, $F(1,28) = 67.96$, $p < .001$, as well as a main effect for block, $F(9,252) = 15.46$, $p < .001$ and day, $F(1,28) = 68.07$, $p < .001$. The circle-feedback groups had lower error throughout acquisition (M = 28.14°) as compared to the limb-feedback groups (M = 63.53°) and all groups decreased their error across blocks and days in a linear fashion.

Although the predicted Instruction-group × Feedback-group interaction was not significant ($p = .24$), there were a number of higher-order interactions indicating that acquisition rate was affected by the group manipulations. Instruction-group interacted with Block, $F(9,252) = 2.45$, $p < .01$ and Feedback-group interacted with Block, $F(9,252) = 3.33$, $p < .001$ and Day and Block, $F(9,252) = 2.81$, $p < .01$. There was also a four-way interaction, $F(9,252) = 3.24$, $p < .001$. The Instruction-group × Block interaction was due to the greater decline in error at the start of practice for the no-instruction as compared to the instruction groups. For the no-instruction groups, block 1 was significantly different from all other blocks, except block 2. For the instructed participants, block 1 was only different from blocks 9 and 10. The circle-feedback groups showed a steady decline in error across blocks, whereas the limb-feedback groups did not. This was evidenced by a significant linear trend component to the Feedback-group × Block interaction.
Figure 2.3  RMSE of goal relative phase (°) for each of the four possible Instruction x Feedback-group combinations. Performance was assessed across the two days of acquisition, in immediate (R1) and delayed retention testing without (R2) and with feedback (R3), and under secondary task (ST) and increased speed (SP) transfer conditions.
interaction, $F(1,28) = 7.04, p < .001$. The three-way interaction was primarily due to the significant decrease in error on day 1 for the circle-feedback groups. However the four-way interaction showed that this decrease in error as a function of block on day 1, was most pronounced for the no-instruction, as compared to the instruction, circle-feedback group. Specifically, the no-instruction group showed significantly less error than the instruction group from blocks 3 to 7 on the first day of practice.

### 2.3.1.2 Retention

Immediate and next day retention tests were originally conducted in the absence of feedback. However, on inspection of the data it was apparent that withdrawing the concurrent feedback had marked effects on the circle-feedback groups, such that the nature of the task, that is to produce a circle pattern, had changed dramatically. The concurrent feedback had become an intrinsic part of the task. Therefore participants were brought back to the laboratory for testing four months later to reassess performance both with and without the feedback available during acquisition. These data are compared to immediate retention without feedback and the last block of acquisition. Not all participants were able to return for testing, which reduced the power of the analyses. However it was possible to re-test seven participants in each group (6 in the no-instruction, limb-feedback group). The group means displayed in the graphs for delayed retention (R2 & R3) and transfer (ST & SP), therefore, have reduced values of ‘n’, as compared to the acquisition means.

Immediate and delayed retention were first examined in the absence of feedback and compared to the last block of acquisition with feedback, which is illustrated in the right half of Figure 2.3. R1 and R2 refer to immediate and delayed retention without feedback. Main effects for feedback, $F(1,23) = 30.73, p < .001$ and test condition, $F(2,46) = 9.03, p < .001$ were observed. There was also a Feedback-group x Test condition interaction, $F(2,46) = 7.82, p < .01$. As before, the circle-feedback groups demonstrated less overall error ($M = 29.43°$) than the limb-feedback groups ($M = 53.96°$). In addition, there was an increase in error for all groups over the three test conditions. Delayed retention ($M = 49.30°$) was significantly different from both immediate retention ($M = 40.29°$) and acquisition ($M = 35.48°$), which did not differ from each other. On inspection of the two-way interaction, it was observed that the increase in error was significant only for the circle feedback participants. The circle-feedback groups showed significantly less error than the limb-feedback groups for all test conditions, except delayed retention. In delayed
retention without feedback the persistent difference between the feedback groups was no longer significant.

In contrast, when delayed retention was measured with the concurrent feedback available during acquisition (R3) and compared to the last block of acquisition, there was no significant increase in RMSE as a function of the delay between testing period. The main effect for feedback-group was still significant, $F(1,23) = 84.05, p < .001$ and the interaction between Instruction and Feedback-group showed the expected trend, $F(1,23) = 3.02, p = .09$. In accord with the original predictions, under circle feedback conditions, the no-instruction group showed less error than the instructed participants did, whereas under limb feedback conditions, the instruction group had less error than the no-instruction group.

2.3.1.3 Transfer

As with retention testing there was a main effect of feedback-group, $F(1,23) = 67.54, p < .001$ and the Feedback-group x Instruction-group interaction approached conventional levels of significance, $F(1,23) = 3.87, p = .061$. The transfer data is illustrated on the far right of Figure 2.3. The secondary task transfer test is denoted ST and the increased speed condition is denoted SP. The limb feedback participants demonstrated more error than the circle feedback participants, although it was the no-instruction group who showed the most error under limb feedback conditions, but the instruction group under circle feedback conditions. There were no interactions with test condition, only a main effect, $F(2,46) = 7.87, p < .01$. All participants showed a significant increase in error when transferred to the secondary task ($M = 46.54^\circ$) and increased speed ($M = 44.10^\circ$) conditions as compared to delayed retention ($M = 40.01^\circ$).

2.3.2 Relative Phase (RP)

2.3.2.1 Acquisition

In order to examine more specifically the type of patterns the participants produced, analysis was conducted on mean RP. The means for the four groups are displayed on the left side of Figure 2.4. Only main effects for feedback-group, $F(1,28) = 73.51, p < .001$ and day, $F(1,28) = 10.19, p < .01$ were observed. However, a similar trend to the RMSE analysis with respect to interaction effects was observed. A breakdown of the main effects showed that on day 1, the overall mean relative phase value was $127.95^\circ$. By day 2 this value was closer to the criterion of $90^\circ$ at $119.10^\circ$. The circle-feedback groups had a mean value of $102.15^\circ$ RP, as compared to the limb-feedback groups whose mean value was $144.90^\circ$. The latter groups showed
Figure 2.4  Mean relative phase (°) for each of the four possible Instruction x Feedback-group combinations. Performance was assessed across the two days of acquisition, in immediate (R1) and delayed retention testing without (R2) and with feedback (R3), and under secondary task (ST) and increased speed (SP) transfer conditions.
a stronger tendency to produce movements closer to the anti-phase pattern and were not as successful as the circle-feedback groups at resisting the attraction of this pattern. Additional analysis of the first practice trial showed that 69% of the instructed participants showed a tendency to produce patterns close to anti-phase. This was indexed by a mean relative phase value between 160° and 180°. In comparison only 19% of the no-instruction groups showed this preference. For the no-instruction groups there was a tendency to switch between the in and anti-phase patterns during the first practice trial, as was noted for 38% of the participants within these groups.

### 2.3.2.2 Retention

Similar to the RMSE analysis a main effect for both feedback-group, $F(1,23) = 23.86, p < .001$ and test condition, $F(2,46) = 6.72, p < .01$ was observed, as well as an interaction between these, $F(2,46) = 4.42, p < .05$. The circle-feedback groups produced patterns closer to the required 90° pattern ($M = 107.57°$) than the limb-feedback groups ($M = 134.77°$) and there was an increase in RP across the testing intervals. Only the circle-feedback groups showed an increase in RP in the direction of the anti-phase pattern in retention tests without feedback as compared to their performance at the end of acquisition (mean RP = 95.04°, 102.33°, 125.34° for acquisition, immediate and delayed retention, respectively). When RP was examined in delayed retention with concurrent feedback, only a significant main effect for feedback-group was observed, $F(1,23) = 55.56, p < .001$ (circle feedback, $M = 98.65°$, limb feedback, $M = 137.73°$).

### 2.3.2.3 Transfer

Again, a main effect for feedback-group was observed, $F(1,23) = 54.70, p = .001$. The circle feedback participants mean RP was closer to the required ($M = 104.49°$) than the limb feedback participants ($M = 145.95°$). There was also a main effect for test condition, but no interactions, $F(2,46) = 7.97, p < .01$. Under secondary task conditions there was a significant increase in mean RP as compared to delayed retention. The speeded transfer task did not differ from either retention or secondary task conditions (see right side of Figure 2.4).

### 2.3.3 SD of RP

#### 2.3.3.1 Acquisition

Within-trial standard deviation in relative phase was also analyzed separately and is displayed on the left side of Figure 2.5. No main effects for feedback or instruction condition.
Figure 2.5  Within-trial SD of relative phase (°) for each of the four possible Instruction x Feedback group combinations. Performance was assessed across the two days of acquisition, in immediate (R1) and delayed retention testing without (R2) and with feedback (R3), and under secondary task (ST) and increased speed (SP) transfer conditions.
were found, although Feedback-group interacted with Day, $F(1,28) = 14.56$, $p < .001$ and Block, $F(9,252) = 3.88$, $p < .001$ and there was a three-way interaction of Instruction-group, Feedback-group and Block, $F(9,252) = 2.64$, $p < .01$. Post hoc tests conducted on the three-way interaction showed that participants in the no-instruction, circle-feedback group decreased their variability in relative phase across blocks. Block 1 was significantly more variable than block 9. In contrast, the no-instruction, limb feedback participants showed a general increase in variability across blocks, although this was not significant. Additionally, the instruction, circle-feedback group did not significantly decrease variability as a function of practice.

2.3.3.2 Retention

When performance was examined in the absence of concurrent feedback, there were no significant main effects, only a Feedback-group x Test condition interaction, $F(2,46) = 8.26$, $p < .001$, which is displayed on the right side of Figure 2.5 (R1 and R2). Only in acquisition when concurrent feedback was still available were the limb-feedback groups significantly more variable than the circle-feedback groups. Given this reduced variability for the circle-feedback groups in acquisition, they were the only groups to increase within-trial variability across the delayed retention interval. When delayed retention performance with concurrent feedback (R3) was compared to acquisition, there were no interactions. Only a main effect for feedback condition was observed, $F(1,23) = 12.31$, $p < .01$. As before the circle-feedback group evidenced less variability ($M = 13.85^\circ$) than the limb-feedback groups ($M = 20.99^\circ$).

2.3.3.3 Transfer

In transfer there was a main effect of test condition, $F(2,46) = 6.81$, $p < .01$ and a Feedback-group x Test condition interaction, $F(2,46) = 5.51$, $p < .01$. The circle feedback participants did not show a difference in variability across delayed retention and transfer. The limb feedback participants, however, showed a significant decrease in within-trial variability when required to produce the circle pattern under secondary task conditions, ($M = 14.66^\circ$) as compared to delayed retention ($M = 19.61^\circ$) and increased speed demands ($M = 21.01^\circ$). It is important to remember that this decrease in variability was accompanied by increased RP values in the direction of the anti-phase pattern. This finding suggests that participants were unable to destabilize the anti-phase pattern under these attention demanding conditions.
2.3.4 Number of Cycles

2.3.4.1 Acquisition

In order to meet the temporal constraints of the task participants were required to produce ten cycles per trial. This data is illustrated in Figure 2.6. Analysis of the number of cycles showed a significant main effect for feedback-group, $F(1,28) = 4.35, p < .05$. The circle-feedback groups produced more cycles per trial ($M = 9.25$) than the limb-feedback groups ($M = 8.64$). A three-way interaction between Instruction-group, Feedback-group and Day, $F(1,28) = 4.84, p < .05$ showed that the instructed, circle-feedback group produced more cycles on the first day only than the instructed, limb-feedback group. However, for the non-instructed participants the difference between the feedback groups remained across both practice days with the circle-feedback group producing more cycles per trial.

2.3.4.2 Retention

When acquisition was compared to retention without feedback there were no significant effects. When feedback was available there was a significant Instruction-group x Feedback-group interaction, $F(1,23) = 6.79, p = .016$. Under circle feedback conditions the no-instruction group produced more cycles within a trial, whereas the reverse was observed under limb feedback conditions.

2.3.4.3 Transfer

A similar pattern of results as the retention data was observed for transfer. There was an interaction between Feedback and Instruction-group, $F(1,23) = 6.48, p < .05$ due to an increased number of cycles for the non-instructed, circle participants as compared to the instructed, circle participants. The reverse was found for the limb-feedback groups. Due to the increased speed demands of the final transfer test, there was a main effect for test condition, $F(2,46) = 140.80, p < .001$. The mean number of cycles for the increased speed transfer test was 12.67, even though the required mean was 15. This was significantly different from delayed retention ($M = 10.13$) and secondary task conditions ($M = 10.15$) which did not differ from each other. There were no Test condition interactions.

2.4 Discussion

The purpose of this experiment was to determine the learning effects of augmented information provided both prior and during the acquisition of a novel bimanual coordination
Figure 2.6  Mean number of cycles during a 10 s trial for each of the four possible Instruction x Feedback-group combinations. Performance was assessed across the two days of acquisition, in immediate (R1) and delayed retention testing without (R2) and with feedback (R3), and under secondary task (ST) and increased speed (SP) transfer conditions.
skill. It examined the possible interaction effects of prior instruction with augmented feedback and how different types of feedback influence the acquisition process. It was predicted that instructions would not benefit acquisition when only feedback pertaining to the circle pattern was provided and may even be detrimental to learning. However, when limb feedback was provided it was predicted that the instructed participants would perform with less error than the non-instructed participants.

The most consistent finding in acquisition was a clear advantage for participants who received the circle feedback on-line, as compared to the limb feedback. Although the limb feedback detailed both the movements of the individual limbs as well as the correct positions of the limbs (i.e., the presence of errors and how to correct them), this feedback was not beneficial to learning, at least when performance was compared to the circle-feedback groups. Rather, providing simple information in the form of a moving cursor on the computer screen (i.e., the circle feedback), which indirectly alerted to the relationship between the limbs, was more beneficial. This feedback may have helped to constrain the two limbs to act as a coordinated unit and as proposed by Scully and Newell (1985), make the relative motion information salient to the learner. The limb feedback also required participants to simultaneously attend to two sources of concurrent feedback, both the displacements of the left and right limbs. In this situation, as compared to the circle feedback conditions, the attention demands were likely increased making the limb feedback difficult to process and use effectively. Even though participants were never explicitly made aware of the relationship between their movements and the circle feedback this information was not necessary to achieve the task goal. In fact, as discussed below, informing individuals how to move the limbs to make the circle pattern was detrimental to performance, at least in acquisition.

Although the instructional manipulations did not have a strong impact on acquisition, possibly due to the overriding influence of the concurrent feedback, the instructed participants in the circle-feedback group showed a disadvantage in acquisition rate as compared to the non-instructed, circle feedback participants. This was evidenced by a slower decrease in error across the first day of practice. As suggested in the introduction, when the feedback conditions are not compatible with the instructions and/or movement demonstrations, these instructions may actually interfere with problem-solving activities required to learn the task, especially the processing of the on-line visual feedback. The no-instruction, circle-feedback group also showed high within-trial variability in relative phase at the start of practice. This variability may encourage the discovery of new movement patterns and the break from pre-existing stable
behaviours (see Zanone & Kelso, 1992). Vereijken and Whiting (1989) have suggested that demonstrations and instructions may promote copying behaviour (see also Gentile, 1972; Higgins, 1991) leading to stable performance at an incorrect pattern.

Contrary to the predictions and the performance of the circle-feedback groups, instructions and movement demonstrations did not affect acquisition performance for the limb-feedback groups. No advantage or disadvantage was found from watching repeated demonstrations of the to-be-acquired movement pattern, at least in acquisition. This was despite the initial expectation that coupling limb feedback with movement instructions would benefit learning. Although there was little evidence to support this hypothesis it should not be altogether discarded. Given that the feedback was arguably too complicated to be used effectively, any potential benefits of instruction would be masked. Additionally, the artificial nature of the limb feedback (i.e., two displacement traces scrolling down a computer screen) may not have been sufficient to promote compatibility between the two sources of information. Filming participants during acquisition and providing this information as feedback would perhaps better encourage the link between instructions and feedback, due to the fact that an actual visual demonstration of the required movement was provided pre-practice. This type of feedback would presumably aid the comparison process between the produced movement and the desired movement or reference template, developed as a result of the pre-practice instructions (see Bandura, 1986; Swinnen, 1996).

The fact that the limb feedback was particularly detrimental to performance as compared to the circle feedback is in agreement with recent findings from Wulf and colleagues who explored attentional focus and learning. For example, Wulf, Höss and Prinz (1998) found that performance on a ski-simulator was aided by instructions that directed attention to the external effects of the action (i.e., the apparatus) as compared to the internal effects of the action and the movement of the feet. This limb related feedback, coupled with instructions that also directed attention to the limbs might disadvantage performance by diverting attention from goal-attainment and an external focus of attention. Also, Temprado, Zanone, Monno and Laurent (1999) found that attending to the limbs during anti-phase movements increased the stability of this pattern. Subsequently, a limb-related focus of attention may delay acquisition by hindering the break from anti-phase, which was encouraged by the movement-related instructions and demonstrations.

In retention and transfer, different interpretations of the data could be reached depending on the method of assessment. It is common practice in retention tests to equate all groups with
regards to the manipulation of the independent variable, such that in this study all groups would perform retention tests in the absence of concurrent feedback. This would remove any 'temporary' guiding effects of the feedback. On inspection of retention tests conducted without feedback there did appear to be 'temporary' effects associated with the feedback. The circle-feedback groups showed a significant increase in error and variability when this information was removed, as compared to the limb-feedback groups. In delayed retention, the difference between the feedback groups was no longer significant, despite the obvious advantages demonstrated for the circle-feedback groups during acquisition. It is suggested that this continuous feedback helps guide the participant's movements when it is available (see Swinnen, 1996; Swinnen, Dounskaia, Walter & Serrien, 1997), but may cause participants to become dependent on the information, such that when it is removed, decrements are observed. Due to the fact that the circle feedback was an intrinsic component of task performance, this dependency should not be unexpected.

In a number of coordination studies the coupling of movement with visual information has been emphasized. Schmidt et al. (1990) showed that the phase relations between people, coupled only by visual information (i.e., looking at each other), were governed by the same principles underlying inter-limb coordination. Perhaps not so surprisingly, stability in performing a newly acquired relative phasing may also be dependent on the visual information. However, Swinnen, Lee, Verschueren, Serrien and Bogaerds (1997), in a similar task to the present study, found concurrent circle feedback to facilitate both acquisition and retention assessed in the absence of any feedback. The conclusions, however, were based on comparisons with groups who had learnt without any feedback or without vision of the limbs. Additionally, all participants were provided with detailed task instructions prior to practice. This may be an important difference, given that in the present study it was the no-instruction group who was most affected by the withdrawal of circle feedback in delayed retention. Although this difference between the instruction groups was not significant, it is possible that instruction acts to reduce the negative impact of the removal of concurrent feedback when the feedback is helpful for performance. Given that the performance of the limb-feedback groups was not affected by the removal of feedback, one conclusion is that this feedback was not a useful information source for performing the task. Additionally, because the limb feedback was not specifically related to the task goal, that is production of the circle pattern, it would not become an intrinsic component of task performance.

In retention and transfer with feedback there was some support for the original predictions. The no-instruction, circle feedback participants continued to show less error than the
instructed participants under the same feedback conditions. In fact there was no significant increase in error as a function of the four month delay between testing periods. The instructed, limb-feedback group showed less error in retention and transfer than the non-instructed, limb feedback participants. Given that performance improved for these participants when the feedback was removed in immediate retention, it is suggested that the instruction compensated for the difficult feedback, rather than interacting with the feedback in a positive manner.

If the secondary task was supposed to provide a window into the cognitive resources demanded of the task then this condition would be expected to produce differential effects as a function of instruction. However there were no interactions with test condition in transfer, suggesting that both the secondary task and the speeded task interfered with performance in similar ways. Due, perhaps, to the visual as opposed to written nature of the instructions in this experiment, as compared to the initial investigation outlined in the introduction, the cognitive-verbal demands may have been decreased.

In summary, the task environment was important during both acquisition and final performance conditions in determining whether instructions would benefit, or hinder the learning of novel movements. Providing instructions and movement demonstrations detailing how to perform a complex movement were not helpful to acquisition when feedback was available that alerted participants to task goal attainment. In fact, the instructions interfered with performance, perhaps decreasing the variability necessary to break from pre-existing, unwanted behaviours. Learning to move the hands in a difficult coordination pattern was aided by the provision of concurrent circle feedback that specified the relationship between the arms in a simple, but indirect manner. This was compared to limb feedback where the exact displacements of the limbs were explicit. The suggestion is that the complex nature of this feedback failed to render pre-practice information useful to learning, at least as compared to the circle feedback. The limb feedback, like the instructions, promoted attention onto the arms and the movements required to make the circle pattern. Whether the attentional effects of feedback and instructions are at least in part responsible for performance detriments in both acquisition and retention requires further examination and was the rationale behind Experiment 2 (chapter 3).
III. Experiment 2

Attention Focusing Instructions and Coordination Bias: Implications for Learning a Novel Bimanual Task

3.1 Introduction

Theoretically, there is good reason to suppose that instructions and movement demonstrations benefit learning. The classic motor learning theories of Schmidt (1975) and Adams (1971) are based upon the idea that learning results in the development of a representation of the movement, which is then used to guide movement production. Carroll and Bandura (1982) and Swinnen (1996) claimed that initial instructions or demonstrations concerning how to perform a novel motor skill, facilitate the development of this movement representation, or what has been termed a reference-of-correctness. This reference is proposed to act like a template with which performance can be compared. Despite these claims there is very little empirical data to show that information provided prior to the execution of the act, provides any benefit to learning beyond simply specifying the task goal.

Green and Flowers (1991) found that providing rules underlying movements of a stimulus for a joystick-control task led to increased error as compared to withholding this information. The authors suggested that the instructions increased the attention demands on the learner, which interfered with goal attainment. Movement variability was also inhibited early in learning for participants who received instruction. In a whole-body movement task requiring ski-like movements, Wulf and Weigelt (1997) found that strategy instruction pre-practice was detrimental to both acquisition and retention. Providing instructions at a later stage in acquisition also affected the type of movements produced. After instructional provision jerkier, slower and smaller movements were exhibited.

In the initial investigation (see Chapter 1) and in Experiment 1, participants were required to learn a novel bimanual coordination movement. Methodologies derived from studies of inter-limb coordination and dynamical systems theory were adopted, which provided a way of quantifying the learning process, describing behaviour before practice and assuring that the to-be-learned motor skill was novel (see Walter, Lee & Sternad, 1998 who advocate the use of these methods to explore acquisition). In these studies participants learnt how to move their arms in a 90° relative phase relationship, which was represented as a circular shape. Feedback was provided relating to attainment of this goal and instructions were manipulated specifying how to achieve this goal in both written and visual form.
As with the studies from Green and Flowers (1991) and Wulf and Weigelt (1997), movement related instructions and demonstrations failed to facilitate acquisition. Goal-related information in terms of relative phase feedback was sufficient, even though this feedback was non-prescriptive, specifying only that an error was made and not how to correct it. Not only was this information sufficient, but augmenting this feedback with instructions specifying how to perform the new pattern caused reduced performance in acquisition and retention, the latter being dependent on feedback availability.

Based on these findings it was proposed that when feedback is provided on-line relating to goal attainment, instructions specifying what to do divert attention from this information. A slower rate of acquisition and poor retention results when performance is assessed under the same feedback conditions as practice. In contrast, withholding instruction, encourages attention to the feedback which facilitates performance. The non-instructed participants in both the initial investigation and in Experiment 1 showed increased movement variability early in practice as compared to the instructed participants. As suggested elsewhere, this variability is needed to break from pre-existing patterns of coordination. Attention to the task goal and the associated feedback, which is encouraged indirectly by withholding instructions, might encourage this early variability (see Swinnen, 1996) and the discovery of new movement patterns. The provision of instructions may encourage attention to the movement itself and attaining the correct movement form, at the expense of goal attainment (see Vereijken & Whiting, 1989).

The down side of this goal-related focus to facilitate acquisition was that once this information alerting as to the required relative phase was removed in retention, reduced performance was observed (see Experiment 1). This suggested that there was continued competition from pre-practice behaviours, when visual information was not available to modify the influence of early stable movement patterns such as anti-phase. Given that attention was primarily devoted to processing this visual feedback, other feedback processing mechanisms may be downgraded or ignored. The ideal learning environment would, therefore, be one where both attention to the feedback is promoted, such that attainment of the task goal is facilitated, and attention to additional sensory feedback sources is encouraged. This may involve increased kinesthetic awareness and/or the development of a representation of the movement that acts as a reference when augmented feedback is removed (see Swinnen, 1996).

These attentional explanations are supported by the empirical data of Wulf and colleagues. Wulf and Weigelt (1997) suggested that strategic instruction based on skilled performance was detrimental to performance, as it prompted an internal focus of attention onto
the effectors, which resulted in smaller and slower movements on the ski-apparatus. Wulf and colleagues (Shea & Wulf, 1999, Wulf, Höss & Prinz, 1998, Wulf et al., 1999) provided direct support for this attention hypothesis in a number of studies. They showed that an external focus of attention onto a stabiliometer, the ski-apparatus, or a golf club, respectively, was more beneficial to learning than a limb-related focus of attention onto either the feet or arms. Only in the Wulf, Höss and Prinz (1998) study was a control group examined who did not receive attention-directing instructions. Although this non-instructed group did not differ from the external focus of attention group in acquisition, there were differences in retention. The externally-directed group out-performed the control group as evidenced by significantly wider movements on the ski-apparatus, which was an important task goal requirement. It was suggested, therefore, that an external focus of attention provided a benefit to learning, which was not evidenced when only instructions were withheld. However, in this situation only an external focus was encouraged, rather than the coupling of strategy instruction with the external focus feedback. It may be that this attentional instruction coupled with important information concerning how to attain the task goal may be particularly beneficial for acquisition.

In the following study information was manipulated concerning both movement form and focus of attention, to determine what instruction would be most advantageous for both acquisition and retention of a new movement pattern. It was predicted that demonstrations specifying correct movement form, would benefit learning if additional instruction was provided that directed attention to the external effects of the action and attaining the task goal. This additional instruction was expected to decrease the internal focus prompted by movement related instructions and demonstrations. Due to the fact that a movement demonstration might be expected to aid the development of a reference-of-correctness, at least later in practice, augmenting movement demonstrations with this external instruction was expected to decrease the negative effects associated with feedback removal in retention. As such, retention was examined both with and without on-line feedback.

Prior to acquisition, participants were screened for knowledge of the required pattern using the scanning procedure described in the opening chapter. This procedure allowed determination of the participant’s performance at all relative phase values, including 0° and 180°, prior to practice; this is referred to as a dynamical landscape. Using this method it was possible to ensure that the to-be-learned movement was not already part of an individual’s movement repertoire. This procedure was expected to yield a relatively homogenous sample, which is especially important given that the acquisition process for tasks of this nature have been shown
to be highly variable across participants, irrespective of practice manipulations (e.g., Walter and Swinnen, 1994).

Four groups were compared that differed in the amount and type of information provided. The control group received no information concerning the movements required to produce the circular pattern (NO DEMO). Three other groups received demonstrations of the required movement pattern. For two of these groups, the demonstrations were augmented with instruction that directed attention either towards the feedback display and the effects of their actions on the environment (EXTERNAL), or to the relationship between the movements and the feedback (RELATION). The third group received only demonstrations of the required movement pattern (DEMO).

Based on the previous findings it was expected that providing only a movement demonstration would hinder movement skill acquisition and lead to decrements in retention due to an internal, limb-related focus of attention prompted by this type of instruction. The additional instruction provided to participants in the EXTERNAL and RELATION groups was expected to decrease the attention onto the limbs and encourage a goal-directed focus of attention onto the effects of the action on the environment. This focus was predicted to aid goal attainment and decrease attraction to pre-practice behaviours. If the demonstrations coupled with the goal-related instructions actually benefit movement acquisition, then these groups were expected to outperform the NO DEMO control group. The expected advantage for the EXTERNAL and RELATION groups was in retention when performance was assessed in the absence of goal-related feedback. The additional information provided to these two groups in the form of movement and focus of attention instruction, was expected to encourage additional processing operations and the development of more refined movement representations during acquisition, to help maintain performance when the guiding effects of the visual feedback were removed.

Wulf, Höss and Prinz (1998) found advantages for the external focus of attention group in retention when compared to a no-instruction control group. However, Wulf and colleagues never examined whether these attention-directing instructions, coupled with strategy instruction, would provide an additional benefit to learning, not realized when either instruction was provided alone. This is especially important, given that no advantage of external focus compared to a non-instructed control group, was observed during acquisition.

In the original investigation, a fifth group was examined whereby an internal focus of attention onto the limbs was promoted. Due to the complexity of the design with five groups and the lack of strong predictions as to differences between this group and the DEMO group, this INTERNAL group was not included in the final analysis and journal submission of the experiment. However, in Figure A1 (Appendix), the data for this group has been presented.
The RELATION group was included because this particular instruction directs attention to both the external feedback and the movements, possibly facilitating the coupling between the two information sources (i.e., the movement demonstration and the circle feedback). There was reason to believe that this instruction would benefit learning based on findings from Tsutsui, Tsukamoto, Hirose and Lee (1999). They found that participants with this type of information, in a similar coordination task, performed with less error in retention than both an observational learning group and a non-instructed control group.

After retention tests all participants were transferred to a new 45° relative phase pattern, depicted as a right elliptical shape. This transfer task was included to help elucidate on the nature of learning with respect to what information had been acquired. It was predicted that the RELATION group who received explicit knowledge of the relationship between their arms and the feedback would be best equipped to use this explicit instruction to produce the new movement pattern (see Senge & Sterman, 1992). It was expected that the EXTERNAL group would also do well in transfer due to a greater awareness of the effects of the movement on the computer-generated feedback, as compared to the DEMO only and NO DEMO groups.

3.2 Method

3.2.1 Participants

All individuals underwent an initial scan of their coordination dynamics. This involved bimanual tracking of two flashing stimuli on a computer screen that varied in relative phase. Only those who showed attraction to just the in- and/or anti-phase coordination patterns participated in the learning study. Attraction was primarily indexed by a negative slope through a particular task requirement, when delta relative phase (observed – required relative phase) was plotted as a function of the required relative phase. Low error at the 90° plateau (± 20° or less) coupled with low variability (< 20°), was also used as a criterion to exclude participants. These values were based on previous measures of relative phase and variability attained on this task as a function of practice at 90°. This procedure allowed counterbalancing across groups as a function of bias, either primarily in-phase (0°), anti-phase (180°) or both.

A switch from in-phase to anti-phase biased movements before or at the 60° task requirement, led to a classification of anti-phase biased. No switch before or at the 120° requirement, resulted in a classification of in-phase biased. A switch after 60°, but before 120°, led to a classification of bias to both patterns. Participants who switched to anti-phase but returned back to in-phase, were classified as showing a bias to both. This conservative procedure
resulted in the testing of seventy-one individuals. Forty-two participated in all experimental manipulations and were divided among the four groups in a pseudo-random fashion, such that there were 10 participants in the DEMO and EXTERNAL groups and 11 in the NO DEMO and RELATION groups. Twenty-seven were excluded based on the above criteria, and two failed to complete the required three testing sessions. Participants ranged in age from 18 to 35 years. Table 3.1 details group allocation as a function of gender and bias.

3.2.2 Apparatus and Task

3.2.2.1 Scanning Task

The scanning task required participants to continually flex and extend their arms such that at peak flexion they were coordinated with two flashing squares on the computer screen. Participants were positioned facing a colour computer monitor, with their forearms strapped comfortably into two angular manipulanda. The set-up was the same as in Experiment 1 (see Figure 2.1). The computer displayed two boxes (3 cm x 5 cm) at eye level, that were located in the centre of the screen, 5 cm apart. During the practice trial, feedback of limb displacement was provided by a moving cursor on a line located directly underneath each box. Movements of the limbs were compatible with movements of the cursor on the line. During the actual trial, no feedback was provided. The two boxes would flash green (a single flash lasted 200 ms) which was controlled by a customized computer program. This enabled different onset times so that relative phase (RP) could be manipulated. The green squares flashed synchronously at the start, i.e., 0° RP, and then in 15° RP increments, 12 steps of 12 s duration, the squares began to flash alternately (i.e., 180° RP). The cycle time was consistent at 1 Hz.

3.2.2.2 Learning Task

In the learning task participants were required to make 15 circle patterns on the screen by continuously flexing and extending their arms in a continuous, 90° RP pattern of coordination. They were eventually required to move in time with an auditory metronome that beeped every second in a 15 s trial. The positioning of the computer monitor, participant and manipulanda were the same as detailed for the scanning trial. For this task, movements of the right manipulandum produced horizontal movements of the cursor on the screen and movements of the left manipulandum produced vertical movements of the cursor. A 40° movement
Table 3.1  Group Allocation as a Function of Gender and Bias to In-phase (IP), Anti-phase (AP), or Both, as Assessed on the Scanning Task

<table>
<thead>
<tr>
<th>Group</th>
<th>Men</th>
<th>Women</th>
<th>AP Bias</th>
<th>IP Bias</th>
<th>AP/IP Bias</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXTERNAL</td>
<td>2</td>
<td>8</td>
<td>2</td>
<td>6</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>RELATION</td>
<td>4</td>
<td>7</td>
<td>2</td>
<td>7</td>
<td>2</td>
<td>11</td>
</tr>
<tr>
<td>DEMO</td>
<td>5</td>
<td>5</td>
<td>2</td>
<td>5</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>NO DEMO</td>
<td>4</td>
<td>7</td>
<td>2</td>
<td>7</td>
<td>2</td>
<td>11</td>
</tr>
</tbody>
</table>
corresponded to a 15 cm movement of the cursor. All instructions and demonstrations concerning how to produce the circle pattern were shown to participants on a pre-recorded video (see Experiment 1).

3.2.3 General Instructions and Procedure

3.2.3.1 Scanning Task

All participants familiarized themselves with the manipulanda and the corresponding amplitude constraints of the task. They were then informed of the requirements of the scanning trial, which was to try and coordinate maximum flexion of each arm with the onset of each of the flashing green boxes on the screen. They were told to try and be back at the “in” position the same time the ipsilateral box flashed green and a demonstration was provided. Participants were told that the trial would last for about 3 minutes during which time the squares would first flash synchronously and then slowly start to flash alternately. Participants were reminded to keep both arms moving continuously, even if they encountered difficulty coordinating with the green squares. A 12 s practice trial was given, where the squares flashed on and off together simultaneously. Limb displacement feedback was provided only during the practice trials. Participants received up to three practice trials until they were satisfied with the task demands. The scanning trial was then administered. Based on performance, participants were either included or excluded from further testing.

3.2.3.2 Learning Task

All participants received the same general task instructions. The criterion circle was displayed on the monitor and participants were told that their task was to make a similar pattern, by moving their arms in a particular manner. Summary feedback from a 15 s exemplar trial was also illustrated and the task explained. All participants received 60 practice trials over two days, each trial lasting 15 seconds. Concurrent feedback was provided during each trial relating participant’s performance in reference to this pattern. The feedback was displayed such that a history plot of the trial emerged. Throughout practice the criterion circle remained on the screen. During the trials, an auditory metronome dictated the participant’s required speed. It beeped once every second (1 Hz) and participants were told to try and produce one full cycle with each of the hands each beep. A full cycle was explained as moving the full distance between the “in” and “out” markers to arrive back in the same position.
No further instruction was given to the NO DEMO group. For the other three groups, instruction and demonstrations concerning how to produce the circle pattern were provided on a pre-recorded video. The same demonstrations were provided to all groups, but the instruction differed as a function of instruction group. A well-practiced model performed a 15 s demonstration of the required movement pattern at both a slow speed (roughly half as fast as the required) and at the normal, required speed of 1 Hz. During the demonstration participants also viewed the model’s feedback on-line, relating to circle production. The demonstrations and instruction were provided prior to practice on each day of acquisition and after the first block and second block of 10 trials (the NO DEMO group received a 3 minute rest during these intervals). To maintain consistency across the groups the inter-trial interval was approximately 10 s. No further instructions were given to the DEMO only group, whereas attention-directing instructions were additionally given to the EXTERNAL and RELATION groups.

The EXTERNAL group was asked to watch and attend very carefully to the feedback from the model during the demonstration. They were told that the feedback on the computer monitor was important information to attend to when producing the circle pattern. Additional instructions were provided at the end of each trial that reminded participants to use the feedback to guide movement production and pay attention to the effects of their movements on the computer feedback. The RELATION group received instruction about the relationship between the movements of the arms and the output on the computer monitor. Specifically, they were told that movements of the right arm produced horizontal movements of the cursor on the screen, which was subsequently demonstrated and movements of the left arm produced vertical movements of the cursor on the screen, which was also demonstrated. They were informed that moving the arms together resulted in a positive sloping straight line and that moving the arms alternately resulted in a negative sloping straight line; this was also demonstrated. Following the demonstration of the circle pattern, participants were reminded of the relationship between the arms and the feedback and were continually reminded throughout practice.

After the two days of acquisition, all participants performed three retention trials where computer-generated feedback was withheld, both on-line and terminal to task performance. One week later delayed retention was assessed without concurrent feedback and then under the same conditions as practice (i.e., with feedback). Again, three test trials were administered. Finally, participants were given one practice attempt at producing a new movement pattern to assess transfer. This was represented as a rightward slanting, elliptical shape on the computer monitor and could be produced by moving the arms 45° out-of-phase. On-line feedback was provided
during the trial and participants were given the opportunity to think about how to perform the movement before the trial began.

3.2.4 Data Analysis

3.2.4.1 Scanning Task

Discrete measures of relative phase were calculated at points of peak flexion. Specifically, the angular difference between the two closest limbs was computed by subtracting the point in time of right limb flexion (i.e., 0 ms) from the point in time of left limb flexion, as a function of the corresponding cycle duration (i.e., period). This equation yielded a positive value of relative phase when the right limb was leading the left. For analysis, all values were converted to positive values between 0° and 180° RP and only the last 10 seconds of each plateau were examined. This measure accurately reflected the ability of the participant to coordinate their limbs at the discrete point required in the task, that is, at peak flexion. From the relative phase data, error in relative phase was calculated, as well as the within-trial SD of RP. These data were used to determine eligibility and strength of attraction to in- and anti-phase.

3.2.4.2 Learning Task

Continuous measures of relative phase (RP) were calculated, given that participants were required to continuously move their limbs 90° out-of phase to make circular patterns. The displacement data for each limb were filtered at 10 Hz and were plotted as cosine functions. Peak displacements within a cycle were designated 0°, 180° and 360° values and the intermediate points of 90° and 270° were determined at points of maximum slope in displacement as a function of time (i.e., peak velocity). These points were normalized for displacement and velocity within the range of 1 to -1. The angle formed when velocity and displacement were plotted on a phase plane diagram gave a phase angle for each sample point (i.e., 500 samples / second). This was calculated for both arms and the difference between the limbs at any point in time gave a phase angle difference from -360° to +360°, depending on the lead-lag relationship. To facilitate analysis, that is averaging within a trial and avoiding wrapping that occurs when signed relative phase is used, unsigned relative phase between 0° and 180° RP was calculated.

For analysis purposes, only mean values of RP were calculated for each cycle and within-trial performance was computed as an average value of mean cycle RP. Root mean squared error (RMSE) was again obtained as an overall performance measure, determined from error in relative phase and within-trial variability. In the following analysis RMSE was the primary
measure of performance, but variability (between cycle SD of RP) was examined separately to help identify the locus of group differences. For example, early in practice high variability may be desirable, indicating exploration of new coordination patterns and the break from old ones (e.g., Lee et al., 1995). However, later in practice and retention, low variability would be preferable if coupled with low error, indicating performance stability.

The acquisition data was analyzed in a Group (4) x Day (2) x Block (10) mixed ANOVA with repeated measures on the last two factors. Immediate and delayed retention, both with and without on-line, computer-generated feedback were compared in a Group (4) x Day (2) x Condition (2) mixed ANOVA with repeated measures on the last two factors. Transfer performance on the right ellipse pattern was analyzed in a one-way between groups ANOVA. All post-hoc tests were conducted using the Tukey HSD method, p < .05.

3.3 Results

3.3.1 Learning Task

3.3.1.1 Root Mean Squared Error

Acquisition

The data for RMSE is illustrated in Figure 3.1. All groups were able to learn the new pattern of coordination as evidenced by main effects for day, F(1,37) = 164.31, p <.001, and block, F(9,333) = 68.40, p <.001. There was no significant main effect for group (p =.25) although the Group x Day x Block interaction was highly significant, F(27,333) = 1.84, p = .008. The DEMO group showed a slower rate of acquisition than the other three groups, who did not differ from each other. The DEMO group continued to show a decrease in error on the second day of practice, whereas the other three groups produced plateaus in performance. By the final block of practice the difference between the groups was no longer significant.

Retention and Transfer

Performance during immediate (see R1, Figure 3.1) and delayed retention, without (R2) and with on-line feedback (R3) was compared and is displayed on the right side of Figure 3.1. The on-line feedback condition in immediate retention corresponded to the last block of acquisition. The main effect of group was significant, F(3,38) = 3.35, p =.03. Irrespective of time of testing, or feedback, the DEMO group showed the greatest error and was significantly different to the EXTERNAL group. The main effect for day approached conventional levels of significance, F(1,38) = 4.08, p = .051. Error increased for all groups after the week retention
Figure 3.1 RMSE of goal relative phase (°) for the four groups across the two days of acquisition and in immediate (R1) and delayed retention without (R2) and with feedback (R3) and in transfer to a novel elliptical shape (EL).
interval. There was also a significant main effect for feedback condition, $F(1,38) = 68.07$, $p <.001$ showing that all participants performed more accurately when feedback was available. This difference was especially pronounced for the NO DEMO participants when feedback was removed immediately following practice, although the Group x Feedback condition interaction was not significant, $F(3,38) = 1.21$, $p = .32$.

Finally, ability to transfer their acquired skill to a new coordination pattern (i.e., the right ellipse, EL on Figure 3.1) was determined for all groups. There were no significant differences across the four groups, $F(3,38) = 1.41$, $p = .25$. However the RELATION group showed the least error on this transfer task ($M = 32.02$), as compared to DEMO ($M = 47.74$), NO DEMO ($M = 39.63$) and EXTERNAL ($M = 34.54$) groups.  

### 3.3.1.2 SD of RP

**Acquisition**

The data corresponding to variability in relative phase is displayed in Figure 3.2. There was a significant decrease in variability across practice as shown by main effects of day, $F(1,37) = 230.46$, $p <.001$ and block, $F(9,333) = 33.19$, $p <.001$. The main effect of group approached conventional levels of significance, $F(3,37) = 2.85$, $p = .051$. The DEMO group evidenced high variability in relative phase throughout practice. However there was also an interaction of Group with Block, $F(27,333) = 1.57$, $p <.05$ and a significant three-way interaction, $F(27,333) = 1.75$, $p = .01$. On day 1, block 1, the NO DEMO group showed the most variability in within-trial performance, significantly different from the EXTERNAL group. The RELATION and DEMO groups showed intermediate levels of variability. However, by the second block of practice variability had decreased significantly for the NO DEMO group. The RELATION group started to show a decrease in variability by block 4, the DEMO group did not show any significant decrease in within-trial variability on the first day of practice. By the second day all groups demonstrated similar performance in terms of variability.

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$^4$ An additional transfer task was included in the original design to examine how internal focus instructions, which directed participants to attend to their arms and limb positioning when performing the circle pattern, affected performance. Although there were no interaction effects, all participants showed a significant increase in error as a result of these internal focus instructions.
Figure 3.2 Within-trial SD of relative phase (°) for the four groups across the two days of acquisition and in immediate (R1) and delayed retention without (R2) and with feedback (R3) and in transfer to a novel elliptical shape (EL).
Retention and Transfer

Analysis of between-cycle variability did not show a group effect ($g = .34$). The only significant effect was for condition, $F(1,38) = 26.48, p < .001$. Variability for all participants increased when feedback was removed. There was no significant difference across the groups when transfer to a new movement pattern was assessed. The locus of group differences in retention was attributed to a consistent tendency to produce a pattern either close to the required, or far from the required pattern, depending on the group and condition.\(^5\)

3.3.2 Pre-Practice Bias and Learning

Due to the high within-group variability on the learning task and the differential performance of participants on the scanning trial, a secondary analysis was performed on the learning data as a function of pre-practice bias. The participants were divided into two groups based on whether they showed a strong bias to in-phase during the scanning trial. A resistance to break from symmetrically biased movements, even though the perceptual demands dictated otherwise evidenced this bias. Based on this analysis participants were categorized as in-phase or anti-phase biased. The same analyses as that conducted on the instructional groupings was performed, with bias as the between-participants factor. A roughly equal number of participants in each instruction group showed the same distribution of bias (see Table 3.1). Only qualitative analyses of the interactions of instructional group with pre-practice bias are reported, due to the low power associated with any quantitative analysis.

3.3.2.1 Root Mean Squared Error

Acquisition

In Figure 3.3 mean RMSE (primary Y-axis) has been plotted as a function of acquisition and retention for the in-phase (IP) and anti-phase (AP) biased participants. Although there was no main effect of bias, there was a significant Bias x Block interaction, $F(9,351) = 2.66, p = .005$ and the Bias x Day interaction was close to significant, $F(1,39) = 3.69, p = .062$. The in-phase biased participants generally evidenced more error in acquisition on the first day and during the early practice blocks, however, post hoc analysis did not differentiate between the groups across each practice block. On inspection of mean relative phase values, all groups showed phase values in the direction of the anti-phase pattern, irrespective of initial bias.

\(^5\) The relative phase means as a function of group and bias are displayed in the Appendix, Table A1.
Figure 3.3  RMSE of goal relative phase (°) and within-trial SD in RP (with between-participant standard error bars) for the in-phase (IP) and anti-phase (AP) biased participants across the two days of acquisition and in immediate (R1) and delayed retention, both without (R2) and with feedback (R3).
In Figure 3.4 the acquisition performance of the four instruction groups has been graphed as a function of bias to either in-phase (top panel) or anti-phase (lower panel). Although only a qualitative analysis was performed due to the low power, what is most noticeable is that the in-phase biased participants could not be differentiated as a function of instruction group. However the DEMO participants, who evidenced a bias to anti-phase, failed to show the same advantages associated with this initial preferences as observed for the other three groups.

**Retention**

Bias interacted with Day, $F(1,40) = 6.60$, $p = .014$ and there was also a three-way interaction of Bias with Day and Condition, $F(1,40) = 8.29$, $p = .006$. The in-phase-biased participants showed a significant increase in error across the week retention interval that is illustrated on the right hand side of Figure 3.3 (R2). This was due to high error under the no-feedback condition, significantly different from the anti-phase participants. Again, the high error for the in-phase-biased participants was not due to mean RP values in the direction of the in-phase pattern. Rather, the mean values increased in the direction of the anti-phase pattern.

**3.3.2.2 SD of RP**

**Acquisition**

There was no main effect of bias, however the Bias by Block interaction approached conventional levels, $F(9,351) = 1.90$, $p = .052$ and there was a three-way interaction of Bias x Day x Block, $F(9,351) = 2.14$, $p = .026$. The variability data were also displayed in Figure 3.3 with the secondary Y-axis corresponding to mean SD of RP values. On the first block of practice the anti-phase biased participants were more variable than the in-phase, although post hoc analysis did not yield significant differences. This trend had reversed by the second block. The three-way interaction showed that this effect was located in the first day of practice only.

**Retention**

There were no significant differences between participants as a function of bias.

**3.4 Discussion**

It was predicted that a movement demonstration coupled with instruction, that directed attention onto the goal relevant feedback (i.e., EXTERNAL and RELATION), would facilitate acquisition and retention of a novel coordination pattern. This facilitation would be in
Figure 3.4  RMSE of goal relative phase (°) for the four instruction groups, as a function of bias to either in-phase (top panel) or anti-phase (lower panel) across the two days of acquisition and in immediate (R1) and delayed retention both without (R2) and with feedback (R3).
comparison to providing only a movement demonstration, as was the case for the DEMO group, or withholding information specifying what to do (i.e., NO DEMO), at least during no feedback retention testing. In accord with the original predictions, the DEMO only group showed a slower rate of acquisition than the other three groups. This was arguably due to an increased focus of attention onto the movement itself and away from the goal-relevant feedback, which facilitates task acquisition and performance.\(^6\) Even though the NO DEMO group failed to receive any instruction concerning how to move their limbs to produce the circle pattern, they were not disadvantaged in acquiring the new movement pattern. This is particularly interesting given that the other three groups watched twelve demonstrations of the to-be-acquired pattern, at both the regular and reduced speed. The RELATION group was also provided with detailed instructions concerning how to move their limbs to produce the circle, which were repeated after every trial. By the end of acquisition, however, the difference between the groups was no longer significant.

Early in practice the NO DEMO group showed particularly high variability in within-trial performance as evidenced by Group interactions with Day and Block. This is perhaps not surprising given that no direction concerning how to perform the new coordination pattern was provided. Early variability in relative phase has been proposed to be an important variable in the acquisition of new coordinative actions, facilitating the break from stronger relative phasings, such as anti-phase. In the initial investigation and in Experiment 1, the non-instructed participants also showed high variability early in acquisition, which was associated with acquisition and retention advantages. In support of these findings, the NO DEMO group showed the greatest decline in error over the first day of practice.

Retention performance was examined both with and without feedback due to the differential predictions based on the availability of this information. Again in support of the predictions, the DEMO only group continued to show the greatest error in retention across all feedback conditions. This group was significantly different to the EXTERNAL group who received additional instruction, continually reminding participants to focus on the feedback during acquisition and the effects of their actions on the feedback. All groups, however, were affected by removal of the circle feedback to assess retention. This is perhaps not surprising given that the strength of the perceptual information alerting to the required relative phase was decreased when this information was removed.

\(^6\) The INTERNAL group also showed performance in acquisition comparable with that of the DEMO group (see Appendix I, Figure A1).
Although the Group x Feedback condition effect was not significant, when feedback was removed following practice the detriments in performance were in the predicted direction. The NO DEMO group was most affected by the immediate withdrawal of feedback, showing errors in performance equal to that of the DEMO group. The RELATION group showed intermediate effects and the EXTERNAL group was least affected by this manipulation. Arguably the additional information provided to the EXTERNAL and RELATION groups, in terms of movement demonstrations and instruction, helped stave off some of the negative effects associated with feedback withdrawal without disadvantaging acquisition. As suggested in the introduction, these attention-directing instructions may have served to focus attention onto other factors that would have gone undetected, or at least not processed as well, such as proprioceptive information. This would reduce the decrements associated with the removal of one information source. These instructions may have encouraged more effortful practice, facilitating performance when the guiding effects of the visual feedback were removed (see Winstein & Schmidt, 1990). Indeed, during the final blocks of acquisition, performance leveled off for all groups. The additional reminder instructions provided to the instruction groups every trial may have helped keep attention directed to both maintaining and improving performance, even though this was only manifest when performance was examined without feedback.

When transfer performance to a new coordination pattern was assessed, all groups showed difficulty producing this new coordination pattern. Although the main effect for group was not significant the DEMO group again showed high error during transfer and, in accord with the original predictions, the RELATION and EXTERNAL groups showed the least error. Given that the RELATION group had been continually reminded of the relationship between their limb movements and the feedback it was of some surprise to find that there were not more participants in this group who at least showed a general idea of how to produce the new pattern. In fact, when debriefed, only 2 out of the 11 participants in the RELATION group were able to correctly explain how to produce the right-ellipse pattern, as different to the circle (i.e., a decreased difference between the limbs, and/or movements that were more symmetrical and biased towards in-phase). The majority of the participants in this group incorrectly reported adjusting the speed or amplitude of one of the arms to produce the new pattern, or merely adopting a trial and error approach.

The INTERNAL group also benefited from this repeated instruction that directed attention towards the limbs and presumably processing of kinesthetic feedback. The means for this group are shown in Figure A1 in the Appendix.
Due to the high between-participant variability, irrespective of instruction condition and the fact that participants could be differentiated quite easily based on their performance on the scanning trial, performance was examined as a function of initial bias. Performance on the scanning task was found to be an important predictor of both acquisition rate and retention. On the first day of practice and across the early practice blocks, the anti-phase biased participants generally showed less error than the in-phase biased participants. The anti-phase biased participants also showed increased variability early in practice, which may reflect decreased attraction to either stable state, enabling the break from competing attractor states.

Zanone and Kelso (1994) proposed that learning rate should differ as a result of the stability of nearby attractive states. For 90° relative phase, both in-phase and anti-phase are equidistant in parameter space. If participants choose (as a result of the instructions, feedback and/or their intentions) to produce patterns within the anti-phase region then, theoretically, learning would be expected to proceed at a faster rate due to decreased stability for this pattern as opposed to in-phase. However, the group mean relative phase values were biased towards the anti-phase pattern for all participants, such that the process of acquisition, at least in terms of attractor region was similar for both groups. Additionally, in the no feedback, delayed retention trials, participants biased to in-phase on the scanning trial showed performance regressions in the direction of the anti-phase pattern. In Experiments 3 and 4, detailed in Chapter 4, participants were allocated to groups based on initial bias. This procedure allowed for a comparison of learning rates as a function of pre-practice bias and ‘closeness’ of pre-practice patterns to the required movement.

It is proposed that the scanning trial, rather than assessing just a specific bias to either in- or anti-phase coordination, assessed a general ability to resist attraction to stable patterns. Participants who demonstrated preference to move towards anti-phase coordination in the scanning trial, or at least not persevere with in-phase coordination for the majority of the phasing plateaus, were more adept at uncoupling their limbs. Alternatively, these individuals may have been better at tasks that required eye-hand coordination, given that the scanning trial was a tracking-type task. This perseverance demonstrated by the in-phase biased participants was manifest as a strong attraction after learning to one of the intrinsic patterns (i.e., anti-phase). Although this bias could be over-ridden when feedback was available on-line, when the guiding properties of this information source were removed, attraction to pre-practice behaviours were again manifest. As discussed earlier, the feedback was expected to reduce the competing effects associated with pre-existing biases in coordination. In the case where biases were particularly
strong or stable (as for the in-phase biased participants), then the role of environmental information alerting as to the required movement pattern was increasingly important.

Walter and Swinnen (1994) suggested that individuals who show difficulty dissolving bad habits would benefit from different learning strategies. The findings from this study offer support for this conclusion, with respect to provision of feedback. Due to the low power associated with the Instruction group x Bias interactions it is difficult to make any strong conclusions with respect to how instructions differentially mediate performance depending on strength of pre-practice behaviours. Although there did not appear to be any differences across the instruction conditions for the in-phase biased participants, the advantages noted for anti-phase biased were not observed for the DEMO participants. Arguably, instructions specifying how to produce a particular movement pattern, in the absence of goal-focused instructions, may serve to increase the competition from early pre-practice behaviours.

The fact that relative phase values for all participants tended more towards anti-phase, is indicative of anti-phase destabilizing to give way to 90° relative phase. During no feedback retention testing, when environmental information was not available to attract 90°, the anti-phase pattern continued to attract performance. This supports the proposition that 90° and 180° relative phase continue to compete with each other after performance plateaus are observed in acquisition and immediate retention. Typically, a physical change, such as increased speed (e.g., Lee et al., 1995), or cognitive perturbation, as was observed in the initial investigation detailed in chapter 1, would be necessary to observe this competition.

The performance of the in-phase as compared to the anti-phase biased participants suggests that differential stability of the pre-existing attractor states, influences the rate of acquisition in accordance with predictions of Zanone and Kelso (1994, but see Fontaine et al., 1997 who failed to support this hypothesis). However the differential performance was not due to a bias to perform movements within the region of the in-phase attractor. Neither acquisition nor retention showed competing influences from the in-phase attractor. This suggests that the scanning trial may provide a window into general coordination ability, which can then be used to predict learning, rather than specific biases after learning.

One way to directly examine how bias impacts on performance is to manipulate the instructions prior to practice to direct attention to one of the intrinsic patterns. It might be expected that attention to either of these patterns would hinder the acquisition process, as compared to withholding instruction. If being in a weaker attractor region is advantageous for learning, then directing attention to anti-phase should not hinder acquisition as much as directing
attention to in-phase. However, anti-phase may interfere more with the learning of 90° relative phase due to its inherent instability and, therefore, perhaps continue to compete with performance after practice. This issue is examined in Experiment 3 (chapter 4).

From the findings reported here and the results of similar studies reported in this chapter recommendations for instructional provision in more applied settings could be suggested. If movement demonstrations are to be provided they should be coupled with goal-focusing instruction, so that acquisition and retention performance is not adversely affected. For example, when learning to perform a chip shot in soccer, although instruction concerning how to do this shot may help in terms of movements of the hips, legs and feet, the goal of the task should be emphasized throughout practice. Instruction or feedback that focuses on the ball trajectory, for example, where the importance of raising the ball in the air would be encouraged, could be used to direct attention appropriately. Alternatively, a physical obstacle could be implemented to encourage a goal-focus, so that the learner is aware of the necessity to clear the obstacle.

In conclusion, an external focus of attention helps to both attain and retain a new movement pattern. Beyond the findings from Wulf and colleagues, this external focus coupled with strategy instruction may not only stave off the negative effects that have been associated with instructional provision, but may also aid retention and transfer. Repeated instruction that directs attention to other feedback sources during practice, or at least encourages effortful practice, may have an additional benefit to learning especially when performance is assessed under changed sensory conditions.
IV Experiments 3 and 4
Learning as a Function of Coordination Bias: Building upon Pre-Practice Behaviours

4.1 General Introduction

Very little research has been directed to understanding how training strategies should accommodate differences in pre-existing motor skills (Walter & Swinnen, 1994). This has been somewhat related to the nature of the laboratory tasks that have been examined, since, for the majority of these tasks, individual differences have been minimized. Either very simple tasks have been examined, where a certain proficiency was expected before practice, or novel tasks were studied where the level of previous experience was expected to be nil, or at least minimal (see Fontaine et al., 1997; Zanone & Kelso, 1992, 1997). However, recent methodological and theoretical advances in coordination research have provided a format for studying, both qualitatively and quantitatively, individual differences in the acquisition of novel motor skills (see Kelso, 1995 for a review). The purpose of this research, was to use the knowledge and methodology provided by inter-limb coordination tasks, to explore how instructions that focus on pre-existing behaviours affect the learning process.

The majority of individuals demonstrate bi-stable dynamics prior to any practice at dual-limb coordination tasks (Kelso, 1984). Bi-stability is characterized by a strong bias to perform in-phase and anti-phase movements, where the limbs are tightly coupled in both space and time. These two intrinsic patterns are also referred to as 0° and 180° relative phase, respectively, reflecting the average difference between the limbs at any one point in time. It has been demonstrated under a number of conditions that the in-phase pattern is more stable than the anti-phase pattern. For example, in-phase coordination is typically performed with less variability than anti-phase and increasing the pacing frequency when performing anti-phase causes a transition to in-phase (e.g., Kelso & Scholz, 1985; Kelso et al., 1986, Scholz & Kelso, 1989). Due to the inherent stability of these two patterns, individuals face considerable difficulty learning new coordination movements intermediate to these.

A number of researchers have shown how these two stable patterns compete with the acquisition of 90° relative phase, both at the early stages of acquisition and even after considerable practice (e.g., Fontaine et al., 1997; Lee et al., 1995; Zanone & Kelso, 1997). Motor learning theorists, practitioners and the learner's themselves are therefore faced with the task of determining how competition from these pre-practice behaviours can be decreased so that learning can be optimized. That is, both accelerating the break from these pre-practice
behaviours and continually resisting the influence of these patterns in retention. Variability in relative phase, or what are termed 'critical fluctuations', is proposed to be essential in effecting behavioural transitions. Zanone and Kelso (1992, p405) proposed that “fluctuations...allow the discovery of new (or other) available states.”

In the studies reviewed in this thesis, the effects of movement instructions, demonstrations and feedback have been examined during practice of a 90° relative phase pattern of coordination. The task goal has been represented as a circular shape, which is produced when the displacements of the left and right limbs are plotted orthogonally (i.e., a relative motion plot). In this way participants were always aware of the task goal, but, information concerning how the limbs should move to achieve this goal was manipulated. Despite the fact that the movement demonstrations specified to the individuals what to do to acquire a new movement goal and arguably should facilitate the development of a movement template to guide production (e.g., Carroll & Bandura, 1982; Swinnen, 1996), this type of instruction has failed to produce any learning benefits. This may be due to the lack of ability the learner has at this very early stage of skill acquisition, which makes it difficult for them to use the information in any useful way. Goal-relevant feedback in terms of circle production was sufficient information to encourage acquisition of a new coordination pattern. In fact, supplementing this feedback with instructions specifying how to move the limbs in some instances produced learning decrements. This finding was particularly surprising given that the feedback alone was non-prescriptive, alerting only that an error was made, but not how to correct this error.

These effects were related to a decreased variability in instruction group performance early in acquisition, which may have hindered the break from competing, pre-practice patterns. This lack of variability may be a result of repetition in trying to copy the movement demonstration, or implement the instructions (see Gentile, 1972; Higgins, 1991; Vereijken & Whiting, 1989), and/or inadvertent attraction to already existing behaviours, particularly anti-phase. This hypothesis was somewhat supported by the fact that, in the absence of on-line feedback, instructional provision was found to cause a strong anti-phase attraction during the initial stages of skill acquisition. Given that 90° was not part of the learner’s repertoire initially, knowing what to do was not sufficient to break from anti-phase, but rather caused a bias towards this pattern. However, implicit from watching the demonstrations was an awareness that moving the arms symmetrically in-phase was not the correct way to perform 90° causing an avoidance of these movements. Even though anti-phase is inherently less stable than in-phase, this bias to anti-
phase did not help performance. This may be because switching between both in- and anti-phase movements early in acquisition promotes the discovery of new movement patterns.

If instructions promote attention onto these pre-practice patterns and inhibits early variability in the movement, supplementing the instructions with knowledge of these biases might be expected to further increase these effects (i.e., decreased variability in relative phase and a bias to anti-phase coordination). Competition between the required pattern and the intrinsic patterns would be promoted and delays in acquisition would be observed. Continued interference from these patterns in transfer testing would also be expected. Similar observations have been made by sport psychologists, who propose that undesirable behaviours are often reinforced by drawing attention to them (e.g., Gill, 1986; Kauss, 1980).

Bias to in-phase may be particularly harmful to learning due to the inherent stability associated with this pattern. However, Temprado et al. (1999) have shown that the less stable, anti-phase pattern, was more affected by attention-focussing instructions than was the in-phase pattern. This was evidenced by increased pattern stability (i.e., lower standard deviation of relative phase) when attention was directed onto the performed coordination pattern. Subsequently, instructions directing attention to anti-phase would also be expected to delay acquisition by increasing the stability of this pattern, leading to similar performance as in-phase instructions.

Alternatively, additional knowledge alerting participants to these habitual behaviours might be expected to facilitate awareness and actually benefit learning. Although awareness of the anti-phase pattern may help, explicit awareness of the in-phase pattern was unlikely to be helpful, due to the redundancy in the information conveyed. Movement demonstrations and instructions clearly alert participants to the fact that moving the arms symmetrically in-phase is not the correct pattern of coordination, hence the bias to anti-phase observed in earlier studies as a result of instructions. Both types of instruction, however, might be expected to enhance error detection processes, as the participant would be encouraged throughout practice to continually make comparisons across two patterns (i.e., in- or anti-phase and 90°). In a similar fashion to random practice schedules, building upon past behaviours to acquire new motor skills might promote more effortful practice and the development of more defined movement representations, leading to benefits in retention (see for e.g., Shea & Zimny, 1983).

In addition to these stable coordination patterns (i.e., in- and anti-phase), a smaller number of individuals perform patterns intermediate to these, such as 45° or 135° relative phase (where the two limbs are offset from each other in varying degrees between 0° and 180°),
demonstrating multi-stable dynamics. This may be a result of previous practice experiences such as playing a musical instrument, video games or rhythmic sports or dance. In the motor learning literature, very little attention has been paid to individuals who show preference to these intermediate patterns prior to practice. It was thought that more attention should be given to these individuals given that, in Experiment 2 (chapter 3), 38% of volunteers showed an ability to uncouple their limbs pre-practice and move in patterns other than 0° and 180° relative phase (including 90°).

A notable exception is work done by Zanone and Kelso (1992, 1997). They proposed differential pathways to learning as a result of pre-existing movement tendencies. When learning a pattern far from a person’s initial bias (e.g., learning 90° relative phase when the initial bias was 0° or 180° relative phase), an abrupt transition in the form of the learning curve was proposed, to allow the formation of an additional attractor in the participant’s dynamical landscape. In this first learning route a significant increase in the variability of relative phase would be required to break from competing, stable patterns. However if the initial pattern of behaviour was close to the to-be-learned pattern (e.g., learning 90° when the initial bias was 45° relative phase), then the learning route was proposed to be more gradual, resulting in replacement of the initial attractor. In the latter example, variability was not expected to the same degree as in the former, because the competition between the existing and required patterns would not be as great and only a gradual shift in the initial dynamical landscape would be needed.

Due to the fact that the coordination ability of participants who show multi-stable dynamics before practice, is generally better than the bi-stable participants, it is expected that these individuals would experience less difficulty transforming the information in the demonstrations into useable knowledge to facilitate acquisition. In the studies by Zanone and Kelso (1992, 1997) comparisons across different learning requirements and initial biases were generally made on an individual basis to enable more precise descriptions of the learning process. These individual descriptions were particularly important, as only 4 out of the 14 participants tested in their 1997 study showed attraction to patterns other than 0° and 180° pre-practice.

Experiment 3 was conducted on individuals who only demonstrated ability to perform in- and anti-phase movements before practice (i.e., bi-stable). The purpose of this study was to examine whether knowledge of particular pre-practice behaviours (i.e., in- and anti-phase), in addition to movement demonstrations, would serve to mediate the competing influence of these
patterns on learning. Given the reviewed empirical data and predictions based on dynamical theory this additional instruction was not expected to help, but rather cause detriments in movement skill acquisition.

In Experiment 4 the importance of pre-practice ability and related variability in mediating instructional effects was examined. Given that Zanone and Kelso (1997) proposed different routes to learning as a function of pre-existing biases it was anticipated that high variability in relative phase would not be a necessary requirement for participants who were biased to patterns other than in- and anti-phase pre-practice (i.e., multi-stable). Rather, instructions and movement demonstrations were expected to promote this gradual adjustment of an existing pattern in the direction of the required movement pattern. Allocation across the two experiments as a function of initial bias was determined prior to practice using scanning procedures similar to those used in Experiment 2. Current research conducted in our laboratory has suggested considerable variability in performance across repeated scans, in the absence of intervening practice sessions (McGarry, Hodges, Bredin, Franks & Chua, 2000). Therefore both discrete and continuous scanning procedures were adopted in the following experiments to allow greater validity in assignment of participants across the two studies.

4.2 Experiment 3

4.2.1 Introduction

The purpose of Experiment 3 was to determine how instructions designed to build-upon old behaviours to acquire new, influence the process of motor skill acquisition. Participants were required to learn a bimanual coordination movement that involved moving the arms 90° out-of-phase, which produced circular patterns on a computer monitor. Instructions directing attention either to the in-phase pattern or the anti-phase pattern were manipulated, to determine whether they differentially mediate performance. Only those individuals who showed attraction to these two stable patterns pre-practice on scanning tasks participated in the first study. Participants were randomly allocated to one of three groups. Two groups received instruction and demonstrations that alerted them to either the in- or anti-phase pattern, coupled with movement information concerning how to produce 90° relative phase. A third group did not receive any movement-related instruction, although all participants received goal-related feedback at the end of each practice trial. Two conflicting hypotheses were proposed. The anti-phase instruction might serve to increase awareness of this pre-practice behaviour and decrease the attraction to this pattern typically observed when only a movement demonstration has been provided. Due to the
redundancy in the in-phase instruction when coupled with a movement demonstration of the required pattern, this instruction was not expected to provide any additional benefit. However, the instructions were generally expected to improve the acquisition process, particularly retention and transfer, by increasing the effort required.

Despite these arguments, there was also considerable theoretical and empirical evidence to suggest that coupling movement demonstrations with additional information concerning pre-practice biases, would serve to further degrade movement skill acquisition. Because movement demonstrations and instructions have failed to benefit learning (see Experiments 1 and 2), due to increased attraction to pre-practice behaviours (in particular anti-phase) and a focus of attention onto the movement and the limbs, this additional information may further increase the competition from early, stable behaviours. Given the greater stability of in-phase coordination, this instruction was expected to hinder acquisition more than instruction concerning anti-phase. However, Temprado et al. (1999) have shown that anti-phase is more sensitive to focus of attention encouraged by instructions, such that the stability of both patterns would be high if attention was directed to either.

These predictions were tested in the following study where the three groups underwent two days of practice, followed by retention and transfer tests and post-practice scanning trials, to assess changes to the underlying coordination dynamics. Both retention and post-practice performance on the scanning tasks was expected to indicate the strength of the newly acquired movement pattern. The quality of learning, as indexed by pattern stability, was also examined by studying performance under increased movement frequency conditions. Variability in relative phase was expected to increase for all groups as movement frequency was increased, and this was expected to cause transitions to more stable patterns. It was expected that transitions to either in- or anti-phase would be dependent on both the instructional manipulations and the quality of learning (i.e., pattern stability). If instructions serve to further increase the stability of either in-phase or anti-phase, then transitions to these patterns may be hastened for the two instruction groups, as compared to the control group. Finally, participants underwent transfer testing to new movement patterns. These patterns were represented as elliptical shapes, that could be produced by moving the arms out-of phase in various degrees between 0° and 180°. If continuous comparison across two movement patterns in acquisition serves to enhance conceptual processes that are proposed to facilitate transfer (see Shea & Zimny, 1983), then the instruction groups were expected to show better transfer performance than the non-instructed group.
4.2.2 Method

4.2.2.1 Participants

Participants volunteered for the study and were all self-reported right handed. On completion of testing participants were paid $25. Prior to any practice manipulations, two scanning tasks were performed to assess coordination bias. These tasks allowed assessment of relative phase (RP) between 0° and 180°. Low error and low variability (i.e., less than 20°) at any of the RP plateaus between 45° and 135°, was used to determine coordination bias. A negative slope through a required pattern on the delta RP graph (error in RP plotted as a function of required RP) indicated bias. Based on this information, participants were assigned to groups or excluded if low error at 90° RP was observed.

Forty-eight individuals met the criteria for study inclusion. Thirty-two were excluded (11 men, 21 women), because they showed the ability to move their arms 90° out-of-phase before practice. Three failed to complete all testing conditions and, due to a computer failure, data from 3 participants was irretrievable. The computer failure affected data from an additional ten individuals, although this was only one or two trials and therefore analysis was conducted with a reduced number of trials when data were missing. Participant characteristics as a function of group are detailed in Table 4.1.

Of the forty-two participants who underwent testing and whose data was retrievable, twenty-nine showed only bi-stable dynamics; all participants showed a predominant anti-phase bias. These individuals were randomly allocated to one of three practice conditions: No instruction (BI-NO); instruction concerning in-phase (BI-IP); or instruction concerning anti-phase (BI-AP). There were nine participants in the BI-NO and BI-IP groups and eleven in the BI-AP group. Individuals who showed a bias to intermediate patterns other than 90° (multi-stable dynamics) participated in Experiment 4.

4.2.2.2 Task and Apparatus

Scanning Task

Two scanning tasks were used to assess performance before, during and after practice on the learning task. Participants were required to make continuous flexion and extension movements to coordinate with two flashing squares. Movements were made using angular manipulanda as in Experiment 2. Visual markers on the tabletop, depicting maximum flexion and extension positions, specified amplitude. Additionally, a marker was placed at every quarter mark as well as at the third and two-thirds point to facilitate instruction.
Table 4.1  Group allocation across Experiments 3 and 4 as a function of age, gender and bias to either $0/180^\circ$, $135/120^\circ$, or $45/60^\circ$ relative phase.

<table>
<thead>
<tr>
<th>Characteristics</th>
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<tbody>
<tr>
<td>Gender Coordination Bias (n)</td>
</tr>
<tr>
<td>Group</td>
</tr>
<tr>
<td>Experiment 3: Bi-stable</td>
</tr>
<tr>
<td>No-instruction</td>
</tr>
<tr>
<td>In-phase</td>
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<tr>
<td>Anti-phase</td>
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<tr>
<td>Experiment 4: Multi-stable</td>
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<tr>
<td>No-instruction</td>
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<tr>
<td>Instruction</td>
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</tbody>
</table>
Participants had their coordination dynamics assessed between 0° and 180° relative phase (RP) on two different tasks. In the first task, which will be referred to as the discrete scanning task, participants were required to coordinate peak flexion movements in seven discrete 15 s trials where the lights flashed in one of seven RP’s (0°, 45°, 60°, 90°, 120°, 135°, and 180°). No feedback was provided during the test trials. A maximum of three practice trials at 0° RP were performed prior to testing, where moving cursors underneath each square provided on-line feedback as to angular displacement. Movements of the manipulanda were compatible with movements of the cursor on the screen. A video camera (with 12x lens) was secured to an attachment in the ceiling directly behind the participant’s chair. Filming of participants during the initial scanning trials facilitated instructional provision during practice.

In the second scanning task, referred to as the continuous scanning task, the green squares started flashing synchronously (i.e., 0° RP), and then in 15° increments, 12 steps of 12 s duration each, the squares began to flash alternately. The 12 steps allowed a scan of the dynamics between 0° and 180° RP, where the right square flash would gradually lead the left in corresponding 15° increments. In this second scanning task the participants’ arms were covered using a black felt sheet to minimize any learning effects (due to response-produced feedback for example) that may result from repeated scanning trials.

**Learning Task**

The task goal for all participants was to learn how to correctly move the arms to produce circle patterns on the computer screen, that matched as closely as possible a criterion circle. An additional goal was to produce 15 circles within a 15 s trial by moving in time with an auditory metronome. The task set-up and apparatus was similar to that used in Experiment 2. Instructions and demonstrations regarding pre-practice bias and how to produce circles (i.e. 90° RP) were pre-recorded and played to participants on a video cassette recorder via a big screen colour monitor (50 cm x 65 cm, Sony Trinitron, KV-32S22), which was located to the left and facing the participant.

4.2.2.3 Instructional Manipulations

All demonstrations were filmed with the camera positioned behind and above a well-practiced model. Each participant was filmed during the discrete scanning run and dependent on performance and instruction condition, this video was used for instructional purposes to highlight initial coordination bias. To further illustrate initial bias, two videos were produced before
testing that showed in-phase and anti-phase. The starting position of the arms was first illustrated, followed by a 15 s demonstration of one of the patterns. The right arm was always at maximum flexion and the left arm either at flexion or extension. No feedback pertaining to the model’s performance was provided on the video.

Following this instruction, video instruction pertaining to production of the circle pattern (i.e., 90° RP) was provided. All instructional groups received the same demonstration and instruction. Participants were again told the starting positions of the arms (i.e., right arm flexed, left arm at the middle position) and then instructed as to the corresponding positions of the arms every quarter of a cycle. The model then demonstrated the required pattern in a continuous 15 s trial. Again, no feedback pertaining to the model’s performance was provided. Reminder instructions were provided verbally during and after each video and every alternate trial for the first 15 practice trials and every 5 trials thereafter (when the video demonstrations were not provided). These instructions reminded participants of their initial bias and how the arms should be adapted to correctly produce 90°. For example, the anti-phase instruction group was told that their initial preference was to move with the right arm ahead of the left arm by half a cycle. To produce the required pattern, however, participants were told that the right arm must lead by only a quarter of a complete cycle.

4.2.2.4 General Instructions and Procedure

Scanning Task

The instructions were similar to those provided in Experiment 2. Participants first received 1 to 3 practice trials, where the squares flashed green on and off together at the same time (i.e., in-phase). This was followed by seven test trials at each of the RP plateaus that lasted 15 s. Before each test trial, participants previewed the whole trial before attempting to move in coordination. It was stressed to each participant the importance of trying to make the movements as smooth and continuous as possible. The discrete scanning trials were administered in a predetermined random order, such that each person within each group underwent a different order of conditions. These orders were counterbalanced across groups.

Following the discrete scanning tests, some participants were excluded for showing low error at 90° RP. There then followed a three-minute continuous scanning trial. Based on performance on both the discrete and continuous scanning tasks, participants were allocated to one of the three conditions. A second continuous scanning trial was administered before practice
on day 2 and a week later in retention. During retention the discrete scanning task was also administered in the same order as pre-practice.

*Learning Task*

The same general instructions were given to all participants. These were similar to those provided in the previous experiments. Participants were told they would receive two days of practice, 40 trials per day, each trial lasting 15 s and their final goal was to produce 15 circles on the screen during a single trial. They were informed that an auditory metronome would beep once every second (1 Hz) throughout each trial and they should try and move in time with the metronome. Feedback was withheld during the trials, but summary feedback was provided after every trial overlaying the criterion circle. After the first, fifth, fifteenth and thirtieth trial on each day of practice, a playback of the previous trial was provided.

The experimental instructions were provided just before practice on the first and second day, as well as after every 5th, 15th and 30th trial on both practice days. The no-instruction group was given a two-minute rest at corresponding intervals. One week later, participants were tested for retention. Two trials on the learning task were performed without feedback. After these trials all participants were required to perform the circle task under a number of different conditions. In the first condition, participants were required to make circle patterns in time with an auditory metronome that gradually increased in speed from 0.5 Hz to 2 Hz within a continuous 60 s trial. Specifically the metronome would sound once every 2000 ms to start (0.5 Hz) and in decreasing 300 ms intervals every 10 s; the metronome would eventually sound once every 500 ms (2 Hz). Participants were encouraged to maintain the same movement amplitude and to try and move in time with the metronome. No performance feedback was provided at any time.

In the final conditions, participants were required to perform a number of transfer tasks with on-line feedback. Two 15 s trials were performed at each of four different patterns displayed as elliptical shapes (i.e., Lissajous figures). The pattern order was pre-determined in a random fashion, such that the order was different across participants within a group, but maintained across the groups. Moving the arms in either a 45° or 60° RP pattern produced two leftward slanting elliptical shapes (both a thin and more circular ellipse, respectively). Two rightward slanting elliptical shapes corresponded to 135° and 120° RP. No instruction concerning how to produce these patterns was provided. Participants were permitted approximately 30 s
before the production of each pattern to think about what to do. They were encouraged to keep both arms moving and, if they felt comfortable, to try and move in time with the metronome.

4.2.2.5 Data Analysis

Scanning Tasks

The last 12 s for each of the discrete scanning trials were analyzed. The last 10 s of each plateau for the continuous scanning trials were analyzed. Discrete values of RP at flexion were calculated (see Experiment 2). From the RP data, delta RP was obtained (i.e., observed – required RP), as well as between cycle SD of RP. The linear relationship of required RP (between 30° and 180° for the continuous scan and 45° and 180° for the discrete scan) as a function of delta RP was examined in reference to the gradient of the negative slope across the three testing sessions. Root mean squared error (RMSE) was also calculated to provide a general measure of performance. Analysis of variance techniques were used to compare performance across days and plateaus for the three groups in a 3 (Group) x 2 or 3 (Day) x 7 (Plateau: 0°, 45°, 60°, 90°, 120°, 135° & 180°) mixed ANOVA with repeated measures on the last two factors.

Learning Task

Continuous RP was calculated from the angular displacement data (see Experiment 2). As with the scanning data, RMSE was calculated and used as an overall measure of performance. Between cycle SD of RP, in addition to mean RP are reported where necessary to help elucidate on the locus of performance differences due to a bias to in-phase or anti-phase as a result of pre-existing coordination tendencies and/or the instructions.

Data in acquisition was analyzed in a Group (3) x Day (2) x Block (8) mixed ANOVA with repeated measures on the last two factors. Performance on the last two trials of acquisition was also compared to performance in delayed retention in a Group (3) x Condition (2) mixed ANOVA with repeated measures on the last factor. Similar analysis was conducted on the speeded trials comparing error and variability in RP across the various frequency plateaus. In addition, frequency histograms were constructed to illustrate the distribution of RP values across the groups as a function of increased speed. Finally, performance on the four transfer patterns was analyzed in a Group (3) x Pattern (4) mixed ANOVA, with repeated measures on the last two factors. All post-hoc tests were conducted using the Tukey HSD method, p < .05.
4.2.3 Results

4.2.3.1 Learning Task

Root Mean Squared Error

Acquisition

The average RMSE values as a function of acquisition are illustrated on the left side of Figure 4.1, along with between-participant standard error bars. Comparisons across the 2 days of practice showed main effects of day, $F(1,26) = 33.23$, $p<.001$ and block, $F(7,182) = 17.19$, $p<.001$, confirming that all groups improved with practice. Although there was no main effect for group, $F(2,26) = 1.93$, $p = .17$, there was a significant interaction of Group x Day x Block, $F(14,182) = 2.01$, $p = .02$. This interaction highlights the predicted difference in the rate of acquisition across the three groups. Most noticeably on day 1, the BI-IP group demonstrated a slower acquisition rate than the other two groups. On the last block of acquisition on day 1, the BI-IP group was significantly less accurate than the BI-NO group. The BI-AP group was not significantly different to either group. These differences remained at the start of acquisition on day 2, but were no longer significant by the end of acquisition (block 8).

Retention

There were no significant group effects, when performance in acquisition was compared to retention (R in Figure 4.1), $F<1$. This was despite the fact that the BI-IP group continued to show more error than the other two groups.

Transfer to New Patterns

Transfer performance to four different elliptical patterns was examined. Only a significant effect of pattern was observed, $F(3,75) = 61.23$, $p < .001$ which is shown on the right side of Figure 4.1. The $45^\circ$ pattern (i.e., the right ellipse) was performed with the most error, particularly by the BI-IP group, although the three-way interaction was not significant, $F(6,75) = 1.10$, $p = .37$. Both the $45^\circ$ and $60^\circ$ patterns (right ellipses) were performed with more error than the $120^\circ$ and $135^\circ$ patterns (left ellipses).

Increased Frequency Condition

Analysis of the performance data did not show any effects of increased movement frequency. This was primarily due to the fact that the participants were not moving at the required speed, which was evidenced by high constant errors in frequency. Specifically, at the
Figure 4.1  RMSE of goal relative phase (°) and between participant standard error bars for the three bi-stable groups (BI-N0 = no-instruction, BI-IP = in-phase instruction and BI-AP = anti-phase instruction) across the two days of acquisition and in retention (R) and transfer to four new relative phase patterns represented as elliptical shapes (45°, 60°, 120° & 135°).
fastest frequency (2 Hz), all participants were on average 0.59 Hz too slow. Additionally, many participants performed with high performance error even at the low frequencies such that increasing the speed to 2 Hz was not sufficient to elicit transitions in RP.

**Standard Deviation of Relative Phase**

**Acquisition**

The group effect approached conventional levels of significance, $F(2,26) = 3.18, p = .058$. The BI-NO and BI-AP groups generally showed more within-trial variability than the BI-fP group, which is displayed on the left side of Figure 4.2. There was also a significant day effect, $F(1,26) = 4.78, p = .04$ and a Group x Day interaction, $F(2,26) = 5.97, p = .007$. In accord with predictions, the BI-NO group was significantly more variable than the BI-fP group on the first day. On day 2 the difference between the groups was no longer significant. Only the BI-NO group showed a significant decrease in within-trial variability across the two practice days.

**Retention**

There were no significant effects.

**Transfer to New Patterns**

As illustrated on the right side of Figure 4.2, only a main effect for pattern was observed, $F(3,75) = 12.25, p <.001$. The 45° and 60° patterns were produced with more variability than the 120° and 135° patterns.

**Increased Frequency Condition**

Analysis of between-cycle variability yielded a significant movement frequency effect, $F(3,66) = 9.34, p <.001$, although there was no effect of group, $F<1$ and the Group x Speed interaction was not significant, $F(6,66) = 1.62, p = .16$. Variability at the fastest speed, 2 Hz ($M = 21.83°$), was significantly increased compared to 0.5 Hz ($M = 10.64°$), and 0.91 Hz ($M = 10.01°$). Variability at 1.25 Hz ($M = 16.16°$) was not significantly different to any of the other conditions.

**Relative Phase**

**Acquisition**

To determine the effects of both the instruction and initial coordination bias on the early process of acquisition, RP was examined during the first block of five trials (not illustrated). A
Figure 4.2 Within-trial SD of goal relative phase (°) and between-participant standard error bars for the three bi-stable groups across the two days of acquisition and in retention (R) and transfer to four new relative phase patterns represented as elliptical shapes.
significant effect for group was observed, F(2, 25) = 21.37, p < .001. The BI-NO group had an average RP of 99.51 ± 59.68°, due to high individual and within-group preference to produce patterns around the in-phase and anti-phase attractors, early in acquisition. In contrast, the two instruction groups showed a strong bias to perform around the anti-phase attractor only (BI-IP, M = 152.40 ± 12.01°; BI-AP, M = 151.98 ± 19.58°) coupled with markedly reduced within-group error.

The group means across the two days of acquisition are illustrated on the left side of Figure 4.3. When the two days of acquisition were analyzed, there was a significant effect of group, F(2,26) = 8.68, p = .001, day, F(1,26) = 7.02, p = .01 and block, F(7,182) = 6.61, p<.001, as well as a Group x Block interaction, F(14,182) = 3.77, p<.001. The BI-NO group (M = 109.66 ± 29.44°) was significantly different to the BI-IP (M = 142.83 ± 20.25°) and BI-AP (M = 133.42 ± 21.04°) groups. The differences between the groups was particularly pronounced on the first practice block.

Retention

The group effect was not significant, F(2,26) = 1.28, p = .29, although the BI-NO group continued to show mean RP within the vicinity of the required 90° RP pattern, as can be seen on the right side of Figure 4.3 (R).

Transfer to New Patterns

There were no significant group effects, only a significant effect for pattern, F(3,75) = 11.28, p<.001. For the 45° and 60° patterns the mean RP values were 103.07° and 113.12°, respectively. These were significantly different from the 120° and 135° patterns, where the average RP was 130.05° and 131.60°, respectively.

Increased Frequency Condition

From examination of individual subject data it was clear that some participants were showing deviations from the required RP as a function of movement speed and that these differences were somewhat dependent on group. In particular, a high proportion of participants in the BI-IP group were not performing the required RP at the low speeds, but rather were performing anti-phase biased movement. Any increase in variability noted for these groups was more likely due to destabilization of 180°, rather than 90°. Given that 180° is proposed to be
Figure 4.3. Mean relative phase (°) and between-participant standard error bars for the three bi-stable groups across the two days of acquisition and in retention (R), and transfer to four new relative phase patterns represented as elliptical shapes.
more stable than 90°, any deviations in RP, or fluctuations in observed RP, are likely to be due to the differential stability of the two patterns.

It was decided to look more closely at the distribution of RP within a frequency plateau, by dividing the RP values (every 100 ms) into 20 degree bins. From this analysis frequency histograms were produced for each group, based on mean percentage frequency of RP within each bin, for each speed plateau. Figure 4.4 a-c shows these distributions for the three bi-stable groups as a function of speed (0.5, .91, 1.25 and 2 Hz). What is most noticeable from these graphs is the poor performance of BI-IP (b) group, irrespective of frequency scaling. There was little evidence of a peak around the required 90° pattern for any speed requirement. The BI-NO group (a) showed evidence of a multi-stable landscape with peaks at 0°, 90° and 180°. However, as speed increased, the peak around 90° (between 80° and 120°) started to dissolve and the peak about 180° grew. Similar results were observed for the BI-AP group (c) although they were more consistent as the frequency requirements increased.

Learning Progressions

In Figures 4.5 – 4.8 sample data have been plotted for individuals in each of the three groups, to illustrate the learning progressions on the criterion task. The displacements of each arm were plotted orthogonally, to produce Lissajous figures. These data correspond to the feedback that participants received at the end of each trial in relation to the criterion circle pattern. Linearity in the data shows a bias to perform either in- or anti-phase movements, depending on the direction of the slope. A negative slope indicates an anti-phase bias, whereas a positive slope indicates an in-phase bias. Reading from left to right, top to bottom, the data from day 1, trials 1, 5, 20, 30 and 40 have been plotted, as well as the first trial on day 2 (trial 41) and trials 60 and 80 on day 2. The last plot corresponds to the first retention trial.

In the BI-NO group, data from participants # 47 and # 25 were plotted to illustrate two types of learning progressions for participants in this group. On the first five trials for participant # 47 (Figure 4.5), a strong anti-phase bias was evident, whereas participant # 25 showed a bias to perform more in-phase movements (Figure 4.6). For both participants, however, these tendencies were short-lived. By the middle of practice on day 1 (trial 20) participant # 47 was able to uncouple their limbs and perform circular patterns. This ability was particularly evident on day 2 and a week later in retention. By the middle of practice on day 1, participant # 25 also showed evidence of an anti-phase bias which remained throughout day 1, although the pattern was more
Figure 4.4  Frequency histograms for each of the three bi-stable groups (a = no-instruction, b = in-phase instruction, c = anti-phase instruction). Mean percentage frequency of relative phase for each relative phase bin (in degrees) is plotted as a function of each speed plateau (0.5, 0.91, 1.25 & 2 Hz).

a) BI-NO

b) BI-IP

c) BI-AP
Figure 4.5  Individual trial data across acquisition and in retention displayed as Lissajous figures for participant #47 from the BI-NO group.
Figure 4.6 Individual trial data across acquisition and in retention displayed as Lissajous figures for participant #25 from the BI-NO group.
Figure 4.7  Individual trial data across acquisition and in retention displayed as Lissajous figures for participant #55 from the BI-IP group.
Figure 4.8  Individual trial data across acquisition and in retention displayed as Lissajous figures for participant #41 from the BI-AP group.
elliptical (around 135° RP), rather than linear. This pattern became more circular during practice on the second day and in retention.

Data from one participant in the BI-IP group have also been plotted in Figure 4.7. Participant # 55 failed to learn how to uncouple their limbs to perform circular patterns, but rather continued to show a strong bias to anti-phase. This was despite the fact that instruction and movement demonstrations were provided throughout the two practice days. Finally, data from participant # 41 from the BI-AP group is illustrated in Figure 4.8. Again the anti-phase bias was clearly evident throughout practice and into retention for this participant. However, at least by the second half of practice on day 2, more circular type movements were also evidenced.

4.2.3.2 Continuous Scanning Task

Root Mean Squared Error

Performance across the three groups was analyzed pre-practice, during practice and after practice at the same seven task requirements examined in the discrete scanning task. In Figure 4.9 the performance of the bi-stable participants (indicated in solid lines) is plotted as a function of day and task requirement between 0° and 180° RP, every 30°. Although there was no significant effect of group, the Group x Day effect was significant, F(4,52) = 2.76, p = .037, and the Group x Day x Plateau interaction approached conventional levels of significance, F(24,312) = 1.49, p =.069. Only the BI-NO group reduced their error across the three days. The reduction in error for the BI-NO group was most marked between the 45° and 60° RP requirements.

Learning Progressions

Inspection of delta RP showed that the decrease in error across days was manifest as a decreased attraction to anti-phase across practice, rather than the development of a new attractor at 90°. To quantify these data, gradients and linear regression coefficients were calculated to describe the extent and linearity of the negative slope about 180° as a function of practice. The relation between error and required RP was examined at values between 30° and 180° RP (15° increments). These data are displayed in the top half of Table 4.2. The gradient of the regression line through 180° actually increased for the BI-IP and BI-AP groups across practice, but decreased for the BI-NO group.

The individual delta RP graphs as a function of practice day and task requirement are plotted in Figure 4.10, a-c. What is particularly noticeable from these graphs is that only participant # 20, in the BI-IP group (b) showed attraction to patterns between 45° and 135°
Figure 4.9 RMSE of goal relative phase (°) on the continuous scanning task for the three bi-stable groups and the two multi-stable groups from Experiment 4. Error is plotted as a function of required relative phase and practice (pre-practice, at the start of day 2 and post-practice in retention).
Table 4.2  Linear regression equations and coefficients of the relationship between required RP (x) and error (y) for the three bi-stable groups (Experiment 3) and the two multi-stable groups (Experiment 4) across days, for the continuous (30°-180°) and discrete scanning tasks (45°-180°).

<table>
<thead>
<tr>
<th>Task x Group</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>equation (°)</td>
<td>R²</td>
<td>equation (°)</td>
</tr>
<tr>
<td><strong>Experiment 3: Bi-stable</strong></td>
<td></td>
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<tr>
<td>Continuous</td>
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<td></td>
<td></td>
</tr>
<tr>
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<td>.86</td>
<td>-0.56x + 97</td>
</tr>
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<td>In-phase</td>
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<td>.93</td>
<td>-0.70x +123</td>
</tr>
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<td>.92</td>
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<td></td>
<td></td>
</tr>
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<td>.99</td>
<td></td>
</tr>
<tr>
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<td>.93</td>
<td></td>
</tr>
<tr>
<td>Anti-phase</td>
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<td>.98</td>
<td></td>
</tr>
<tr>
<td><strong>Experiment 4: Multi-stable</strong></td>
<td></td>
<td></td>
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<tr>
<td>Continuous</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>-0.60x + 84</td>
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<td>.69</td>
<td>-0.54x + 79</td>
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<tr>
<td>Instruction</td>
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<td>.97</td>
<td></td>
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</table>
Figure 4.10  Individual delta RP (°) graphs for the three bi-stable groups (a = no-instruction, b = in-phase instruction, c = anti-phase instruction) on the continuous scanning task as a function of required RP (°) across the three days (pre-practice, start of day 2 and post-practice in retention).
during or after practice on the continuous scan. This was evidenced by a negative slope through the task requirement of 135° on day 3. Indeed, one participant (# 28) developed an attractor around 0° (in-phase) after one day of practice, although this was modified on day 3. In contrast, 56% of the BI-NO participants showed evidence of an additional attractor in their dynamical landscape after practice at 90° which is shown in panel a. No participant showed an abrupt change in their landscapes across practice to evidence an immediate attractor at 90°. Participant # 25 showed decreased error between 105° and 135° on the second day and evidence of an attractor at 90° on Day 3. Participant # 47 showed multiple attractors, on day 3, around 30°, 75°, 100° and 180° RP. Two participants showed attraction around 45° (# 19 & # 3) and one person was attracted to 135° on day 3 (# 31). In the BI-AP group (c), 36% of the participants were attracted to new patterns after practice (# 2, # 48, # 51 & # 14). However, on the final day, only one participant showed a negative slope through 90° (# 14). The other three participants showed attraction close to the practiced pattern only on the second day (between 105° and 120° RP).

4.2.3.3 Discrete Scanning Task

Root Mean Squared Error

The discrete scanning trial data were analyzed pre-practice and post practice. RMSE as a function of day was plotted for the three bi-stable groups (solid lines) in Figure 4.11. Similar results to those observed for the continuous scan emerged. There were significant effects of day, F(1,24) = 16.49, p < .001 and plateau, F(6,144) = 216.75, p < .001 as well as a three-way interaction of Group x Day x Plateau, F(12,144) = 1.85, p < .05. On the first day there were no differences across the three bi-stable groups. However, by the end of practice the BI-NO group had decreased its error on the 45° and 60° patterns. The delta RP data failed to show evidence of an attractor at 90°, but did show a decrease in the slope of attraction through 180°. The gradients and linear regression coefficients across the two days for task requirements between 45° and 180° RP are displayed in Table 4.2. The slope of the regression line decreased from -0.88 to -0.62 for the BI-NO group. A small decrease pre to post practice was noted for the BI-IP group (-0.87 to -0.82) and the anti-phase participants also showed a reduction from -0.95 to -0.78. No participants in the BI-IP group evidenced attraction to any other patterns after practice and only one participant in the BI-AP group did (at 60° and 130°). In contrast, four participants in the BI-NO group showed attraction to patterns intermediate to 0° and 180°. However, only one showed a slope through the 90° attractor.
Figure 4.11  RMSE of goal RP (°) on the discrete scanning task for the three bi-stable groups and the two multi-stable groups from Experiment 4. Error is plotted as a function of required RP (°) and practice (pre-practice and post-practice in retention).
Although all participants in the bi-stable groups generally showed attraction to the anti-phase pattern before practice, the strength of attraction differed between participants. For example, some individuals showed a strong attractor through 180° for both types of scanning tasks, whereas others showed either a slower departure from 0° RP, or a plateau in the negative slope through 180°, such that attraction to 165°, in addition to 180°, was observed. Seven participants were classified as having a strong attractor at 180°. The average delta RP for both the discrete and continuous scans for these seven participants is plotted in Figure 4.12a along with between-participant standard error bars. Three of these participants were in the BI-NO group, and two in each of the other bi-stable groups. The acquisition data, which is plotted in Figure 4.12b, shows that the four participants in the bi-stable instruction groups displayed high error throughout acquisition (#39, #55, #23 & #30). In the BI-NO group one of these participants (#63) maintained high error in acquisition, but the other two participants, #10 and #77 showed a decrease in error across blocks.

4.2.4 Discussion

Instructions directing participants to build upon either anti-phase or in-phase coordination patterns in order to perform 90°, failed to benefit acquisition. Rather, the no instruction group showed the fastest rate of acquisition, especially compared to the BI-IP group. This is particularly interesting given that this group was only provided with summary feedback at the end of each trial. As evidenced from the variability and RP data, the BI-NO group was highly variable on the first day of practice and showed evidence of switching between the in- and anti-phase patterns early in practice. As argued elsewhere, this variability is an important feature for the acquisition of new coordination actions.

Instructions directing participants to the in-phase pattern were detrimental to acquisition. The BI-IP group, showed a slow rate of acquisition and continued to show high error in retention and transfer, in addition to showing very little change to their underlying coordination dynamics as a result of practice. Performance of the BI-IP group was linked to low variability in RP early in acquisition. It was predicted that in-phase instruction would hinder acquisition more than anti-phase instruction due to the increased inherent stability associated with in-phase. However, participants in this group, rather than showing attraction to in-phase, showed a strong bias to anti-phase coordination. It is proposed that the instructions encouraged participants to avoid symmetrical, in-phase movements, which subsequently limited variability in performance. This
Figure 4.12  In the top graph (a) the average delta RP (°) for both the discrete and continuous scans is plotted along with between-participant standard error bars for the seven participants who showed a strong attractor to anti-phase pre-practice. In the lower graph (b), the acquisition and retention performance data (RMSE) for these participants has been plotted.
avoidance of one behaviour created a strong bias to another stable behaviour (i.e., anti-phase). Some support for this hypothesis is found in the transfer data. Participants in the BI-IP group showed particularly high error for the 45° RP pattern, which required more symmetrical movements as compared to the other patterns. The high error for this group was probably due to avoidance of these in-phase type movements, although the Group x Pattern effect was not significant.

Contrary to the predictions, instructions did not facilitate transfer performance, even though participants were continually reminded to make comparisons between two different patterns. This elaborate processing has been proposed to aid transfer performance, due to a more developed and refined knowledge base (Shea & Zimny, 1983). Perhaps more extensive practice is required before advantages for this type of instruction will be observed. The anti-phase instruction, in particular, coupled with instruction concerning 90° RP would be expected to facilitate error detection procedures and subsequently retention and transfer performance. Given that the BI-AP group was not significantly different to the BI-NO group in acquisition and retention and on the speeded transfer task evidenced multi-stable dynamics, these instructions may have had at least a minimal effect.

On the scanning tasks conducted throughout practice, examination of the group means failed to elucidate on the development of additional attractors. However the BI-NO group decreased their error on intermediate phases between 30° and 90° RP, reflecting decreased attraction to anti-phase with practice. These findings show that changes to a participant’s underlying dynamics are observed as a function of practice on the criterion task. Individuals in both the BI-AP and BI-NO groups developed attractors at patterns intermediate to 0° and 180°. For the no-instruction group, there was some evidence to suggest that this process was more gradual than proposed in the literature (cf., Zanone & Kelso, 1997). Although an initial qualitative change was observed in the coordination dynamics to a multi-stable regime and appearance of an attractor at 45° or 135°, this appears to have been followed by a more gradual adaptation in the direction of the practiced pattern. For one of the participants in the BI-NO group, multiple attractors were evident on the final day. These findings may be a result of discrepancies between the learning and scanning task.

In the learning task, visual guidance was not provided, nor was visual feedback available on line. In this situation participants tended to produce patterns closer to 45° and 135°, rather than circle patterns early in practice, which may then transfer to low error on the scanning task at these requirements. The Lissajous figures for participant # 25, for example (Figure 4.6), supports
this suggestion. This participant produced elliptical patterns in the direction of the anti-phase pattern throughout practice on the first day, which accompanied evidence of an attractor at 135° on the scanning task at the start of practice on day 2. On the final day, this participant showed an attractor through 90° on the scanning task and was also able to produce well-defined circle patterns. The alternative conclusion is that participants learnt a general coordination ability which enabled them to discoordinate their limbs to produce a variety of RP patterns.

There was evidence that strong attraction to 180° was detrimental to acquisition and retention and that withholding instructions and movement demonstrations during practice may reduce this attraction. These results support findings from Experiment 2, where anti-phase biased participants in a demonstration-only group performed with more error than other anti-phase biased participants who were directed to goal-related feedback, or did not receive instruction. Directing attention from limb positioning and the movement itself may be an important strategy for participants who show strong biases to pre-practice movements. However the limited number of participants in this study who showed this attraction, coupled with the fact that one of the non-instructed participants also showed a slow rate of acquisition prevents conclusions from being made.

It is worth remarking on the fact that participants in this study were attracted to anti-phase coordination on the scanning task pre-practice, rather than in-phase. This result was contrary to the findings from Experiment 2 where only half of the participants showed this pattern of behaviour. The difference between these studies was the addition of a discrete scan prior to administration of the continuous task, where participants previewed each trial before performance. This procedure presumably encouraged participants to perform anti-phase movements, such that when transferred to the continuous scanning task a change in the light sequence from simultaneous flashing prompted an early switch to anti-phase. This supports findings from a recent reliability study conducted by McGarry et al. (2000). It was found that performance on repeated probes under the continuous scanning procedure did not result in consistent performance from trial to trial, even though no practice was undertaken between scans.

In conclusion, instructions that directed participants to build upon pre-existing stable behaviours to produce new movement patterns did not facilitate acquisition or retention. It was the BI-IP group who was most affected by the manipulations, although on the scanning tasks after practice the BI-AP group also failed to show a significant decrease in error. It is proposed that instructions which specify how a movement should be performed promote movement
consistency early in practice, such that individuals are faced with considerable difficulty breaking from stable, pre-practice behaviours. Augmenting this instruction with information that alerted participants to these interfering behaviours did not decrease the bias, but may have increased the competition between the intrinsic dynamics and the new task requirement.

According to Zanone and Kelso (1994, 1997), a qualitative change is needed to break from stable, pre-practice behaviours which is accompanied by high variability in RP. If individuals show evidence of additional attractors other than in- and anti-phase pre-practice, learning is proposed to be more gradual. High variability in RP would not be required to break from stable behaviours, far from the task requirement. Rather, only a refinement of an existing pattern would be needed. Therefore the purpose of the following experiment was to test the predictions from Experiment 3 with participants categorized as multi-stable pre-practice.

4.3 Experiment 4

4.3.1 Introduction

In Experiment 3 it was predicted that high levels of movement variability would be required during the initial stages of skill acquisition to facilitate the break from pre-existing coordination biases. Support for this hypothesis was subsequently demonstrated. However, if individuals show a preference to move in patterns other than in- and/or anti-phase prior to any practice manipulations this high variability would not be a requirement for the acquisition of 90° RP. Rather, a gradual refinement of the pre-existing movement pattern would be expected. Due to the increased coordination capability for participants who can discoordinate their limbs before any practice manipulations, less difficulty might be experienced understanding and using the movement demonstrations to produce the required movement pattern.

It was predicted that instructional provision would benefit acquisition for participants who demonstrate multi-stable dynamics, since only a parametric (i.e., quantitative) adjustment of an existing attractor would be expected to be required, rather than a break from stable competing patterns, far from the task requirement. Given that the two sources of information were still somewhat competitive (i.e., pre-existing bias plus the required pattern) and that demonstrations promote more anti-phase type movements, the alternative hypothesis was not discounted. That is, even when participants show the ability to dissociate their limbs before practice, instruction that builds upon existing behaviours could be detrimental to acquisition and retention. These predictions were tested in the following study.
Two groups were compared who were randomly assigned into either an instruction group, where they were shown how to perform the required RP and alerted to their pre-practice bias, or a no-movement-instruction group. Although Zanone and Kelso (1997) did not report differences in rate of acquisition across multi-stable and bi-stable participants, there was theoretical reason to suppose that acquisition rate would generally be improved for the multi-stable participants. If patterns intermediate to 0° and 180° are less stable than in- and anti-phase, the competition between the task requirements and the existing pattern dynamics were expected to be reduced, thus leading to more rapid learning. Due to the decreased distance in parameter space between the to-be-learned pattern (i.e., 90°) and the pre-existing pattern, learning rate was expected to be enhanced (Zanone & Kelso, 1994). For example, if participants showed attraction to either 135° or 45° RP pre-practice a difference of only 45° RP would be observed between the required pattern and the initial bias, as compared to a difference of 90° if attraction was shown towards either 0° or 180° RP pre-practice.

4.3.2 Method

4.3.2.1 Participants

Based on performance on the scanning trial (see Participants section, Experiment 3) participants were randomly allocated to either a no instruction (MULTI-NO), or an instruction group (MULTI-INS). Thirteen participants showed preference to an intermediate pattern other than 90° RP. There were six participants in the MULTI-INS group and seven participants in the MULTI-NO group. In Table 4.1, group allocation as a function of age, bias and gender is detailed.

4.3.2.2 Task and Apparatus

The apparatus and tasks were the same as in Experiment 3.

4.3.2.3 Instructional Manipulations

The instructions were provided in the same format and order as in Experiment 3. The instruction concerning initial coordination bias was provided on four videotapes that showed a model performing one of four different coordination patterns; 45°, 60°, 120° and 135° RP. The starting positions of the arms were first illustrated, followed by a 15 s demonstration of one of the patterns. The right arm was always at maximum flexion and the left arm was at one of four positions between maximum flexion and extension. After this initial demonstration, participants
were shown how to produce the circle pattern and the difference between the two patterns in terms of the lead-lag relationship between the arms was described.

4.3.2.4 General Instructions and Procedure
The general procedures were the same as those used in Experiment 3.

4.3.2.5 Data Analysis
The same analyses as were conducted on the data from Experiment 3 were used here, except there were only two levels of the between groups factor.

4.3.3 Results

4.3.3.1 Learning Task

*Root Mean Squared Error*

*Acquisition*

The data for the multi-stable participants is illustrated on the left side of Figure 4.13. Although the no-instruction group showed less error than the instruction group, especially on the second day, neither the group, F(1,11) = 2.19, p = .17, nor Group x Day effect was significant, F(1,11) = 3.25, p = .10. Only significant effects of day, F(1,11) = 9.08, p = .01 and block, F(7,77) = 9.24, p<.001 were observed.

*Retention*

There were no significant differences in retention across the two groups, F(1,11) = 1.92, p = .19, although the MULTI-INS group continued to show elevated levels of error in retention as compared to the MULTI-NO group.

*Transfer to New Patterns*

The main effect of group approached conventional levels of significance, F(1,10) = 4.89, p = .05. The MULTI-NO group generally evidenced more error than the MULTI-INS group. There was also a significant pattern effect, F(3,30) = 61.85, p <.001 and a Group x Pattern interaction, F(3,30) = 7.53, p <.001. All participants had more difficulty producing the rightward slanting elliptical shapes that required phase offsets of 45° and 60° as displayed on the right of Figure 4.13. The interaction effect was due to the fact that the MULTI-NO group had the most
Figure 4.13  RMSE of goal RP (°) and between-participant standard error bars for the two multi-stable groups (MULTI-NO = no-instruction, MULTI-INS = instruction) across the two days of acquisition and in retention (R) and transfer to four new relative phase patterns represented as elliptical shapes (45°, 60°, 120° & 135°).
trouble performing these patterns, although the differences across the groups were significant for the 45° pattern only.

**Increased Frequency Condition**

There was no main effect for group, $F(1,10) = 2.77, p = .13$, but the Group x Speed effect was significant, $F(3,30) = 3.36, p = .031$. The no-instruction group showed significantly less error ($M = 34.70 \pm 13.84°$) than the instruction group at the 0.5 Hz speed ($M = 65.63 \pm 14.48°$). Due to the high error of the instruction group, irrespective of speed, only the no-instruction group showed an increase in error as a function of increased speed (0.5 Hz was significantly different from 1.25 Hz, $M = 52.51 \pm 21.85°$).

**Standard Deviation of Relative Phase**

**Acquisition**

The within-trial variability data across the two days of practice is displayed in Figure 4.14. Although the no-instruction group was generally more variable than the instruction group, especially during the early blocks of practice, there were no significant differences across the two groups, $F(1,11) = 2.04, p = .18$.

**Retention**

There were no significant group effects in retention.

**Transfer to New Patterns**

All participants showed high levels of variability on the 45° and 60° patterns as evidenced by a main effect for pattern, $F(3,30) = 10.27, p<.001$ which is illustrated on the right side of Figure 4.14. None of the group effects were significant.

**Increased Frequency Condition**

Only a significant effect of speed was observed under increased frequency conditions, $F(3,30) = 4.04, p = .02$. Movement variability increased as the required movement speed increased from 0.5 Hz ($M = 11.68°$) to 0.91 Hz ($M = 18.66°$). It then decreased at 1.25 Hz ($M = 9.77°$) and increased again at 2 Hz ($M = 23.30°$). Post hoc analysis showed that the 2 Hz condition was significantly more variable than the 0.5 Hz and 1.25 Hz conditions.
Figure 4.14  Within-trial SD of goal RP (°) and between-participant standard error bars for the two multi-stable groups across the two days of acquisition and in retention (R) and transfer to four new relative phase patterns represented as elliptical shapes.
Relative Phase Acquisition

Performance across the first five trials was examined to ascertain whether the instructions encouraged the groups to approach the task in different ways. A significant effect of trials was observed, as well as a Group x Trial interaction, $F(4,44) = 2.91, p < .05$. On the first trial the no-instruction group had a mean RP of $37.75 \pm 48.69^\circ$, which was significantly different to the instruction group, $M = 126.21 \pm 54.96^\circ$. Only the no-instruction group showed a significant increase in RP across the first few practice trials. The RP data as a function of Day and Block is depicted on the left side of Figure 4.15 along with between-participant standard error bars. There was a main effect of group, $F(1,11) = 5.24, p < .05$ and a Day x Block interaction, $F(7,77) = 4.35, p < .001$. The average RP for the no-instruction group was $112.14 \pm 22.55^\circ$, whereas for the instruction group the average was $133.79 \pm 25.03^\circ$. On the first day there was a general increase in RP after the first practice block, that started to decrease again after block 5. On the second day there was a significant decrease in RP across the first two practice blocks only.

Retention

The group effect failed to reach significance, $F(1,11) = 3.23, p = .10$. The no-instruction group, however, continued to show mean RP values closer to the required $90^\circ$ RP pattern ($107.14^\circ$ as compared to $124.46^\circ$ for the MULTI-INS group).

Transfer to New Patterns

On the far right of Figure 4.15, the RP means for the transfer data are plotted. A significant effect for group and pattern was observed, as well as a two-way interaction, $F(3,30) = 5.76, p = .003$. Only the instruction group showed a reduction in mean RP when attempting to produce the $45^\circ$ and $60^\circ$ pattern as compared to the $120^\circ$ and $135^\circ$ patterns.

Increased Frequency Condition

As with the data from Experiment 3 (see Figure 4.4), frequency histograms were examined to ascertain how the RP distributions differed as a function of group and speed. These are illustrated in Figure 4.16 (a & b). With increased speed, the no-instruction group depicted in the top panel developed a more pronounced peak around the anti-phase attractor, as well as a slight peak between $40^\circ$ and $80^\circ$ RP. In contrast, the instruction group shown in the bottom panel
Figure 4.15  Mean RP (°) and between-participant standard error bars for the two multi-stable groups across the two days of acquisition and in retention (R) and transfer to four new relative phase patterns represented as elliptical shapes.
Figure 4.16  Frequency histograms for the two multi-stable groups (a = no-instruction, b = instruction). Mean percentage frequency of relative phase for each relative phase bin is plotted as a function of speed plateau (0.5, 0.91, 1.25 and 2 Hz).

a) MULTI-NO

b) MULTI-INS
showed very little evidence of attraction to patterns other than 0° and 180°, irrespective of the speed requirements.

**Learning Progressions**

Similar to Experiment 3, sample data have been plotted in Figures 4.17 – 4.20 from four participants, to illustrate performance in relation to the task goal. In the no-instruction group the data from participants #68 (Figure 4.17) and #67 (Figure 4.18) are illustrated. These participants were classified as showing a bias to 45° and 135°, respectively. Participant #68 evidenced a strong in-phase bias on the first practice trial and also showed a bias to 45° RP pre-practice. Participant #67 initially showed this same in-phase bias. For both participants this bias was short-lived, at least in terms of performance on trial 5 where both participants produced circular type patterns. Thereafter, participant #67 continued to produce more circular type movements, whereas participant #68 evidenced a strong bias to anti-phase for the remainder of practice trials on day 1. This bias was still evident on the second day and in retention, although the pattern was more circular.

Participant #54 in the instruction group was also classified as showing a bias towards 45° RP on the scanning trial pre-practice, whereas participant #60 showed a bias to 135°. Similar to the two participants in the no-instruction group, participant #54 also performed in-phase biased movements on the first practice trial which is illustrated in Figure 4.19. By trial 5 this participant produced more elliptical shapes, but now in the direction of the anti-phase pattern. Although by the end of practice on day 1, this participant was able to produce circular patterns, they had regressed back to performing anti-phase biased movements on day 2 and more noticeably one week later in retention. Participant #60 whose data are shown in Figure 4.20, was biased to 135° pre-practice and showed a bias in the direction of this pattern, although closer to anti-phase, throughout practice and in retention. Not until the middle of the second day of practice did this participant begin to produce more circular type movements.

**4.3.3.2 Continuous Scanning Task**

*Root Mean Squared Error*

The performance of the multi-stable participants on the continuous scan, across the three testing days is displayed in Figure 4.9 to enable comparisons with data from Experiment 3. There was no significant difference between the multi-stable groups. The pattern of errors did not change as a function of practice.
Figure 4.17  Individual trial data across acquisition and in retention displayed as Lissajous figures for participant #68 (initial 45° bias) from the MULTI-NO group.
Figure 4.18  Individual trial data across acquisition and in retention displayed as Lissajous figures for participant #67 (initial 135° bias) from the MULTI-NO group.
Figure 4.19 Individual trial data across acquisition and in retention displayed as Lissajous figures for participant #54 (initial 45° bias) from the MULTI-INS group.
Figure 4.20 Individual trial data across acquisition and in retention displayed as Lissajous figures for participant #60 (initial 135° bias) from the MULTI-INS group.
Learning Progressions

On inspection of the average group delta RP no attraction to 90° was evidenced in this data during or after practice. The linear regression equations and coefficients are detailed in the bottom half of Table 4.2. Both groups showed an increase in the slope of the regression line as a function of practice. For the instruction group, the zero crossing was at 120° RP pre-practice (coupled with low error at 15° and 30° RP), but shifted to about 150° RP post-practice, away from the task requirement. The no-instruction group showed a small zero crossing through 180° RP before practice, but after practice on the second day a zero crossing between 135° and 150° RP was observed, although this did not remain in retention.

In terms of individual performance, which is illustrated in Figure 4.21, 3 of the 7 non-instructed participants (a) showed strong attraction to 90° after practice (#76, #67 & #13) as evidenced by a negative slope through this task requirement. In addition, one participant showed attraction to 70° on day 3, showing a progression from 45° to 60° across the first two days (#68). Only 1 participant in the instruction group evidenced attraction to 90° as a function of practice at this pattern (#54).

4.3.3.3 Discrete Scanning Task

Root Mean Squared Error

In Figure 4.11, the performance of the multi-stable participants on the discrete scan is illustrated pre and post practice. Although the instruction group showed an increase in error post-practice, the difference between the groups was not significant. No attraction through 90° RP was noted as a function of practice when the group data for delta RP was examined. However, the instruction group showed increased slope in the regression line through 180° as a function of practice (-0.66 to -0.81), whereas the slope remained relatively unchanged for the no-instruction group (-0.63 to -0.61). The full regression equations and regression coefficient values (R^2) are displayed in the bottom half of Table 4.2. In terms of individual performance errors, 3 of the 7 participants in the no-instruction group showed attraction to 90° after practice (#s 67, 68 & 76) whereas only one participant in the instruction group showed any evidence of an attractor through 90° after practice (#72).

Strength of Attraction and Learning

Six participants were attracted to patterns between 45° and 60° RP prior to practice, particularly on the continuous scanning task; four in the no instruction group (#76, #56, #68 &
Figure 4.21 Individual delta RP (°) graphs for the two multi-stable groups on the continuous scanning task (a = no-instruction, b = instruction) as a function of required RP (°) across the three days (pre-practice, start of day 2 and post-practice in retention).
# 59) and two in the instruction group (# 65 & # 54). An additional two in the instruction group evidenced a negative slope through the in-phase attractor, but were classified as showing attraction to 135° due to low error and evidence of a zero crossing through this task requirement (# 60 & # 72). Finally, five showed attraction to patterns between 120° and 135° RP, in addition to 180°, three in the no-instruction group, (# 67, # 11 & # 13) and two in the instruction group (# 66 & # 7). The delta RP means are illustrated in Figure 4.22, panel a, for both the continuous and discrete scans. The two participants who showed attraction to in-phase (0°), coupled with attraction to 135° showed the most error in acquisition and retention. These data are displayed in Figure 4.22, panel b. The six participants who showed attraction to patterns between 45° and 60° evidenced poorer performance than the five who were only attracted to patterns between 120° and 135°. However, inspection of RP failed to show evidence of attraction to more symmetrical type movements around in-phase, as might be expected if 0° and 45° interfered with production of 90° during and after practice.

4.3.4 Discussion

Contrary to the predictions, instructions specifying how to perform a new coordination pattern, accompanied with information specifying pre-practice bias, did not facilitate acquisition or retention performance. Rather, the instruction group generally showed poorer performance in acquisition and retention. Zanone and Kelso (1997) proposed two routes to learning depending on initial coordination dynamics. If an individual shows attraction to a pattern intermediate to in- and anti-phase, such as 45° RP, a gradual adjustment of that pattern in the direction of the newly required pattern, e.g., 90°, was proposed. Rather than a break from an early stable behaviour, the individual would be able to build-upon this existing pattern to perform 90°. Despite this prediction there was no benefit to instruction that alerted individuals how to adapt a pre-practice behaviour to produce the newly required movement pattern. Participants in the instruction group generally showed more difficulty performing the new coordination pattern than the non-instructed participants. In retention, a greater proportion of the non-instructed participants showed some attraction to 90° post-practice (57% versus 33%) and showed less attraction to 0° and 180° when performance was assessed on the speeded task. These findings lead to the suggestion that the instructions interfered with the acquisition process, arguably enhancing the competition between pre-existing and required states.
Figure 4.22 In the top panel, a) the delta RP means (°) are shown for both the continuous and discrete scans pre-practice as a function of attraction (120° - 135°, 0° & 135° or 45° - 60°). In the lower panel, b) RMSE of goal RP (°) in acquisition and retention for the multi-stable participants as a function of attraction is plotted.
There was some evidence that the type of pre-practice bias was related to acquisition performance within the multi-stable groups. The two participants who showed attraction to in-phase, coupled with attraction to 135° showed the most error in acquisition and retention. These two participants also received instruction informing them of attraction to 135° and how to refine this to produce 90°. Either this instruction produced considerable difficulties in learning or, like the other participants who were attracted to patterns around 45°, the stability of nearby attractive states continued to interfere with performance. Inspection of the RP data failed to show evidence of attraction to more symmetrical movements.

In Experiment 2 (chapter 3), participants biased to in-phase on the scanning task showed slower rates of acquisition and poor performance in retention when feedback was removed. Again errors on the learning task were in the direction of the anti-phase pattern. Based on this finding it was suggested that the scanning task assessed general coordination ability and that perseverance with one type of pattern (i.e., more symmetrical type movements), as the task demands suggested otherwise, was indicative of poor coordination ability. Participants in this study who were biased to more symmetrical type movements may have also faced difficulty adapting to changing task conditions. Even though there was evidence of some decoupling of the limbs pre-practice (leading to classification as multi-stable), this may have been due to individual asymmetries between the arms, causing greater lead-lag relations, rather than a general coordination advantage (see for e.g., Treffner & Turvey, 1995).

4.4 General Discussion

The findings from these two studies were partially in line with the predictions, particularly concerning the performance of the bi-stable participants. Instructions directing participants to build upon either anti-phase or in-phase to perform 90° failed to benefit acquisition and instructions directing participants to the in-phase pattern hindered acquisition rate. It was predicted that in-phase would slow learning more than anti-phase due to the inherent stability of in-phase. However this instruction did not create a performance bias towards in-phase, but rather a strong bias towards anti-phase was observed. It was hypothesized that the instructions encouraged participants to avoid symmetrical, in-phase movements, which limited variability in performance. The instruction groups in both experiments showed a greater bias to anti-phase than the non-instructed groups, but this bias was particularly pronounced for participants who received the in-phase instruction.
It was also predicted that participants showing multi-stable dynamics pre-practice would benefit from instructions that directed them to build upon existing abilities to produce a new pattern. Contrary to these predictions the MULTI-INS participants showed more error in acquisition and retention than the MULTI-NO participants. The MULTI-NO group performed in a similar manner to the BI-NO group in Experiment 3. More specifically, the performance of the non-instructed participants in both experiments was accompanied by high variability in within-trial performance during the early practice trials. As has been argued elsewhere, this variability is necessary to break from stable pre-practice behaviours. Even though the multi-stable participants showed ability to dissociate their limbs on the scanning task before practice, without visual guidance in the learning task, this ability may have been reduced. The participants were not able to use the information relayed by the demonstration, because neither the required response, nor initial bias to an intermediate attractor was sufficiently developed. Subsequently, the anti-phase pattern continued to compete with acquisition of 90° and high variability was required to break from this pattern.

Based on these findings, there was little evidence to suggest different learning rates as a function of multi-stable dynamics, or differences in ability before practice. The MULTI-NO group approached the learning task in a similar way to the BI-NO group in Experiment 3, although they showed less bias to anti-phase early in skill acquisition. Either differences between individuals, with respect to attractor layout before practice, do not differentially affect the rate and process of acquisition, at least for the criterion/learning task, or the scanning tasks were poor predictors of performance on the learning task. Given that, in the learning task, environmental information specifying RP was no longer available, the competition from stable attractors such as anti-phase may have been enhanced and the ability to dissociate the limbs and show attraction to other patterns decreased. This is true because bias was not always determined by the appearance of a strong negative slope through a particular task requirement pre-practice.

In dynamical systems' terminology, the forcing constraints on the scanning tasks and the learning task were different leading, at least, to quantitative differences in performance. This would be a result of the strength of the behavioural information afforded, or not afforded, by the environment in each situation. In the scanning tasks, the required pattern was prescribed by flashing squares, whereas the learning task was non-prescriptive, instead providing information only as to errors and not how to correct them. Perhaps a better method for evaluating multi-stable dynamics and thus examining learning would be to allow participants to practice 45° or 135° on the learning task until attraction at the practiced pattern was observed on the scanning task. At
this point, the instruction manipulation could be administered to teach the 90° pattern. In this way all participants would be familiar with the task, which may be an important requirement for instructions to be effective, in addition to showing strong attraction to a pattern intermediate to 0° and 180° before the manipulation. Indeed, after two days of practice the MULTI-INS group showed an advantage in transfer, at least for the 45° and 60° patterns, as compared to the MULTI-NO participants.

The transfer results were the only ones that contrasted with the findings from the bi-stable participants in Experiment 3. There were no significant differences in transfer for the bi-stable participants, although the BI-IP group displayed the most error when asked to make a rightward slanting, elliptical shape (i.e., 45° RP). For the multi-stable participants, irrespective of initial bias (to 45° or 135° for example) and therefore the type of instruction received, the instruction group outperformed the no-instruction group in transfer to both the 45° and 60° patterns. Rather than a motor advantage, especially given the better performance of the non-instructed group on the discrete scanning task at the same RP requirements, some sort of cognitive advantage was likely provided. The instruction group would have been more aware of additional patterns in light of the repeated instruction and demonstrations that alerted them to intermediate patterns. The non-instructed participants who showed proficiency on the learning task, could have experienced difficulty breaking from this pattern and subsequently evidenced some negative transfer, as a result of increased stability at 90°. However, the same disadvantages were not observed for the bi-stable participants who also showed decreased error in acquisition and retention on the criterion/learning task.

In practical situations, instructions are often provided that build upon past behaviours to facilitate the acquisition of new skills. Given that the instructions in this study failed to yield performance benefits for both the bi-stable and multi-stable participants and were somewhat detrimental to learning, this method of instruction is brought into question. The competing nature of the two sources of information is likely to be important. Providing instruction that makes both the required and existing movements explicit would serve to increase this competition between the two patterns and thus cause interference in both acquisition and retention. It remains to be seen whether instruction concerning only the required RP would have produced similar effects for the multi-stable participants as those observed for bi-stable participants in earlier studies (i.e., Experiments 1 & 2, chapters 2 & 3).

Only the bi-stable participants decreased their variability in RP across the two days and were more variable than the multi-stable participants on the first day of practice. Although this
increased variability on the first day for the bi-stable participants, as compared to the multi-stable participants, was predicted from theory, why this variability increased for the multi-stable participants across practice is not clear. Given that variability suggests unresolved competition between the underlying dynamics and the behavioural (i.e., environmental) information, this finding might reflect the difficulty in replacement of pre-existing intermediate attractors with new ones. Perhaps a consequence of a more articulated dynamical landscape (i.e., multi-stability) is high levels of variability when the individual intends to produce only one of these patterns. This would be caused by increased interference from attractor regions close to the task requirement in parameter space. Due, to the decreased stability of these regions, interference between patterns would be increased. This interference, as a result of decreased stability, was also proposed to be the reason behind regressions to anti-phase type movements, rather than in-phase, when the test conditions increased in difficulty (e.g., withdrawal of feedback in Experiments 1 and 2 and addition of a secondary task in the initial investigation).

For participants who developed attractors between 0° and 180° in the BI-NO group, the acquisition process appeared to be more gradual than suggested in the literature (cf. Zanone & Kelso, 1992, 1994, 1997). Low error and/or attraction at 45°, 60°, or 135° RP prior to attraction at 90° suggests an ability of the participants to partially dissociate their limbs and break from competing intrinsic attractors. Again this is likely to be related to the differences between the criterion task and the scanning task where practice at these intermediate patterns may have been gained. For example, participant # 25 (see Figure 4.6) showed in-phase biased movements on the first practice blocks (i.e., rightward slanting elliptical shapes) followed by anti-phase biased movements for the remainder of trials on day 1 (i.e., leftward slanting). These patterns preceded the circular shapes evidenced on the second day of practice and in retention.

For the multi-stable participants there was some evidence to suggest that adjusting the 135° attractor to perform 90° was easier than adjusting the 45° attractor to perform 90° RP. These findings might be predicted theoretically if one assumes that attraction and performing 120° or 135° would be easier than showing attraction to and performing 45° or 60°. This would be due to the decreased competing influence of the less stable anti-phase pattern, rather than in-phase (see Zanone & Kelso, 1994). However, because RP failed to show competing influence from in-phase for these participants, this interpretation is speculative. Again given the difference between the learning and scanning tasks, further experiments are needed to examine this prediction using the same task throughout.
These results suggest that it may be better to avoid instructions and demonstrations when learning novel motor skills. Obviously, instructions have an important role to play in motor skill acquisition, not least because they are useful for relaying the task goal to the learner. However in the series of studies reported in this thesis, caution is recommended in their usage, particularly in the early stages of acquisition. As long as feedback is provided that relates performance to the task goal, it may be preferable to leave the learner to explore and familiarize him or herself with the task before instructions are given. When they are provided, emphasis on pre-practice behaviours should be minimized.

Demonstrations that relay a skill that is not already part of an existing movement repertoire (or at least not a well-developed component) may serve to inadvertently increase attraction to other habitual type behaviours, or lead to a consistent bias to one type of movement, rather than another. This would cause a decrease in movement variability and subsequently inhibit the discovery, or production of new movement patterns. Further experiments are needed to discover strategies that reliably facilitate acquisition of novel motor skills. In Experiment 2, instructions and demonstrations which additionally focused attention onto the task goal and the effects of the movement were found to decrease the harmful effects associated with providing just a demonstration of the required movement. However, the only advantages observed over a group who did not receive instruction was in retention when task-goal feedback was removed (which was provided on-line throughout acquisition). In Experiments 1 and 2 visual feedback was shown to play an important role in mediating the learning process for new coordination skills (see also Swinnen et al., 1993). Generally, feedback which informs as to the degree of coupling between the limbs, in non-complex ways, is particularly beneficial to acquisition, acting to decrease the competition from underlying stable behaviours. As long as the learner is aware that an error has been made, is sufficiently aware of the constraints of the task and attempts new behaviours as a result of this information, then this type of feedback may be sufficient to promote acquisition of a new motor skill.
The experiments explored how instructions and movement demonstrations affect the process of acquisition when learning a novel coordinative action. They were designed to examine the early stages of skill acquisition and to determine how existing behaviours become adapted or modified during the acquisition process as a result of instructional manipulations. The methodology adopted to examine these questions provided a unique opportunity to examine learning in comparison to pre-existing behaviours, which have been shown to compete with acquisition of bimanual skills. Written and verbal instructions, in addition to movement demonstrations, were manipulated that informed as to the correct way to move the arms to achieve a particular task goal.

In Experiment 1, feedback was also manipulated to examine how the task environment mediated the effectiveness of movement demonstrations. In Experiment 2, the instructions were designed to manipulate attentional focus to gain some insight into the mechanism underlying instruction effects, specifically the detrimental consequences associated with instructional provision. Finally, in Experiments 3 and 4, differences in initial coordination ability, as well as information concerning pre-practice behaviours, were examined to determine whether past behaviours can be built upon to acquire new ones and whether the differential stability of earlier behaviours impacts on the effectiveness, or ineffectiveness of these instructions.

It was found that pre-practice information affected the process of acquisition. This was most noticeable when feedback was only provided at the end of each practice trial, as compared to during the trial. These effects were manifest as differences in initial preference to either in- or anti-phase movements and early within-trial variability in performance. In the initial investigation, the cognitive demands associated with acquiring and maintaining a new coordination pattern were demonstrated. Secondary task conditions prevented acquisition (at least over the experimental period examined) and interfered with performance of an instruction group in retention. A second instruction group demonstrated difficulties both in acquisition and retention, irrespective of additional secondary task manipulations.

In Experiment 1 visual demonstrations and verbal instructions were provided, rather than written instructions, but similar disadvantages were observed (although secondary task manipulations in retention did not interfere with performance as a result of pre-practice information). No advantages were found when the task feedback was made more explicit by providing information concerning the exact displacements of the limbs and as such increasing
the compatibility of the feedback with the pre-practice information. However the feedback was still arguably quite complex, such that any interactions between feedback and pre-practice information would be masked.

To examine the mechanism behind these instruction and feedback effects, attentional focus was manipulated in Experiment 2. The task instructions directed participants to focus on either the effects of the action (the feedback), or the relation between the movements of the limbs and the feedback. Although attention-focusing instructions onto the effects of the action generally decreased any negative effects associated with the provision of only movement demonstrations, benefits of this instruction were only apparent in immediate, no-feedback retention tests (when performance was compared to a non-instructed control group). Processing of sensory feedback was implicated as the mechanism responsible for the effects of attentional focus and instructions. An additional finding of interest was that in-phase biased participants, as assessed on a pre-practice scanning task, showed a slower rate of acquisition than anti-phase biased participants and were adversely affected by the removal of feedback in retention. The fact that all participants made errors in the direction of the anti-phase pattern, both early in acquisition and later in practice, led to the conclusion that these differences were not due to the differential stability of in- and anti-phase, but rather general differences in coordination ability.

In Experiments 3 and 4, instruction concerning these pre-existing behaviours was manipulated to examine how instruction that builds upon these behaviours to acquire new coordination patterns affects acquisition. In Experiment 4, individuals who could de-couple their limbs pre-practice were examined to discover whether differences pre-practice would be sufficient to warrant different instructional manipulations. Based on findings by Zanone and Kelso (1997), suggesting different routes to learning, it was predicted that gradually adjusting an existing pattern, other than in- or anti-phase, to acquire 90° would benefit from instruction. Despite this prediction, irrespective of initial bias, instructions that alerted to pre-practice behaviours and how to adjust these to perform the required movement did not benefit either acquisition or retention. In fact, across both studies, there was evidence in favour of withholding these instructions, even though feedback was only provided at the end of each trial.

Until now the results of these studies have been discussed separately, with discussion sections pertaining to each experiment. In this final chapter an attempt is made to bring the findings together to present a coherent picture of the results and address the implications for theory and past and future research. Some pertinent issues are examined that relate to feedback and visual information, variability in the early stages of acquisition, individual differences,
attentional demands, the task itself and potential problems and limits of the methods adopted in this thesis. The first section addresses issues related to the methods used in these studies and the second section discusses theoretical issues, although there are many instances where the two are dealt with concomitantly.

5.1 Methods

5.1.1 The Bimanual Coordination Task: Advantages and Limits

There are many reasons to suspect that the tasks used in these experiments provide a good analogue of real world learning situations. The learner is required to break from pre-existing movement patterns, or habits, to learn a new movement and these play a critical role in influencing the acquisition of new skills. Fitts and Posner (1967, p19) ascribed a primary role to habits in influencing the development of new movement skills when they claimed that “For the most part new skills are built out of already existing skills.” In this task, the learner is required to acquire a new coordination movement, not just a rescaling of an already existing movement. Therefore both spatial and temporal coordination is required, in addition to perceptual-motor coupling. Given that motor skills often comprise many interacting components, such as the legs and arms, interlimb coordination methodologies are expected to be particularly informative with respect to how more complex skills are acquired and maintained.

The problem of coordination is ubiquitous to the learning of sport skills, from the highly complex such as a somersault, to the relatively simple, such as throwing a ball. Not only is the task expected to generalize to learning situations outside of the laboratory, but this methodology also lends itself nicely to controlled, experimental study within the laboratory. This task allows efficient manipulation of variables related to pre-practice information, given the fact that individuals cannot perform the task before practice. The format provides easy measurement of pre-practice performance, which is important when making conclusions about the process of learning and what has been learned. Despite these advantages, limits of the experimental design have to be considered such that reliable generalizations can be made.

The fact that the movement pattern is the goal of the task, puts this task into a special category that has sometimes been defined as a ‘closed skill’ (e.g., Gentile, 1972). Closed skills, in contrast to open skills, do not have different solutions available for solving the motor task. Whether findings generated from these types of tasks are equally applicable to skills that are not constrained by specific movements is not clear. There are a number of reasons to suspect that the differences between the two types of skills, however, are unlikely to limit any generalizations
drawn from the findings. Gentile (1972), for example, 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. Second, 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, movement amplitude or speed) the goal of the task. In the ski-simulator task examined by a number of researchers interested in learning, the achievement of one particular movement variable is often the goal of the task (e.g., den Brinker et al., 1986). When performance on a number of movement related variables has been required withholding instructions, or sometimes feedback, has often been shown to be the more effective method for learning, as compared to providing demonstrations or feedback pertaining to only a single variable (e.g., Vereijken, 1991; Whiting et al., 1987).

What perhaps strengthens the impact of the findings from this thesis is the fact that even though a particular movement pattern was the goal of the task, demonstrating the movement before practice did not help. As long as participants were provided with other goal-related information that informed as to the presence of errors, demonstrations were not only unhelpful, but also detrimental to learning (see also Gentile, 1972, who proposed that early demonstrations might not always be desirable). Not only were they unhelpful, but performance decrements were observed when compared to groups who only received feedback pertaining to errors, but were not told how to move their limbs to attain the task goal. If movement demonstrations are not helpful or detrimental to acquisition of closed tasks, their applicability to open skills, where there is not one specific way of attaining the task goal, is seriously questioned.

Another potential limit of this methodology is the fact that, in many real-world learning situations, it is not possible to relay the goal of the task in any way other than as a movement demonstration. Given that the coordination task examined here was still relatively simple, the displacements of each limb could be plotted orthogonally to produce a simple shape to represent the task goal (i.e., a circle template). However, in the absence of feedback pertaining to attainment of this goal, this circle template would have been meaningless. In some situations it may be difficult to find a simple way of representing the task goal and subsequently provide augmented feedback with respect to attainment of this goal. The goals may also be multi-faceted, such that a decision would have to be made as to what goal to instruct on, if any. At the very least these results caution against the use of movement demonstrations as a default training
method, before other ways of conveying the task goal and providing feedback have been considered.

5.1.2 Type and Amount of Instruction

In this thesis a number of studies have been presented that would lead one to conclude that pre-practice information is not helpful to the early stages of skill acquisition. To make such a statement, however, all possible means of instruction would have to be exhausted. It could be argued that some types of instruction benefits movement skill acquisition and that the instructions examined in this thesis were neither appropriate nor suitable. Given that all the information provided in these studies would be expected to aid acquisition, from both a theoretical and practical standpoint, this is unlikely.

Participants were explicitly told and shown how to perform the required motor skill, in both slow motion and at the regular speed. Both specific and general written instructions that conveyed this same information were provided in the initial investigation. In other studies, participants were also informed as to likely errors in performance due to existing biases in coordination and how these errors should be corrected to perform the required motor pattern (Experiments 3 and 4). In Experiment 2 a group of participants were informed as to the explicit relationship between their movements and the feedback display (i.e., the right arm produces horizontal movements of the cursor and the left arm produces vertical). Although this list is far from exhaustive, it is difficult to imagine what other pre-practice information would be more suitable for this task and subsequently benefit skill acquisition. In light of the findings, however, less obvious instructions might be important and these possibilities are discussed in later sections.

In dynamical systems' terminology, instruction is not instruction unless it produces an effect on the order parameter in question, which in this case would be relative phase. More precisely, behavioural information (e.g., intention to perform a specific movement pattern), functions in so much as it has an effect on the coordination pattern. If the instructions do not effect performance then it could be argued that they are not relevant, or important to study in the first place. This is somewhat of a circular statement and does not help with the decision of what type of instruction, if any, to provide. In all of the studies reported in this thesis, however, the instructions and movement demonstrations were shown to have some effect on the process of acquisition, which was evidenced by a strong bias to anti-phase early in acquisition and less variability in initial performance. Due to the fact that feedback was provided in all the studies, it
is not possible to determine whether the instructions were sufficient to promote a change from constrained patterns of movement such as in-phase and anti-phase coordination. This is an issue that is discussed in the following section.

An additional factor that may impact on any conclusions concerning instructional effectiveness has to do with the amount of instruction, or movement demonstrations provided. One reason why the instructions, or movement demonstrations failed to facilitate acquisition could be due to the limited number of demonstrations or amount of instruction that was provided. Although the amount of information will always be a concern, it was believed that the movement instructions and demonstrations were provided a suitable number of times in all experiments. In the initial investigation, participants were allowed to peruse the written instructions whenever they felt necessary, both before and between practice trials. In subsequent experiments, the number of times participants were shown the instructional video was gradually increased across the three studies and reminder instructions were provided throughout Experiments 2 and 3. For example, in Experiment 1, video demonstrations were provided before practice and half way through practice on each of the two practice days. In Experiments 3 and 4, this had increased to four times a day, accompanied by reminder instructions before every trial for the first 5 trials and every 5th trial thereafter. Despite these differences in the amount of instruction the effects were generally the same across all studies.

In observational learning studies movement demonstrations are often provided instead of physical practice, during a typical acquisition session. An observational practice group is then compared to a control group under physical practice conditions and any difference between these groups is attributed to modeling effects. Although only a limited number of demonstrations were presented to participants in the studies reported in this thesis, there are reasons to believe that an increased number of presentations would have had little effect. Generally, in the five experiments reported in this thesis, the groups who watched demonstrations of the required movement often exhibited increased movement consistency at an incorrect movement pattern, as compared to groups where this information was withheld. Subsequently, more demonstrations of a skilled model may also promote this consistency when the individual is allowed to physically perform the task.

In a number of timing tasks, learning models have been shown to be more helpful practice aids than skilled models, especially when feedback as to their performance was provided (e.g., Adams, 1986; McCullagh & Caird, 1990). For more complex skills, these learning models may also be preferable to skilled models by promoting exploration and variability in
performance across trials. This more active search may alert individuals to possible errors and how to overcome them to discover the correct movement pattern. Arguably, if the learner is encouraged to become more involved in the problem-solving process, then his or her concern will be with goal attainment, rather than just copying the model (see also, Lee et al., 1991; Lee & White, 1990).

5.1.3 Feedback and Instruction: Confounds, Design Suggestions and Theory

The findings from these studies point towards a primary role for feedback in changing and influencing behaviour and less of a role for instructions. Learners did not need to know what they had to do to achieve the task goal, only whether or not it was achieved. In Experiments 1 and 2 where augmented feedback was provided on-line, only a temporary bias to pre-practice patterns as a result of instructional manipulations was observed, suggesting that the on-line feedback played a particularly critical role in guiding and dictating behaviour. When feedback was only available at the end of each trial as in the initial investigation and Experiments 3 and 4, the demonstrations had a greater effect on the process of acquisition, at least in terms of bias to either in- or anti-phase during the early practice trials.

The on-line feedback presented in Experiment 1 may have also caused difficulties for the limb feedback groups. Changing the movements during a trial to attempt new relationships between the limbs would result in rather untidy feedback plots of the movements which would be difficult to understand. This dual-limb feedback provided on-line may have hindered exploration of the task space and as such prevented the break from pre-practice behaviours. In hindsight, post-task feedback may have been a preferable design feature for this experiment, both to encourage more variable behaviour during the trial and to increase the influence of the instruction manipulations.

In Experiment 2, attentional focus could have been manipulated without the necessity of on-line feedback. Participants could still be directed to focus on the effects of their action on either the apparatus or the feedback provided at the end of the trial. This would help determine whether these attentional effects were physically induced, or the result of a more general awareness or attention towards oneself, or the task goal. A physical focus of attention to the limbs might cause the learner to pay less attention to the computer-generated feedback and as such this information would not be processed as efficiently. If computer-generated feedback was not available on-line, then explanations in terms of missed information, or poor processing could be discounted. Eye movement recordings could also be used to determine whether these
attentional manipulations were physically mediated. Interestingly, Shea and Wulf (1999) manipulated attentional focus through both the instructions and the feedback and found that feedback was the most important variable in facilitating performance. Based on these results they suggested that concurrent feedback generally encourages an external focus of attention, irrespective of whether it relates to the feet or the apparatus (although early in acquisition a focus on the apparatus was more beneficial).

Although demonstrations or instructions have generally not helped acquisition, and in some instances have been detrimental to the learning process when feedback was available, whether they are sufficient to encourage learning has not been examined. Instructions have not been examined in the absence of augmented feedback. This manipulation is important to enable strong conclusions about the effects of pre-practice information and the relative influence of feedback and instructions. There is plenty of anecdotal evidence that people can learn without augmented feedback, as long as they are sufficiently aware of the learning goal and receive intrinsic information about attainment of this goal (in either, or both, visual and kinesthetic forms). Error information is needed through some sort of conscious or non-conscious comparison process for change in behaviour to occur. In a motor skill like juggling it is very obvious whether goal attainment has been achieved, that is keeping three balls moving continuously. In this situation, the visual information available naturally from the task negates the need for augmented feedback. However if the learner was trying to copy a skilled juggler, then perhaps additional information would be required to inform as to any differences in movement form or technique between the two skill levels. Whether participants know from simply watching demonstrations that they have performed, or not performed the same movement, is not well understood.

From observing participants in the thesis experiments, a surprising lack of awareness as to whether they were performing the required movement was often shown. This was noticed when participants attempted to recall or copy the movement demonstrations, in the absence of on-line feedback, in retention. When participants were debriefed after retention and asked how they thought they had performed in the absence of feedback they would report having no difficulties performing the required pattern. This was despite the fact that they were often performing anti-phase movements. Observations like these suggest quite marked dissociations between what one expects to do, or believes she or he is doing and what is actually done. In dancing for example, learners often have to watch themselves in the mirror to attain augmented visual feedback about movement form, as insufficient information is available from intrinsic
sources. This augmented information may become more important as the task becomes more complex and individuals experience difficulty transforming what they see into action. In Experiment 1, on-line video feedback was recommended as an alternative source of information to the limb feedback provided on the computer, although a mirror would serve a similar function. Not only would this information be easier to follow or interpret than the limb-feedback, it would provide a more veridical learning situation, where instructors often use mirrors to aid the visual detection of error.

In the ski-simulator task discussed earlier participants were able to perform well on this task in the absence of any augmented information. Both pre-practice instructions, either a skilled model (Vereijken, 1991), or strategy instruction (Wulf & Weigelt, 1997) and feedback (see also, Whiting et al., 1987 who specifically manipulated feedback) have not been necessary for learning to occur. In fact, the discovery learning formats, where all augmented information was withheld was actually shown to produce significantly improved performance, at least with respect to some of the goal-related dependent measures. In this task, participants were required to make fast, wide and fluent movements. Subsequently, the goals of the task were clear to performers and response-produced feedback (primarily visual) was sufficient to encourage improvement on these parameters. Providing a skilled model arguably served to change this goal, to one of attainment of movement form at the expense of fast and wide movements. In the absence of augmented information relating to movement form, participants would face difficulty knowing whether this had been achieved. Indeed, Wulf, Shea and Matschiner (1998) found that when the goal of the movement was not salient (as in the time to exert peak force), regular augmented feedback pertaining to this variable produced significant improvements in performance with respect to this factor. It is recommended that in future studies, augmented feedback is manipulated, to examine whether repeated demonstrations are sufficient for learning. This manipulation would lead to a better understanding of the relative merits of feedback and instructions. Swinnen (1996) made similar recommendations when he discussed how augmented feedback has dominated the motor learning literature, at the expense of other instructional techniques.

In light of the reviewed literature, relatively little benefits are expected from watching movement demonstrations in the absence of feedback for two reasons. Participants may experience difficulty knowing whether their movements matched those conveyed by a skilled model. Although response-produced feedback would be available in both visual and kinesthetic forms it would be limited in its informational value with respect to successful decoupling, an
important task goal requirement that is illustrated effectively and simply by the circle feedback. Second, movement demonstrations may not provide suitable information to act as a template, or goal, with which errors in performance can be judged and compared. In the initial stage of skill acquisition, when the learner does not understand the task, or it is not an existing part of their movement repertoire, movement demonstrations specifying how to move the limbs may be unsuitable, or provide insufficient information to bring about learning. Unless the learner has an understanding of the task, arguably a demonstration of the to-be-acquired movement will not play a role in facilitating goal attainment. Watching a skill and performing it requires a certain amount of transformation on the part of the learner. Beginners may lack the necessary skills for transforming this demonstration into action if the movement is complex and difficult to represent mentally as an image.

Franks (1980) found that early in tracking performance, a generalized image of the form of the required movement was explicitly developed, as determined from freehand sketches. In this manner a generalized image of the act may help guide movement production, especially when the response requirements are relatively simple, but the stimulus pattern is more complex. Newell et al. (1990) found that when the stimulus or criterion was simple, detailed performance feedback was not needed, yet when it was unfamiliar, feedback was needed to provide augmented information about goal attainment. Presumably, this was because participants were unable to store a usable or accurate template of the unfamiliar pattern to guide movement production on line. In Newell et al.'s studies the shape was still geometrical and arguably simple in comparison to a live demonstration of a complex motor response. When the movement is difficult to represent in this manner, a demonstration might not provide any useful information to guide production.

Demonstrations, however, may alert people as to what not to do, which in some situations might be an advantage if the number of possible responses is large. Yet, as was shown in this thesis, knowing what not to do did not ensure that the correct movement was subsequently performed. Rather, this information was at the expense of variability in the produced movement early in acquisition, due to avoidance of certain incorrect behaviours (i.e., in-phase), thus inhibiting discovery of new movement patterns. What pre-practice information, if any, promotes initial understanding of movements that are not an existing part of a person’s movement repertoire remains unanswered? Some suggestions and alternative learning methods are elaborated below.
5.1.4 Other Techniques for Bringing about Change in Movement

5.1.4.1 Transitional Information

Swinnen (1996) proposed that transitional information might help the learner realize what requires change and how this change can be effected. This information may be in the form of a strategy, which could enable correction of an underlying error. The supposition was that this information would bridge the gap between knowing what was required and subsequently doing it. In the studies conducted in this thesis, transitional information could take the form of instruction concerning pre-practice behaviours and how these interfere with production of other more complex movement patterns (i.e., 90° relative phase). In this way, rather than only being told what to do, participants would be informed as to what requires change and how this change can be effected to produce the desired movement. In Experiments 3 and 4 participants were given this type of instruction, yet it provided no benefit to skill acquisition, beyond that provided by the goal-related feedback provided at the end of each trial. Because this instruction was independent of performance it might not serve as effective transitional information. The participants may not have had problems with only one particular movement pattern throughout practice and therefore this instruction would not always be informative. If this information is provided as performance-related feedback, at particular instances when difficulties are encountered, performance advantages or at least not disadvantages, might be observed.

5.1.4.2 Holistic Instruction

When learning to track a complex stimulus waveform, Franks and Stanley (1991) observed that many participants would hum or tap a rhythm to help encode the required pattern. This observation may have implications for instruction where general features of the movement are emphasized, in preference to specific details. In the thesis studies it was observed that a number of participants adopted this type of strategy to help them perform the new movement pattern. For example, some participants reported adopting a “wipe-on, wipe-off” motion, made popular by the ‘Karate Kid’ movie, or a similar idea of one hand passing off something to the other. A significant number of the participants would move other parts of their body to help them maintain a rhythm, such as their legs or head and when asked what instruction they would give to new learners reported that ‘finding the rhythm’ would be helpful. Whether instructions concerning these strategies could be used to improve practice for other individuals is questionable. They may reflect insights that are only useful once the task goal has been attained.
Despite this caution, Swinnen (1996) has recommended similar holistic-type instruction when learning complex movement skills. Through the use of analogies to more everyday movements, such as pulling on shorts when performing a gymnastic move on the uneven bars, the general idea of the movement is conveyed without the detail. In Middle-Eastern dancing, some of the more complex moves are encouraged through the use of analogies to animal movements, to encourage the correct position of the head and arms, without the need to specify these actions independently. In this way the general idea of the movement is relayed, without unnecessary detail that may cause difficulties. In the task examined in this thesis, the analogy of an elastic band could be used to encourage the lead-lag relation between the arms and the fact that the arms may move in both the same and different directions throughout the movement. However, this instruction could also promote an unwanted bias to anti-phase movements.

5.1.4.3 Encouraging Within-Trial Variability

Given the importance attributed to variability early in skill acquisition, alternative techniques, other than movement demonstrations are recommended, to bring about more exploratory-type behaviours in the early stages of skill acquisition. One way that variability in practice has been manipulated is to vary the temporal provision of augmented feedback. It has been found that regular provision of KR leads to greater variability in practice attempts as opposed to decreased relative frequency of KR (e.g., Lee & Carnahan, 1990). Although Wulf and Schmidt (1989) and Lai, Shea, Wulf and Wright (2000) have suggested that constant practice conditions are important to acquire the movement's shape structure, or generalized motor program (e.g., relative timing), these conclusions were made on the basis of simple key pressing tasks. In these tasks no spatial-temporal coordination between effectors was required.

Given the results of these studies and the suggestion that variable practice early in acquisition facilitates learning, KR could be manipulated to encourage or inhibit movement variability. Although increased variability early in practice is expected to facilitate acquisition, once the task goal is attained, constant practice conditions (promoted by reduced feedback or possibly by instructions or demonstrations) may then help refine the movement form. Support for this proposal has been provided by Swinnen et al. (1993) and Wulf, Shea and Matschiner (1998) who both failed to observe retention benefits for reduced feedback during the acquisition of more complex skills. Instead, they found that 100% KR during practice facilitated performance in a no-feedback retention test. For complex movement skills, more information concerning errors may be necessary to bring about change in movement.
5.1.5 The Auditory Metronome

In all the studies conducted in this thesis an auditory metronome was used to dictate the required movement speed. This design feature was included for a number of reasons. Performing the required movement pattern at a speed of 1 Hz made the task sufficiently difficult, such that there was more room for improvement with practice. This movement speed was used in other experiments where similar amplitude constraints for bimanual movements were adopted (e.g., Fontaine et al., 1997; Tsutsui et al., 1998). The 1 Hz speed was believed to be close to the performer's preferred movement frequency, at least when performing in- or anti-phase movements. The metronome also encouraged movement and therefore practice. In the absence of instructions or on-line feedback, for example, participants may have been reluctant to move without the encouragement of the metronome. This feature allowed for the assumption that all participants received roughly the same amount of practice, that is, between 10 or 15 cycles per trial.

Despite the reasons for using an auditory metronome, there are also problems with this procedure. After the initial investigation there was concern as to whether participants were experiencing difficulty implementing the instructions due to the speed constraints immediately placed upon the learner. Therefore, in subsequent experiments, participants were encouraged to move in time with the metronome, but were told that these speed constraints did not need to be rigorously adhered to early in practice. As practice progressed participants were asked to try and increase their movement speed to eventually move in time with the metronome. Much like visual information, auditory information might also serve to couple movements (e.g., at flexion or extension points), increasing the difficulty learners would experience breaking from preferred, yet undesirable, coordination patterns (e.g., Carson, Byblow & Goodman, 1994). However, because all participants underwent practice under these same conditions, this difficulty would be constant across all participants. Indeed, some participants even reported that the metronome helped them perform the required movement pattern, at least at a later stage of practice.

In future experiments an alternative protocol could be used to make the conditions of practice more akin to real world contexts. Rather than controlling the amount of practice trials and the number of cycles per trial, the amount of practice time could be controlled. This procedure may be more informative with respect to how participants approach the task under different instructional manipulations.
5.1.6 Identifying Pre-Practice Bias

5.1.6.1 Defining Attraction

In Experiments 2, 3 and 4 scanning procedures were adopted to ensure task novelty and to examine performance as a function of pre-practice behaviours. In Experiment 2, the prime reason for using this procedure was to ensure that a relatively, naive and homogenous sample was obtained, who were not able to produce the required coordination pattern before the experimental manipulations. Due to this mandate somewhat conservative procedures were adopted to determine inclusion. Low error (both delta relative phase and low variability) at the 90° relative phase plateau (in Experiments 2, 3 and 4) and at any other task requirement between 45° and 135° relative phase (Experiment 2) was sufficient to warrant exclusion. This procedure was different to methods used in previous studies to determine attraction. Zanone and Kelso (1997) proposed that a negative slope through one of the task requirements when delta relative phase was plotted as a function of required relative phase, was also a necessary condition for categorizing a person as showing attraction.

The problem with this definition is that individuals may show low error at all phases in the absence of a negative slope, yet not be classed as showing any attraction. Or they may show low error at 90°, showing that they can perform this pattern, but only show attraction in terms of a negative slope to the in- and anti-phase patterns. Given that in Experiment 2 defining attraction was not the primary concern, less conservative procedures could effectively be adopted to define attraction at patterns intermediate to in and anti-phase. As discussed below, despite the fact that a relatively homogenous sample was obtained before testing, differences on the scanning task were still observed and more importantly these differences were predictive of acquisition and retention performance on the criterion task. This finding suggested that the scanning task was a valid measure of performance.

The results from the scanning procedure adopted in Experiment 2, alerted to the fact that a relatively high number of individuals could perform patterns other than in- or anti-phase before practice, leading to a 38% exclusion rate. Subsequently, in Experiments 3 and 4, scanning tasks were adopted to determine pre-practice bias and investigate learning as a function of differences in initial ability on these scanning tasks. However, the less stringent criteria that was used for defining bias to particular patterns pre-practice may have resulted in classifications of some individuals as multi-stable, even though other relative phase requirements may not have been attracted towards these patterns. Relatively weak attraction to intermediate patterns such as 45° before practice may have been in part responsible for the lack of difference across these final two
experiments. Subtle differences in performance on the scanning task, where visual information was provided on-line to guide behaviour, may not have been sufficient to lead to advantages on the criterion, learning task. No prescriptive information was provided on-line during practice and feedback was only given at the end of each trial. In this way, weak attraction to patterns other than in- or anti-phase would have had little effect on performance when this guiding information was removed.

5.1.6.2 Individual Differences

In Experiment 2, participants were differentiated based on their initial performance on the scanning task. Participants who continued with in-phase movements for a number of task requirements, even though the visual information dictated otherwise, generally showed a slower rate of acquisition and increased error in retention tests conducted in the absence of feedback. In contrast, the participants who switched early to anti-phase coordination and either maintained this pattern, or alternated between in- and anti-phase, showed less error in acquisition and retention and more variability in within-trial performance early in acquisition. Irrespective of the type of attraction, all participants performed movements on the learning task within the vicinity of the anti-phase attractor, at least after the first practice trial. Based on these findings it was concluded that the scanning task provided an assessment of general coordination ability, rather than a specific preference to perform, in-phase biased movements.

These differences between individuals may be related to eye-hand coordination ability or perhaps reflect a general perseverance type of behaviour, characterized by a reluctance to change behaviour even though the task demands dictate that a change is needed. Indeed, on the learning task, the in-phase biased participants showed less variability in within-trial performance early in acquisition, suggesting that perseverance may be an important dimension in predicting performance. A measure of perseverance was developed by Rehfisch (1958) termed the scale for personality rigidity. In future studies it would be interesting to see whether differences in learning complex motor skills could be predicted based on personality dimensions such as rigidity.

Walter and Swinnen (1992) have also shown how differences in initial coordination ability on a discrete bimanual task were predictive of later performance and learning on that same task. They later went on to suggest that some individuals may benefit from different training strategies and claimed that “This approach to the effect of individual differences on appropriate training techniques has not been rigorously examined to our knowledge.” (Walter &
Swinnen, 1994, p509). In contrast to Walter and Swinnen who showed that these differences implicated different practice strategies, there was little evidence from Experiment 2 to suggest the use of different instructional techniques as a result of these biases. This was somewhat due to the fact that only a relatively small number of individuals who demonstrated one or other bias were within each practice group. Feedback, however, was particularly important for the in-phase biased participants in retention and helped prevent the interfering effects of undesirable movements. In Experiments 3 and 4, participants were allocated to groups based on differences in pre-practice behaviours and again, despite the initial predictions, there was no evidence to suggest that differential training strategies should be adopted as a function of initial ability.

Fleishman and colleagues (and more recently, Ackerman, 1988, 1992) have demonstrated differences in coordination ability and the subsequent predictive nature of this ability in terms of performance on a number of motor tasks. Parker and Fleishman (1959), for example, identified two factors that were important predictors of performance on a tracking task. These were spatial orientation and multi-limb coordination. They found that after the third practice session, the contribution of spatial orientation to tracking proficiency decreased, whereas the multi-limb coordination factor increased up to session 9 (there were 17 sessions altogether). This finding and others from Fleishman and Ackerman and colleagues leads to the suggestion that differences in coordination ability do not fully differentiate individuals until later in practice. However, in Experiment 2 at least, initial coordination ability did yield differential performance both early in acquisition and later in retention. Perhaps those individuals who were biased to in-phase coordination in Experiment 2 had particular coordination difficulties which may have been a result of reduced practice experience, personality behaviours related to perseverance, or possibly hardware limitations that result in hemispheric specialization. The fact that only a limited number of practice sessions were conducted across all the experiments cautions against any strong conclusions concerning the role coordination ability plays in influencing performance at different stages of skill acquisition.

5.2 Theory

5.2.1 How Do Instructions Affect the Initial Stage of Learning?

5.2.1.1 Response Selection

As stated in the introduction, the initial stage of skill acquisition is a relatively under-researched area. Although suggestions have been made with respect to the cognitive demands of this early stage (e.g., Fitts & Posner, 1967, Adams, 1971), the importance of spatial-verbal skills
(e.g., Parker & Fleishman, 1959, Ackerman, 1988) and instructional techniques (e.g., Gentile, 1972, Higgins, 1991), there has been little empirical investigation of how the learner acquires a new motor skill that is not an existing part of their movement repertoire. In this thesis an attempt was made to explore this initial stage by manipulating pre-practice information concerning how to produce and learn a complex and novel movement. Despite the fact that the task goal was a particular movement pattern, instructions and movement demonstrations performed by correct models did not produce any learning benefits beyond that available from goal-related feedback. Pre-practice information was associated with a slower rate of acquisition and some disadvantages in retention and transfer. Based on these findings it was concluded that when the movement response is not an existing part of the learner’s movement repertoire, instructions and movement demonstrations do not facilitate learning. In the following paragraphs theoretical rationale underlying these instructional effects are discussed.

Lacking the initial capability to perform a required movement may limit the effectiveness of modeling. Bandura (1986), proposed that movement capability was an important characteristic in determining the effectiveness of modeling techniques. Although Bandura may have been referring to physical or cognitive characteristics, such as height, or verbal ability, this capability may relate to practice experience. Based on the reviewed literature and the findings from these studies it is proposed that if pre-practice information cannot be easily transformed into a workable movement template, due to difficulties in understanding what is required and how this can be represented, then this information will not be of use. Similar ideas were suggested earlier with respect to being able to form a workable image of the act.

Although demonstrations may not be sufficient to convey what should be done for goal attainment to be achieved, demonstrations and instructions may help narrow the search for solutions to the motor problem and influence selection of a response. In the studies reported here, pre-practice information alerted the learner that in-phase, symmetrically biased movements were not the correct way to perform the movement pattern. Subsequently, an anti-phase type of movement response was initially selected, due to the fact that this was the only other movement pattern that could be produced in these early practice trials. Therefore, it is important to consider how initial instruction can impact on the type of motor response that is initially selected at this early stage of practice.

In terms of Schmidt’s schema theory (1975), due to the fact that no schema of the required movement pattern existed at this point, another response was activated by the recall schema, that was incorrect, yet close to the required action. This is similar to proposals made by
Adams (1971, p125) who argued that “the memory trace must be cued to action”. Movement demonstrations or instruction may serve to cue an incorrect response initially, (e.g., the anti-phase pattern), yet after sufficient practice and under certain initial conditions the correct response would eventually be evoked.

As a result of augmented feedback alerting to errors, the anti-phase pattern would gradually be produced with more variability until the learner discovers how to decouple their limbs in order to produce the required pattern. Given that the feedback did not explicitly relate to the movements themselves, a feature that was manipulated in Experiment 1, the learner would have difficulty knowing what to change and how to change, particularly when feedback was only available at the end of each practice trial. When the feedback was available on-line, however, the learner would be able to integrate perceptual information from both augmented visual feedback and intrinsic, response-produced feedback. This presumably would aid the development of some sort of reference template (perceptual trace or recognition memory) with which performance could be compared and evaluated on the next trial.

Although anti-phase is less stable than in-phase and perhaps therefore a better region to ‘hang-out’ in, as suggested earlier, avoiding in-phase movements may hinder discovery of new movement patterns. To produce 90° RP participants are required to move their arms in the same direction for half the time, even though the arms would be at different spatial locations, therefore avoiding in-phase would not be a good strategy. Due to the greater variability associated with anti-phase, this pattern may have interfered more with the production of 90°, whereas it would have been easier for participants to isolate in-phase movements. Zanone and Kelso (1992) predicted that anti-phase would destabilize as a result of continued practice at 90°. Although there has been little evidence for this destabilization, somewhat due to differences in methods of assessment, the fact that anti-phase might destabilize, suggests that this pattern of response will manifest most frequently when participants are learning to perform a new relative phase.

The majority of errors displayed by participants as a result of retention interval, feedback removal, or secondary task manipulations in these studies were in the direction of the anti-phase pattern, whereas regressions to in-phase were rarely observed. This suggests that anti-phase has a more disruptive influence on newly required movement patterns. Given that the pathway to 90° is via the anti-phase pattern, regressions to anti-phase should not be unexpected. Regressions to this pattern may be the result of a poorly defined perceptual trace of the movement, due somewhat to the evoking of earlier, undesirable movement patterns. Regressions as a result of increased attention demands or speed, may be the result of feedback processing limitations, that result in
the cueing to action of patterns of behaviour that require less processing demands. These attentional limits are discussed in more detail below.

5.2.1.2 Movement Consistency

Another way that demonstrations and movement templates have been shown to affect learning in the early stages is to promote movement consistency. Although the learner may have difficulty understanding what is required from watching a movement demonstration, they may still try and form some sort of image of the action, with which they can then use to copy during execution. Due to limits in this capability, copying of a badly formed movement template may also be harmful to skill acquisition. Copying has been shown to produce consistent behaviour, which is undesirable unless the learner has the capability to perform the required movement. Brisson and Alain (1996, 1997) and Young and Schmidt (1992), for example, have shown how movement templates can work to promote movement consistency because the performer is encouraged to match their response from trial to trial. A number of other researchers have also proposed that movement demonstrations promote movement consistency and inhibit the search and discovery of new movement patterns (e.g., Gentile, 1972; Higgins, 1991; Southard & Higgins, 1987; Vereijken, 1991). What has been shown in this thesis, is that feedback can help overcome these effects and promote variability in the response, as long as the feedback is relatively simple and relates directly to goal attainment (as shown in Experiment 1).

An advantage of knowledge developed from studies of inter-limb coordination and dynamical systems theory is the ability and perhaps language to understand what response would be initiated early in skill acquisition, before any memory trace, or representation of the movement response has been developed. Due to knowledge of relative phase and pattern stability in bimanual coordination ways of quantifying and predicting behaviour in the early stages of acquisition are afforded. These initial behaviours provide a background to explore how new behaviours are acquired and maintained separately from these. A potential limit of this approach is that the methods and subsequently the knowledge are somewhat limited to dual limb coordination tasks. When learning a complex action, such as a somersault for example, it would be difficult to predict what action would be selected in the initial stages, although perhaps a general understanding of why certain errors occur may be gained.
5.2.1.3 Attention Demands

In the initial investigation, reported in the introduction, it was shown that attention was needed to break from the intrinsic dynamics, as the secondary task learning group was unable to learn the task under these conditions (at least over two days of practice). This attention may be necessary to enable variability in the movement response, such that new movement patterns can be discovered. Attention demanding conditions may increase the pull of stable, pre-existing patterns by increasing the stability of these attractive states and making it harder for different movements to be produced. If attention and cognitive skills are so important during the early stages of skill acquisition (see also, Adams, 1971; Fitts & Posner, 1967; Fleishman & Parker, 1959) then it is important to decrease additional cognitive demands that may interfere with the attention necessary to break from intrinsic attractors. Cognitive demands could take the form of instructions that encourage the learner to work out the relationship between the movements of the limbs and the feedback (see also Green & Flowers, 1991), which is not necessary to learn the required movements. In the initial investigation, the general instructions hindered learning, possibly as a result of additional, yet perhaps unnecessary cognitive demands placed on the learner early in acquisition which encouraged them to think about the task in ways that interfered with goal attainment.

Temprado et al. (1999) have shown that attentional focus onto the anti-phase pattern increases its stability. Given that anti-phase is less stable than in-phase, these attentional effects on movement variability are only observed under anti-phase conditions, perhaps due to some sort of floor effect in terms of in-phase stability. Interestingly, greater cognitive loads, as measured through RT, are required to encourage stabilization of anti-phase, at least at faster movement speeds. If the intention was to de-stabilize this pattern to perform other newly learned patterns, such as 90°, then perhaps similar attention demands would be observed. Rather than anti-phase being more susceptible to attentional focus in terms of variability, the in-phase pattern would require more attention, due to the inherent stability associated with this pattern.

Based on these findings, it would make sense for participants to generally ‘hang-out’ in the vicinity of the anti-phase pattern or to try and switch between both patterns. Under these conditions less attention would be required to break from these patterns to perform 90°. Switching time analysis lends some support to this conclusion where it has been shown that it takes longer to switch from in-phase to anti-phase than visa versa, due to increased stability of the in-phase pattern, especially at higher movement frequencies (e.g., Carson, Goodman, Kelso
& Elliott, 1995; Scholz & Kelso, 1990). Whether the delays are associated with central costs has not been examined.

If participants do not have the capability to perform any other patterns, attention to the limbs may inadvertently stabilize anti-phase. Indeed, Amazeen, Amazeen, Treffner and Turvey (1997) showed how attentional focus onto the dominant hand during performance of bimanual coordination patterns increased the stability of these patterns, even though this was not the desired effect. In Experiment 2 the demonstration-only group (and the internal-focus group reported in the Appendix) showed difficulties in acquisition as a result of instructions that directly or indirectly focused attention onto the limbs. Attentional focus might interact with the stage of learning and existing coordination biases to stabilize both desirable and undesirable coordination patterns. The mechanism underlying internal focus of attention effects in other studies (e.g., Wulf, Hoss & Prinz, 1998) might also be realized through similar stability provoking instructions or procedures.

5.2.2 A Second Stage: Refining the Acquired Movement

In this thesis, both the initial stage of skill acquisition was examined, where the learner was required to break from pre-existing movement patterns and a later, yet still relatively early stage where the learner was required to make refinements to the new movement. This second stage is similar to that referred to by Gentile (1972) as the fixation stage. The fact that in these studies instructional effects were examined across these two stages may account for some of the variability in the findings. Once the movement pattern has been acquired, instructions and movement demonstrations may play an important role in increasing the effort put into practice and attending to information sources that may go unnoticed. This would help refine templates, or memory stores (such as the perceptual trace) that are developed to evaluate the effectiveness of the response and monitor and correct errors.

Support for this proposition was observed in Experiment 2, where attention-focussing instructions had different roles to play depending on the stage of learning. Early in practice, attention to the feedback was more beneficial than attention to the limbs and the required movements. Later in practice, this instruction may have helped the learner process intrinsic information more effectively, such as the processing of kinesthetic feedback, which was evidenced when feedback was removed. In fact, any additional instructions that encouraged attention to the effects of the movement yielded benefits in retention when feedback was removed. The demonstration provided alone was not sufficient to encourage additional
processing and participants who learnt the task without instructions were particularly affected by the removal of visual feedback. Gentile commented in her 1972 paper that ways of facilitating this second stage of acquisition were unknown, although she suggested that instructions directing attention to intrinsic feedback might help.

Once the movement is acquired, demonstrations and instructions may help participants refine this movement pattern. Perhaps individuals are then able to extract important information and ‘store’ some representation of the movement. This template may be in either, or both verbal form, such as “wipe-on, wipe-off”, or visual form, perhaps the circle template. These cues would be sufficient to evoke the correct response that was not available and could not be cued by these commands or images in the initial stage of acquisition. Indeed, when participants were debriefed after Experiment 2, they reported imaging a circle pattern template when they were required to perform the practiced movement in the absence of on-line feedback. Before this skill or movement pattern is acquired, however, this type of strategy or information would not be sufficient to facilitate performance. The movement has to be performed correctly before it can be recalled.

These ideas concerning different stages of skill acquisition have implications for the temporal provision of instructions and movement demonstrations. At a later stage of skill acquisition, at least for a movement skill that requires the consistent production of a single movement pattern, instructions and movement demonstrations would increase the effort put into performing the task. This would promote a better awareness of other sources of sensory information such as kinesthetic feedback. Whether this effect applies across tasks that do not require this same type of refinement is questionable. For example, Wulf and Weigelt (1997) failed to observe advantages for instructional provision after three days of practice on the ski-simulator task, although only a limited number of test trials were examined after the instructions. Further studies are needed to examine this hypothesis.

5.3 Conclusions

In these studies it has been shown that demonstrations and instructions affect the process of motor skill acquisition in ways that can be detrimental to performance and learning. Although these conclusions may at first seem somewhat negative, what is important to take from these findings 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 being conveyed. This would require an appreciation of the many,
and sometimes conflicting, goals a motor skill may have and how attentional processes may be
directed to certain cues as a results 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 may be attempted or indeed avoided as a result of instruction.

In the Introduction, the question was asked as to what type of information contained in
the instruction ensures effective instruction, or at least prevents disruptive effects? From these
studies and ideas presented throughout the thesis a number of suggestions can be made.
Demonstrations, or instructions may help if the task is already part of a person’s existing
movement repertoire and the purpose of the instruction is to inform as to the correct sequencing,
for example. In relatively simple tasks, where greater demands are placed on the cognitive
aspects of the skill, instructions and movement demonstrations are expected to be useful for
acquisition. There is plenty of evidence to support this proposal (e.g., Caroll & Bandura, 1982,
1985). If the feedback is complex, or no other information is available about the task goal, then
instructions have a sometimes necessary and important role to play. In Experiment 1, there was
some evidence to support this suggestion, where it was found that under limb-feedback
conditions, participants who received instructions performed with less error in retention than
non-instructed participants.

Once the learner has figured out what to do and acquired the general pattern of
movement, demonstrations and instructions may help the learner refine this movement pattern
and may actually provide advantages. Indeed, in Experiment 2, coupling external focus
instructions with movement demonstrations was beneficial to retention when performance was
assessed without on-line feedback. Instructions that are repeated throughout practice may help
the learner process task-relevant information more efficiently so that when conditions are
changed somewhat they are less reliant on the primary sensory source. Feedback and externally
focused instructions help the learner maintain a goal focus, which arguably facilitates learning.
This focus away from the movement itself may be particularly important during the early stages
of skill acquisition, but after the general movement has been acquired attention to other sources
of information may be beneficial to performance, at least when learning a specific movement
pattern.

Instructions that built upon past behaviours to help with the acquisition of new
behaviours did not help participants acquire a new coordination pattern. Whether under extended
practice conditions advantages as a result of this more detailed instruction which encouraged
regular comparisons between different behaviours would have helped remains to be examined.
Given the fact that the instruction was independent of performance, post-task feedback pertaining to current errors would perhaps be a more useful information source if coupled with instructions alerting the participant to the error and how to correct it. Arguably, as a result of the limited practice and feedback, there were not enough participants who had acquired the general idea of the movement to be able to use the instructions effectively later in practice. In summary, the results from these studies provide a vital step in aiding the understanding of how instructions work to affect the process of motor skill acquisition. Much work remains to be done in this area, including the examination of instructional effects over extended practice periods and across different tasks that vary based on extrinsic and intrinsic feedback.
REFERENCES


APPENDIX

Figure A1: RMSE, mean and SD of goal relative phase (°) for the five groups in Experiment 2 across the two days of acquisition and in immediate (R1) and delayed retention without (R2) and with feedback (R3) and in transfer to a novel elliptical shape (EL).
Table A1 Mean RP (°) for the five groups in Experiment 2 across the two days of acquisition (10 blocks per day) and in retention and transfer, as a function of bias to either in-phase (IP) or anti-phase (AP).

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