Implicit knowledge, stress and skill failure

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Abstract

At the heart of this work is a curiosity as to why expert performers, who have so practised their skill that they can execute it perfectly time after time, often fail when under extreme pressure to perform well. The work begins with discussion of key issues in performance, such as implicit versus explicit knowledge, the passage of learning - from novice to expert, controlled to automatic - the effects of stress on skill performance and the nature of skill failure.

Once the foundations of the research have been layed the thesis embarks on a number of investigations which suggest that it is possible to teach a motor skill without the learner ever acquiring conscious, explicit knowledge of the rules for executing it, that acquiring a skill in this manner may make it less likely to fail under stress because the performer has no explicit knowledge with which to execute the skill, that some individuals have more of a predisposition than others to try to run their skill with explicit knowledge and that these individuals are more likely to fail under stress.

The thesis concludes that traditional methods of instructing performers, which emphasise explicit, technical 'know-how', and require the performer to be very conscious of the action, are not necessarily the most effective methods of skill acquisition if the skill is not to fail under pressure. The implication, as the author illustrates in the final chapter, is that alternative methods of instruction or coaching need to be developed which at least reduce the degree to which the performer is conscious of the rules for executing his or her chosen skill.

Prologue

In 1958 Boris Pasternak wrote his famous novel "Doctor Zhivago". At one point Yura Andreyevich Zhivago delivers an impromptu lecture to Anna Ivanovna Gromeko on life and death:

> "To try consciously to go to sleep is a sure way to have insomnia. To try to be conscious of one's own digestion is a sure way to upset the stomach. Consciousness is a poison when we apply it to ourselves. Consciousness is a beam of light directed outwards, it lights up the way ahead of us so that we don't trip up. It's like the head-lamps on a railway engine - if you turned the beam inwards there would be a catastrophe."
>
> (from Doctor Zhivago by Boris Pasternak, 1958)

In 1989 in the United States Golf Championship an American, Scott Hoch, missed not one but two *gimmes* (extremely easy putts) at the death. Had he holed either putt he would have been champion. Instead, Nick Faldo of England became champion. In 1986 Steve Davis, that most clinical of the great snooker players, missed the final black of the final frame to lose the World Championship. Ivan Lendl played brilliant grass-court tennis in 1991 to win the Queen's Club tournament yet at Wimbledon the week after, where he so wanted to win, Lendl lost appallingly. In the same week at Wimbledon Martina Navratilova double faulted at match point down to lose to the young American Jennifer Capriati. In the semi-final of soccer's World Cup in 1990 both Chris Waddle and Stuart Pearce missed penalties against West Germany.

On the other hand, Stefan Edberg - the then world number one tennis player - commented on one of his great performances, "I had one of those days when I played almost perfect tennis... In the third set you start to think a little bit and wonder if it is a dream, but I said to myself 'just keep concentrating on each point'. If you start to think you can easily get into trouble" (The Times, Jan., 1990). Following a famous victory in the 1987 French Open Tennis Championships Martina Navratilova told journalists, "I played for an hour and I don't think I missed a shot. Everything was happening without my having to think". Juan Belmonte, the famous spanish bull-fighter, said of the fight which made him a legend in his country, "all at once I forgot the public, the other bull-fighters, myself, and even the bull...I simply fought as I believe one ought to fight, without a thought, outside my own faith in what I was doing" (Atlantic Monthly, Feb., 1937). Lisa Opie, British Squash Champion many times over, said "but the best match I must ever have played, I can't remember a thing about...I might remember the first service, but that's all. I was in a trance of concentration, a cocoon of invincibility. I came off, and still don't have a clue about the score. Except that I beat her. You play by instinct, by auto-pilot, and you win famously. It's uncanny" (The Guardian, Nov., 1988).

How do these periods of peak performance as well as these famous failures of skill relate to a lecture on life and death by a fictional character in a classic novel? In all of the examples cited an inward turning of attention, a focusing of consciousness on the act to be performed, was either absent when peak performance occurred or very probably present when skill failure took place.

This thesis explores the inward turning of 'consciousness' in human motor actions and argues from Yura Andreyevich Zhivago's premise that turning the beam of consciousness inwards while performing can be catastrophic in even highly skilled actions. The thesis will look toward inhibiting catastrophes if inward turning does occur and predicting in whom inward turning of consciousness is most likely to occur.

Chapter One

An Introduction

1.1 Implicit learning

To become conscious of something in Zhivago's terms can be construed as registering knowledge explicitly, with or without intention. According to many authors knowledge can be explicit or implicit (Berry & Broadbent, 1984, 1987, 1988; Evans, 1982; Hayes & Broadbent, 1988; Reber, 1967, 1976, 1989; Reber & Allen, 1978). Explicit knowledge is made up of facts and rules of which we are specifically aware and, therefore, able to articulate. Implicit knowledge is made up of that which we 'know' yet are not aware of, and thus, cannot articulate. Reber (1989, p.219) claims that the term 'implicit learning' was originally employed to describe the development of "intuitive knowledge about the underlying structure of a complex stimulus environment". In earlier work Reber (1967) argued that implicit learning is an unconscious process yielding abstract knowledge in the absence of conscious attempts to learn. Two paradigms most often illustrating implicit learning in the literature are the acquisition of synthetic grammars and learning to control complex systems. A typical example of implicit learning in synthetic grammar can be seen in a study by Reber (1967) in which participants became more sensitive to the underlying structure of the grammar as they learned sets of letter strings from that grammar. The task of learning these strings was described as part of a rote learning memory experiment so participants were not aware of an underlying rule structure to the strings. Implicit learning was shown by the fact that (a) the ability to process and memorise these strings improved with practice on letter strings with an underlying rule structure but not on letter strings lacking such structure and

(b) participants were able to distinguish between grammatically correct and incorrect letter strings, despite an inability to articulate the underlying rules upon which they based their decisions. This has been shown to be a highly robust method of illustrating implicit learning (Brooks, 1978; Howard & Ballas, 1980; Morgan & Newport, 1981; Reber, 1976; Reber & Allen, 1978; Reber, Kassin, Lewis & Cantor, 1980).

The existence of implicit learning has also been shown in the control of complex systems (Berry & Broadbent, 1984, 1987, 1988; Broadbent, FitzGerald & Broadbent, 1986; Hayes & Broadbent, 1988). Such complex systems were invented by Broadbent and his colleagues and commonly involve interaction via computer. In the most well known system, participants are placed in an imaginary manufacturing environment such as the sugar production task (Berry & Broadbent, 1984; McGeorge & Burton, 1989). In this task participants are required to maintain specific production levels by altering variables such as the number of employees or wage scales. Systems such as this function on complex underlying rule structures, suggesting that in order to achieve successful control of production the participant must have some form of knowledge about the rule structure. The consistent finding from studies employing such complex systems is that the underlying rule structures are derived implicitly and adjustments in variables are carried out in the absence of explicit, verbalisable knowledge of the underpinning rule structures governing the way the variables interact in the system. For example, Berry & Broadbent (1984) reported that practice in controlling the sugar production task led to improved performance but made no difference when it came to answering written questions about the completed task, whereas, verbal instruction in how to carry out the task led to improvement in post-task question answering but not in performance. Broadbent *et al* (1986), Morris & Rouse (1985) and Rouse & Morris (1986) also found this.

Little research exists on implicit learning and actual motor-skill performance. The closest approximation in the literature is found in a method employed by Lewicki, Czyzewska & Hoffman (1987) and subsequently replicated by Lewicki, Hill & Bizot (1988) and Stadler (1989) in which implicit learning was demonstrated in a visual search task. The location of every seventh target was determined by the target locations in the previous six trials. Subjects located the target significantly more quickly on the seventh trial when compared to occasions upon which the previous six trials were not determinants of target location, despite having no explicit knowledge of the rules governing the sequencing of target locations. Nissen & Bullemer (1987) employed a somewhat similar method with the same results. Although these results provide support for the concept of implicit learning they do not give an insight into implicit learning and its effects on *motor skill performance.*

1.2 The passage of learning: From inexpert to expert

Despite the scarcity of empirical investigation into implicit learning of motor skill there has been much research into other phenomena associated with skill acquisition, particularly the development of autonomous performance. That is, performance in which little conscious processing occurs, yet the performance is efficient and effortless. Such 'automaticity' (especially in sport where the potential rewards; fame and fortune, provide a high motivation to perfect the skill) is the end result of many performances involving explicit learning, yet it seems to run on a mixture enriched by implicit knowledge. It is widely accepted that a developing skill will pass from a cognitive through an associative phase before reaching an autonomous phase in which the skill is automatic (Fitts & Posner, 1967). In the cognitive phase, knowledge is explicit and rule based, and performance is slow, erratic and requires much effort. In the autonomous phase, knowledge is implicit and non-verbalisable, and performance is smooth, effortless and fast. This basic distinction is common across a number of more recent theories of skill acquisition. For instance, replace cognitive phase with 'declarative stage', autonomous phase with 'procedural stage', make a few minor changes and one is in essence looking at Anderson's (1982) Adaptive Control of Thought Theory (ACT) of skill acquisition. Replace declarative stage with 'controlled processing', procedural stage with 'automatic processing', make a few minor changes and one is looking essentially at the view held by Schneider & Fisk (1983), Schneider & Shiffrin (1977), Shiffrin & Dumais (1981) and Shiffrin &

Schneider (1977). The fundamental communality between the various theories is very much the move from explicit to implicit knowledge. In fact, although there are those who have suggested, in a more cognitive than motor sense, that a skill may initially develop without an explicit, declarative encoding of knowledge (Brooks, 1978; Hayes & Broadbent, 1988; Reber, 1967), most investigators of skill learning rely on the fundamental belief that skill acquisition begins with declarative, explicit encoding of knowledge in which the demands on 'cognitive' processing are high and ends with procedural, implicit encoding in which the demands are low. Take, for example, the explanatory models of motor learning and performance touted by Adams (1971) and Schmidt (1975) in which performance of a motor skill is seen to be slow and jerky early on due to closed-loop type explicit processing of feedback, but smooth and fast later in learning as a result of development of less demanding open-loop movement.[1]

Even Logan's (1988) Instance Theory of automaticity makes way for a shift from explicit encoding of knowledge to implicit encoding. Logan sees automaticity as a phenomenon of the memory related aspects of attention rather than its limited capacity aspects. According to Logan (1988, p.493):

> "Automaticity is memory retrieval: Performance is automatic when it is based on single-step direct-access retrieval of past solutions from memory. The theory assumes that novices begin with a general algorithm that is sufficient to perform the task. As they gain experience, they learn specific solutions to specific problems, which they retrieve when they encounter the same problems again. Then, they can respond with the solution retrieved from memory or the one computed by the algorithm. At some point, they may gain enough experience to respond

[1] Schmidt's Schema Theory was offered as an alternative to Adam's Closed-loop Theory in answer to both the novelty and storage problems presented by Adam's model. The closed-loop nature of Adam's model requires a one-to-one mapping between a previously stored feedback reference and every single movement to be executed. This results in (a) a need for a countless supply of feedback states in storage and (b) an inability to account for the fact that no one movement is ever replicated exactly. In it's barest form, Schmidt's theory negotiates these problems with a generalised motor program (GMP) for each given class of movement and a motor response schema which is an abstraction of the sought movement allowing it to be executed under the auspices of the particular GMP governing that class of movement.

> with a solution from memory on every trial and abandon the algorithm entirely. At that point, their performance is automatic. Automatization reflects a transition from algorithm-based performance to memory-based performance."

Logan goes on to argue that the learning mechanism in skill acquisition is the accumulation of individual episodic traces through experience, leading to gradual development from algorithmic (more explicit) processing to memory-based (more implicit) processing.[2]

1.3 Skill failure: From expert to inexpert

Regardless of the twists and turns in the passage of learning the characteristics of expertise would appear to involve functioning of an automatic, effortless, implicit nature. Expert performance can break down, however, if 'reinvested' with explicit knowledge. This has been expressed in a kaleidoscope of ways. Deikman (1969) called it 'deautomatization' which he conceptualized as the "undoing of automatization, presumably by *reinvesting actions and percepts with attention*" (p.31). Baddeley and Woodhead (1982) suggested that attempting to facilitate automated skills by isolating and focusing on specific components of the skill would often result in a decrement in performance, and Klatzky (1984) expounded on "the common notions that awareness of performance decreases with practice, and that becoming aware impairs execution of a skilled act" (p.62). Hammond (1987) offered this view when discussing slips of action, which are instances in which normally efficient tasks fail:

> "The automaticity framework suggests two basic causes of control failure: failures occurring when the person is in automatic mode but should have been exercising controlled

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[2] A storage problem identical to that present in Adam's Closed-loop Theory (see Footnote 1) exists in Logan's Instance Theory also. Logan's concept of the accumulation of individual episodic traces through experience makes no provision for the fact that countless specific traces must be stored in memory if every possible movement is to be accounted for. While there is no direct evidence that the brain would not be capable of handling such a problem, it would appear to be a very inefficient way in which to operate, given the flexibility of highly skilled performance.

> processing, and the obverse, where controlled processing interferes with an automatic process best left to its own devices." (p.167)

Henry and Rogers (1960) proposed a "memory drum" theory of neuromotor coordination which predicted that efforts consciously to control a movement would interfere with the programming, causing increased reaction latency and poor coordination:

> "The theory of neuromuscular coordination...holds that the detailed motor components of a fast complicated movement are controlled by a nonconscious motor memory mechanism that programs the flow of nerve impulses through the appropriate centers and nerves to produce the desired motor act. According to this theory, attempts to institute conscious control of the movement will interfere with the programming, thus increasing reaction latency and tending to cause a poorly coordinated movement."
>
> (Henry, 1960, p.459)

Henry hypothesised that on these grounds the reaction time and movement time of an individual using motor set to execute a skill, that is, directing attention towards the motor response or skill itself, would be slower than when using sensory set to execute the skill, that is, directing attention towards the stimulus. Indeed, Henry (1960) even showed that both reaction time and motor time were significantly slower when motor set was enforced.

Eysenck (1982) felt deautomatization could occur in even the most taken-for-granted skills:

> "For example, if you think too deeply about the leg movements involved in walking down a flight of stairs, you may well finish up in a heap at the bottom of the stairs." (p.13)

Schmidt (1982) was of the same opinion with regard to more complex motor skills. He felt that "when a person has a well-established movement program developed over years of experience, shifting to a feedback mode places the person in a control mode that is far less smooth and precise" (p.281). As an example, Schmidt suggested that asking a pianist to describe what the hands are doing whilst playing will focus attention on the specific hand and finger movements, causing degraded performance. Keele (1973) actually provided evidence of this in piano playing, and Langer & Imber (1979) illustrated the same phenomenon in typing. When the obverse of the phenomenon occurs, that is, the pianist becomes detached from what the hands are doing, supreme performance follows. For example, two very famous pianists were discussing their great performances on a British chat show (Saturday Matters with Sue Lawley, Oct, 1980). They were Victor Borge and Vladimir Ashkenazy. Borge asked of Ashkenazy, "Has it ever frightened you to play, and watch your fingers moving, and not know who it is that is making them move?".

Support for this is evident in research questioning whether motor-skill acquisition follows the Anderson (1982) progression from declarative to procedural knowledge (Burnett, 1983). It was argued that execution of a secondary task while batting a baseball might influence experts and non-experts differently if batting the ball was proceduralised for experts and declarative for non-experts. One of Burnett's findings was that experts performed significantly better than normal in a secondary task requiring them to recall the colour and location of ribbons on the wrist, elbow and upper portion of the pitcher's delivery arm. In later discussing this finding Allard & Burnett (1985) argued that "it is almost as if giving the declarative system of experts something to keep it busy makes it easier for the procedural system to get down to business" (p.310).

On a more conceptual basis optimum performance appears to follow from employing one route, the more implicit one, whereas lesser performance follows from employing the alternative, more explicit route. In terms of the previously mentioned theories of skill acquisition, performance will degrade if the performer reverts from procedural to declarative processing (Anderson, 1982), automatic to controlled processing (Schneider & Fisk, 1983; Schneider & Shiffrin, 1977; Shiffrin & Dumais, 1981) autonomous to cognitive processing (Fitts & Posner, 1967), direct retrieval to algorithmic-based performance (Logan, 1988) or indeed from open-loop to closed-loop type performance (Adams, 1971; Schmidt, 1975).

1.4 Stress and skill failure

This path emerges at a problem faced by countless performers in sport. It is the inability to cope with pressure of competition. An end product is 'choking' - the failure of normally expert skill under pressure: the double fault in tennis when facing match point, the missed 10-inch putt in golf when needing par. The classic example of 'choking' is the situation where the athlete performs outstandingly in practice but poorly in competition (Leith, 1988). All coaches can name individuals, who, in practice, not competition, are capable of knocking off Nicklaus or beating Borg. Even Freud (1922) referred to this:

> "Many acts are most successfully carried out when they are not the object of particularly concentrated attention... mistakes may occur just on (those) occasions when one is most eager to be accurate." (p.23)

That stress can result in skill failure is incontestable, but that stress brings this about by causing a regression from automatic back to controlled processing due to reinvestment of explicit knowledge requires more than supposition. Again, there is little empirical evidence to be called upon. The Bliss-Boder hypothesis, derived from the work of Bliss (1895) and Boder (1935), says that the effect of competition is that performers consciously monitor their performance, and more recently Baumeister (1984) has argued that competitive pressure encourages the performer to want to do well and hence results in a tendency to focus on the process of performance, but these claims appear to have little empirical backing.

Relevant at a theoretical level may be concepts such as 'composition' (Neves & Anderson, 1981) which is said to occur during the development of automaticity, and is the chunking of "productions" to form single, direct representations of actions. Salmoni (1989) claims that the rapidity of automatic performance results from this process of composition, because the time taken to carry out a skill is proportional to the number of productions fired. Both Anderson (1982) and Klatzky (1984) agree with this in the sense that direct execution of procedures will be quicker than running an action with declarative knowledge. Klatzky (1984, p.55) encapsulates this rather well:

> "The essence of heirarchical structures, whether perceptual, motoric, or conceptual, is that many elements at one level are nested under a single element at a higher level. The arrangement is not arbitrary, in that elements at the lower level "go together" in some sense to form an integrated unit or chunk. The single element at the higher level can be conceived of as an index or unit for all the components in the chunk. This arrangement has some obvious economical virtues when it comes to performance; control of the single chunking element may suffice to coordinate the individual components."

In this context it becomes possible that stress may lead to some level of 'decomposition', that is, a partial fragmentation of the conglomerate representation to individual or lower-order clusters of production units. Another way to view this is that with chunking or composition comes a shift of attentional control to higher-order nodes (Pew, 1974). Stress may involve a regressional shift of attentional control, resulting in a return to use of lower-order production units. The result of attempting to run the skill with these would be slower, less fluent performance, in other words, performance more reminiscent of the learner.

Is it possible that the general idea is exemplified in the experiences of Jaroslav Drobny, one of the great post-war tennis players? As a Czech, he spent many of the war years in forced labour for the Nazis, but survived and became a naturalised Englishman. He was a great favourite with the English public and "played in some of Wimbledon's most dramatic and emotional matches" (Barrett, 1986, p.393). In 1953, despite three appearances in the final at Wimbledon, he still had not taken the crown of tennis. He, and most experts of the day, attributed this to the backhand he had acquired, without coaching, as a small boy in Czechoslovakia. It was most unorthodox - definitely not to be found described in coaching manuals. 'Drob', as he was affectionately known, decided to take some time from serious competitve tennis in order that he might develop a technically correct, 'by-the-book' backhand with which to at last snatch glory. Sometime later, sporting his new, explicitly acquired backhand, he played "The Championships" (Wimbledon to the uninitiated). He was thirty-three. The new backhand took him through the first rounds against weak opposition, but in the final he met Ken Rosewall, a young Australian who would go on to be regarded one of the great players of all time. Under extreme pressure from Rosewall, Drobny found his beautiful new backhand breaking down - he found himself attempting again and again to operate the backhand consciously with his explicit knowledge of it. Finally, when all seemed lost, Drob reverted to his trusty old implicitly acquired backhand, and proceeded to snatch victory from the jaws of defeat.

1.5 Theories relevant to the role of stress in performance

A number of models of stress and performance have been proposed. Predominant has been the inverted-U hypothesis (Yerkes & Dodson, 1908), which attempts to explain the stress/performance relationship in terms of arousal levels. That is, an optimum level of arousal exists for all acts. Should the performer go above or below that level, performance will deteriorate. The implication, as is obvious from Figure 1.1, is that as the level of arousal increases performance will improve, until a peak is reached and any further increase leads to deterioration in performance. Arousal is regarded as a response in which the organism is galvanised for activity (Duffy, 1962). The activation response, in terms of neural excitation, lies on a continuum from deep sleep to high excitement (Malmo, 1959). As will be discussed, the unidimensionality of this definition of arousal leads to difficulty in characterising the arousal/performance relationship. Oxendine, (1970) popularised the inverted-U notion in sports performance with the assumption that gross motor acts, such as boxing, weightlifting and sprinting, requiring strength, speed and endurance need a high level of arousal for peak performance, whereas complex motor acts, such as archery, golf-putting and darts, calling for steadiness and fine coordination require a low level of arousal for optimum performance. At first glance this seems very sensible; however, criticism has been aimed at the inverted-U hypothesis on a number of levels. For example, the categories are too broad. Skills within sports vary greatly. Some may call for high arousal and some low. An archer may require a high level of arousal to draw the bow, but a low level to direct the arrow. A tennis player may need a high level of arousal to maintain the fierceness of his or her serve, but a low level of arousal to make a delicate drop-volley off the return of that serve. Furthermore, the hypothesis ignores obvious variables such as the skill level of the performer, the perceptual characteristics of the skill and the decision-making requirements.

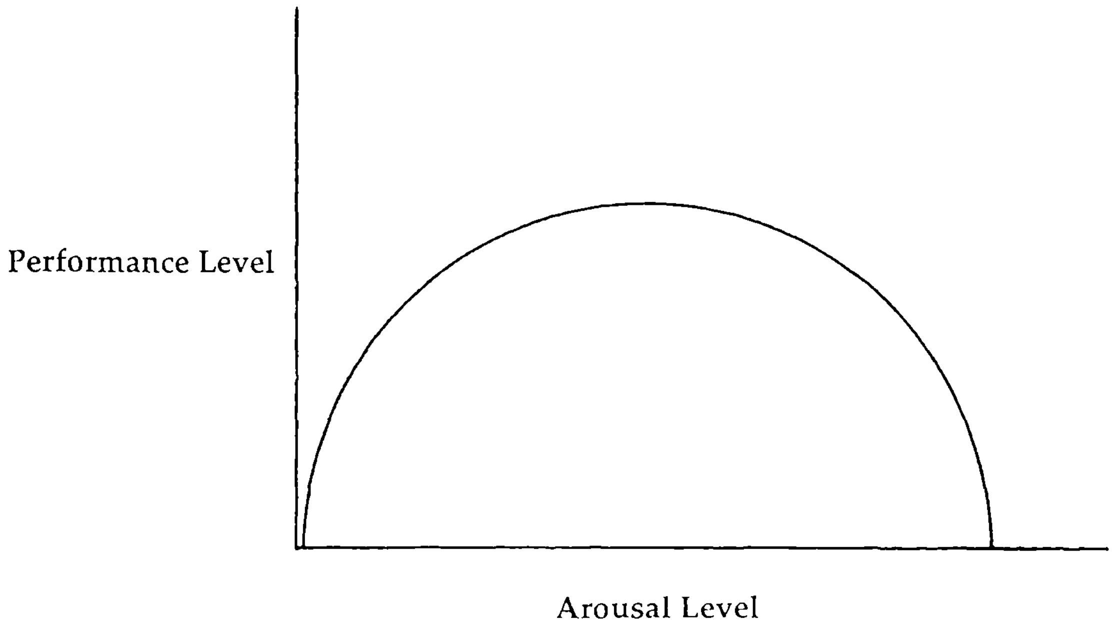

Figure 1.1 The inverted-U performance/arousal curve.

In an effort to clarify the link between stress and arousal Levi (1972) gave the inverted-U hypothesis a brief lease of life by suggesting that the individual becomes more stressed as the level of arousal moves further above or below the optimum level. In other words, both underarousal and overarousal can lead to increased stress, and performance will be seen to decrease as the level of stress increases. This idea is baulked by some simple obstacles. It is the individual's cognition of the situation that controls the level of stress (Cox, 1978; Neiss, 1988; Sanders, 1983), so low arousal, for example, is not necessarily stressful to the person trying to sleep. Nor is overly high arousal necessarily stressful to the boxer preparing for the brutality of the ring. In fact, it may be seen as very positive. Another obstacle is simply that no explanation is provided for why levels of arousal above or below the optimum will impair performance. Weinberg (1989) tried to improvise an explanation with Easterbrook's (1959) original idea that arousal and emotion will influence the rate and quality of cue utilization. As arousal level increases past the individual's optimum level the breadth of attentional selectivity will narrow and cues relevant to successful performance will be missed.

There are problems also with the descriptive validity of the inverted-U. For instance, Hardy & Fazey (1987) argued that its symmetry is unwarranted. They claimed that it is normal for overarousal in a performer to lead to a dramatic deterioration in performance rather than a gradual decline, and moreover, reducing the level of arousal does not, as the inverted-U curve suggests, mean performance will merely return to normal. They pointed out that it is with some difficulty that performance is returned to normal following such a dramatic deterioration. Hardy & Fazey (1987) proposed an alternative, catastrophe model, of the stress/performance relationship. This is based on Thom's (1975) concept of catastrophe theory, developed to model abnormalities in continuous functions - points at which the normal continuity of the function is broken. Hardy & Fazey argued that cognitive anxiety and physiological or autonomic arousal are the two dominant components of stress, with cognitive anxiety determining the strength of the physiological-arousal effect. The three-dimensional structure of the model, as seen in

Figure 1.2, generates clear predictions. For example, the model suggests that high physiological arousal will lead to a deterioration in performance as cognitive anxiety increases, whereas, low physiological arousal will lead to an improvement in performance as cognitive anxiety increases. Furthermore, low cognitive anxiety will result in a moderately inverted-U shape relationship between physiological arousal and performance (back face: Fig. 1.2), whereas, high cognitive anxiety will lead to a 'cusp' type performance curve as physiological arousal increases (front face: Fig. 1.2).

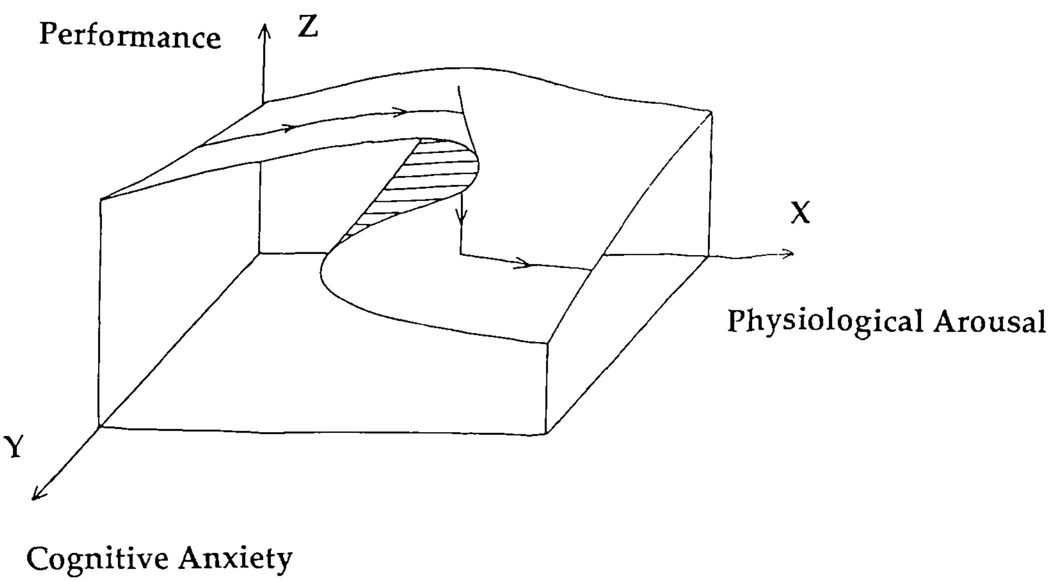

Figure 1.2. The catastrophe model of the relationship between stress, autonomic arousal and performance (Hardy & Fazey, 1987).

Hardy & Fazey described what can occur in the high cognitive anxiety condition as 'hysteresis'. Seen more clearly in Figure 1.3 the performance curve initially parallels the inverted-U curve, in that, as physiological arousal increases performance improves, until a peak is reached. In this case the peak, it is argued, will occur when the performer begins to doubt his or her ability to meet the demands of the situation. At such a point performance deteriorates drastically, and the original performance level can only be recovered if the level of stress is reduced enough for the performer to regain the upper curve. In other words, perfomance follows a different path depending on whether physiological arousal is increasing or decreasing. Hardy, Parfitt & Pates (1990) have provided some support for catastrophe theory by showing what appears to be hysteresis in performance of a basketball set shot. By manipulating physiological arousal (heart rate) under conditions of high and low cognitive anxiety, through testing either one day before or one day after a major basketball game, they were able to show that performance followed a different path when heart rate was increasing from when heart rate was decreasing under the high cognitive anxiety conditions, but not under the low cognitive anxiety conditions. The path parallelled the predicted hysteresis curve. A similar result was evidenced in experienced crown green bowlers. Further to this, in both cases Hardy *et al* were able to show catastrophic drops in performance under high cognitive anxiety.

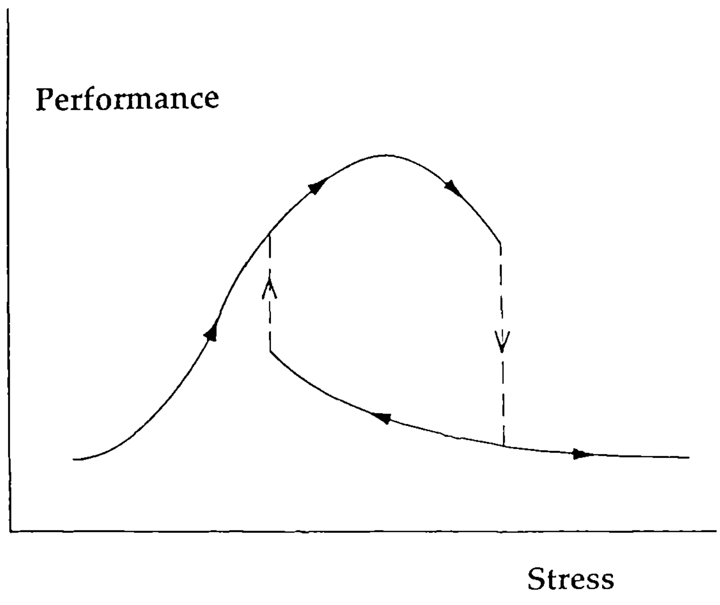

Figure 1.3. Hysteresis, as predicted by the Hardy & Fazey (1987) model under conditions of high cognitive anxiety.

In attempting to offer a more comprehensive explanation of the stress/performance relationship Hardy & Fazey highlighted the risk attached to employing a 'unidimensional' approach to explain such a complex relationship. They emphasised that arousal and anxiety are multidimensional in nature. The idea that one general arousal system is enough to explain the stress/performance relationship has lost considerable ground to multiple systems models (Hamilton, 1959; Broadbent, 1971; Eysenck, 1982, 1984; Hockey & Hamilton, 1983; Sanders, 1983). For example, Hockey & Hamilton (1983) argued that the stress/performance relationship is actually founded on the effect of arousal on processing efficiency, rather than on performance '*per se*'. Their argument was that different stressors, such as noise, motivation, temperature, accuracy, selectivity and short-term memory and so-on, affect different components of performance in different ways. Upon endeavouring to register the specific subcomponent of performance affected by a stressor they found, for instance, that loud noise leads to increased rapidity of information processing, bettter recall of strongly associated items and greater attentional selectivity, but impaired recall of poorly associated items and degraded working memory. A weakness with the research is a discrepancy between the stressor (loud noise) and the type of performance called for (i.e., verbal recall). Ecologically, the type of performance one would expect to fall under such a stressor would be more likely to be a motor task such as that required in an engineering work shop or on a work site, rather than a verbal recall task (Adams, 1983; Parfitt, Jones & Hardy, 1990). A classic example of research which has considered stressors more ecologically relevant to the type of performance is the work by Baddeley (1966) in which he considered diving performance in a pressure chamber and the sea. He found that manual dexterity was poorer in the sea and concluded that there are more or greater stressors in the sea. Later research showed a similar relationship with visual search and short-term memory tasks (Lewis & Baddeley, 1981).

Despite the drawbacks with the work of Hockey & Hamilton (1983) it has served to initiate a slight change in direction in the use of intervention techniques used in sport psychology when attempting to overcome problems thrown up by the stress/performance relationship. That is, the focus is shifting away from emotional-control strategies, such as relaxation techniques commonly used to reduce stress levels in the performer, towards strategies which fall more into the information-processing domain. As an example, Jones & Hardy (1988) suggest that to reduce working-memory deficits performers could learn under dual-task restrictions in order that they learn to make performance-relelvant decisions under stress. Both Guttman (1987) and Kuhn (1987) have shown that this can work. Jones & Hardy also suggest that in situations where a performer suffers from 'hyperdistractability' due to increased selectivity associated with high anxiety, desensitization might be employed to accustom the performer to distractions relevant to the performing environment. Attention-control strategies might also be employed in such a situation.

Following on from the Hockey & Hamilton ideas, Hockey, Coles & Gaillard (1986) proposed a 'wet' model approach to the examination of the stress/performance relationship. This approach required the model to account for the variability in efficiency of the organism's information processing capability under varying environmental and/or internal states. It was argued that any model of the stress/performance relationship must register variablity generated by state changes, such as those occurring in behaviour under stress, or processing changes related to patterns of biological activity in the performer, or indeed individual differences.

A multidimensional, 'wet' model relevant to the relationship between stress and performance in sport was advanced by Sanders (1981, 1983). It suggests that the influence stress has on performance is due to the interaction between 'energetical supply mechanisms' and cognitive processes. The structure of the model is supplied by three neurophysiological systems identified by Pribram & McGuiness (1975) as involved in attention control. They are an 'arousal' system controlling physiological reponses, an 'activation' system controlling tonic readiness to respond and an 'effort' system which coordinates the arousal and activation systems in order to ensure that they accurately coordinate perception with action (therefore, achieving successful decision-making). Such coordination is seen to require effort. According to Jones & Hardy (1988) effort is a "coordinating mechanism in the sense that it attempts to correct any imbalances in the basal arousal and activation mechanisms in order to produce maximal performance" (p.53). They apply Sander's model to a tennis player returning serve. The player has first to perceive the ball in flight (effective perception relies on the state of arousal), then decide on the return shot (such decision-making being influenced by effort) and finally prepare to execute the shot (such preparation being influenced by the state of activation). A modified version of Sander's (1983) model, proposed by Jones & Hardy (1988) is useful in explaining some situations in sport where stress leads to poor performance (Figure 1.4).

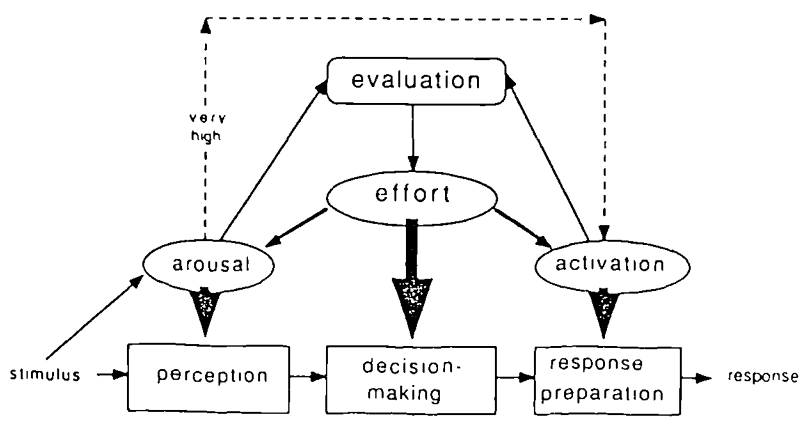

Figure 1.4. The modifed version of Sander's (1983) model of the stress/performance relationship (Jones & Hardy, 1988).

The model has a valuable additional characteristic. Very high arousal can result in an 'overflow' to the activation system, so by-passing the decision-making system. This allows for more rapid responses in well-learned skills, but is disadvantaged by the increased likelihood of inappropriate repsonses due to poor decision-making. An example might be the squash player who, too highly aroused during an important point, reacts very rapidly to the opponent's shot but only to hit it directly back to the opponent, rather than, with the intervention of the decision-making system, making the appropriate decision to play the ball to the furthest part of the court from the opponent. The Zen philosopher might use the example of a swordsman who loses his head in the heat of the battle[3]. Perceiving an opportunity for the '*coup de grace*' the swordsman, in his haste, fails to account for his opponents sword as he drops his guard to make the killing thrust.

Slightly less complex models were proposed by both Broadbent (1971) and Eysenck (1982, 1984). Both distinguished between two arousal systems. On the one hand, a passive arousal system responsive to the task demands and the stuation, and on the other hand, a cognitive control system responsive to the needs of the first system, and able to provide a compensatory boost of 'effort', so to speak, when performance is less than adequate. In many ways this approach is similar to that of Sander's, except that two rather than three systems are required. All three models see effort as a mechanism responsible for correcting imbalances between arousal and activation, with optimum performance the goal.

Another theory with relevance to the stress/performance relationship is Apter's (1982) theory of psychological reversals, as applied to sporting contexts by Kerr (1987a,b,c, 1989). This theory is very much founded on the 'structural phenomenology' of the way an individual experiences and responds to his or her levels of motivation. Reversal theory allows for the existence of four pairs of 'metamotivational states' that can move or reverse in either direction: telic-paratelic, negativism-conformity, autic-alloic and sympathy-mastery. Of greatest interest to Kerr is the telic-paratelic pairing.

3 Pun not intended.

The paratelic state encompasses behaviour of a spontaneous, playful nature preferring high arousal levels, whereas the telic state encompasses behaviour of a serious, planning nature preferring low arousal levels. Under conditions of high arousal reversals can occur between telic and paratelic states, and may explain performance in some individuals claims Kerr (1985a). The classic example being the sudden and often dramatic swings in the behaviour of John McEnroe. Kerr argues that the telic-paratelic pair are relative to sport because they are concerned with the individual's experience of felt arousal and hedonic tone. Felt arousal refers to the individual's feelings of being 'worked up', whereas hedonic tone refers to the individual's experienced pleasure. Different levels of arousal are preferred in the telic and paratelic states. feelings associated with high or low arousal are characterised by excitement, anxiety, boredom or relaxation. Individuals in the telic state experience low arousal as relaxing and pleasant, but high arousal as anxiety provoking and unpleasant. On the other hand, those in the paratelic state experience high arousal as exciting and pleasant, but low arousal as boring and unpleasant. Figure 1.5, borrowed from Apter (1982), illustrates this relationship.

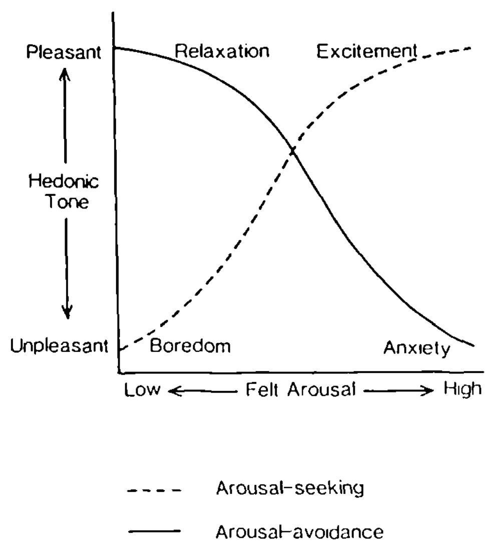

Figure 1.5. The telic-paratelic relationship in Reversal Theory (Apter, 1982).

Reversals can occur if the individual becomes frustrated and his or her needs are not being met, or if events occur to trigger a reversal, such as a change in the environment or in the biological readiness to perform. Reversals may also occur when the individual reaches a satiation point, that is, where too much time has been spent in one state. Examples, such as hang-gliding or public speaking serve to illustrate reversals. When first performed these are accompanied by high arousal, which is experienced as unpleasant anxiety, but after a number of performances a telic to paratelic reversal may occur and the unpleasant anxiety can be experienced as exhilaration or pleasant excitement. Individuals can be predisposed towards spending more time in one metamotivational state than the other, implying a telic or paratelic dominance according to Murgatroyd (1985), who went as far as to develop a Telic Dominance Scale (TDS) to measure this (Murgatroyd *et al*, 1978).

In terms of the stress/performance relationship it has been shown that telic and paratelic dominant individuals can respond differently to stress (Martin, 1985; Martin *et al*, 1987). In particular, the theory seems to predict that increases in the effect of stress can facilitate performance. Martin *et al* (1987) compared telic dominant and paratelic dominant individuals on a video game under stressful (your performance will be compared with the others so do your best) and non-stressful (play for fun) conditions. It was shown that paratelic dominant subjects performed better in the stressful as opposed to non-stressful conditions, whereas the opposite was true for the telic dominant subjects. Moreover, the the paratelic group performed better in the stressful condition than the telic group did in either condition, suggesting to Martin *et al* that paratelic dominance has a stress-moderating effect which may actually provide the individual with enhanced pleasure and excitement from performing under stress.

The complexity of the stress/performance relationship deepens when other individual differences are considered. For instance, individual differences in augmenting and reducing (Petrie, 1967), extraversion and introversion (Eysenck, 1967) and sensation seeking (Zuckerman *et al*, 1964) have been explained in terms of arousal-based models, such as stimulus intensity control (Roger & Raine, 1984). Reducers, extraverts and high sensation seekers have been found to have a greater tolerance to high levels of stimulus intensity than augmenters, introverts and low sensation seekers (Phillip & Wilde, 1970; Zuckerman *et al*, 1966; van Knorring, 1974). In this sense, complications must arise in theories, such as Reversal theory (Apter, 1982; Kerr 1987a, 1989) and Catastrophe theory (Hardy & Fazey, 1987), which predict dramatic changes in dimensions of performance as arousal levels alter.

Another example of the complications created by the vast individual differences literature, is the evidence that females generally exhibit higher levels of sport specific trait anxiety than males (Martens, 1977) and that they have also been found to report higher levels competitive state anxiety (Jones & Cale, 1989b). Whatever the reasons for this, such differences increase the interactive intricacies of the stress/performance relationship. One question often addressed in this respect is concerned with the distinction between the cognitive and somatic components of anxiety - which results in the failure of the skill? The cognitive component is that involving conscious concern about one's performance (worry) and interferes with cognitive performance, whereas the somatic component (emotionality) is that involving interference with motor performance due to physiological effects such as hand tremors and degraded coordination (Morris, Smith, Andrews & Morris, 1975).

Although Morris & Liebert (1969) speculated that the somatic component of anxiety would interfere with motor performance subsequent research with typewriting skills showed no significant correlation. Instead a significant negative correlation existed between the cognitive component and performance. More recently, research employing the Competitive State Anxiety Inventory (Martens, 1977) which assesses state levels of both cognitive and somatic anxiety as a function of competition has provided mixed evidence on the effects of each component on performance (Burton, 1988; Caruso, Dzewaltowski, Gill & McElroy, 1990; Gould, Petlichkoff, Simons & Vevera, 1987; Parfitt & Hardy, 1987; Ussher & Hardy, 1986). One explanation suggested by a number of researchers for this lack of agreement

(Gould *et al*, 1987; Parfitt & Hardy, 1987; Ussher & Hardy, 1986) has been that different skills may have a bias towards negative correlations with either cognitive or somatic anxiety depending on their neuromuscular characteristics. For example, Gould *et al* (1987) suggested that pistol shooting, which they found to exhibit a negative performance versus somatic anxiety correlation, would be more sensitive to altered physiological arousal due to the fine neuromuscular control required for successful performance.

A number of theories have been advanced as consistent with the disparity in results. In particular, Humphreys & Revelle (1984) proposed a model employing dual systems (arousal and on-task effort). The model is somewhat similar to those of Broadbent (1971), Eysenck (1982, 1984) and Sanders (1983), in that, on-task effort is regarded as something of a compensatory control system responsible for allocating resources. Unlike the previously mentioned models arousal is seen as a unidimensional factor linked with alertness. The model endeavours to predict performance on sustained information transfer (SIT) and short-term memory (STM) tasks. Basically, SIT tasks do not call for retention of information, whereas, STM tasks do. Humphrey & Revelle argued that performance on SIT tasks should be improved by increases in both on-task effort and arousal, but STM skills would degrade under high levels of arousal. Finally, the model accepts that performance can be influenced by somatic anxiety resulting in increased physiological arousal, or cognitive anxiety resulting in increased on-task effort. Increased somatic anxiety would improve performance on SIT tasks, whereas increased cognitive anxiety would degrade performance on SIT tasks. Increased somatic anxiety in high-trait anxious performers would degrade STM performance more than in low-trait anxious performers. Although the model is not directly aimed at sporting skills, and although the SIT/STM distinction seems somewhat limited, it serves to (a) offer an explanation of findings such as those provided by Gould *et al* (1987) in the area of pistol shooting and (b) implies, as Jones & Hardy (1988) point out, that the stress/performance relationship "...is determined by a complex interaction between the psychological make-up of the individual, the nature of the stressor encountered and the cognitive requirements of the skill being performed" (p.58).

Borkovec (1976) appears to be one of the few authors to directly suggest the obvious possibility that cognitive and somatic anxiety are so intertwined that one will directly influence the other. In terms of the stress/reinvestment of controlled processing/performance relationship this would lead to the argument that the cognitive component of anxiety interferes with cognitive performance (leading the performer to consciously think about, and eventually attempt to control consciously, his or her skill) and this cognitive interference manifests itself in interference with motor performance by decreasing muscular coordination (a symptom of somatic anxiety) due to forcing the system to process too many commands.

Vague lateral support for this is evident in a study by Weinberg & Hunt (1976) in which participants learned to throw a ball at a specific target. Electromyographic recording of the electrical activity in the muscles during this task showed that the muscular activity of trait-anxious participants was less efficient than in non-anxious participants. The authors suggested in explanation that trait-anxious individuals may be more likely to 'cortically steer' and control the movement they are making.

Such a 'reinvestment' of controlled processing in automatic skill may explain choking, and indeed, may explain more severe forms of choking, such as 'dartitis' or the feared 'yips'[4] . That is, under pressure, the individual begins thinking about how he or she is executing the skill, and endeavours to operate it with his or her explicit knowledge of its mechanics. Indeed, it would appear that Zhivago is correct - the beam of consciousness turns inwards and a catastrophe occurrs.

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4 'Dartitis' is an affliction occasionally suffered by darts players which causes great difficulty in releasing the dart smoothly from the fingers at the end of the throwing movement. The 'yips' are similar in that they are an affliction suffered by golfers causing extreme difficulty in making a smooth strike of the ball during putting.

1.6 The thesis structure

The studies which follow explore issues arising from the prior discussion. Study 1 is launched from the premise that failure of expert motor skill is common in cases where performers are highly motivated to succeed and that one cause of this can be an inward focus of attention in which an attempt is made to perform the skill by consciously processing explicit knowledge of how it works. The resulting disruption of the automaticity of the skill leads to its failure. It follows from this that disruption of automatic processing will be avoided if performers have little or no explicit knowledge of their skill. Subjects in the reported experiment were required to acquire a golf-putting skill, either explicitly (with knowledge of rules) or implicitly (without knowledge of rules) and were then tested under conditions of stress, induced by a combination of evaluation apprehension and financial inducement. Evidence was found to partially support the hypothesis that the skill of performers with a small pool of explicit knowledge is less likely to fail under pressure than that of performers with a large pool of explicit knowledge.

Study 2 tacks slightly from the debate in Chapter 1 in order to solve a problem which only became apparent following on Study 1. When manipulating the acquisition of a motor skill in order to bring about implicit learning the performer is asked to learn a primary task while at the same time carrying out a secondary task. The purpose is to restrict the amount of explicit knowledge the performer adds to any existing knowledge about the primary task. The aim of the investigation was to explore whether surges in performance seen upon withdrawal of the secondary task in the implicit learning condition were due to the lifting of an embargo on processing resources or to a 'reminiscence' phenomenon resulting from a rest period following massed practice of the primary task. Two implicit learning groups and two discovery learning (control) groups performed a golf-putting skill under either massed or spaced practice conditions. While the massed implicit learning condition depressed performance (although not significantly more than the spaced implicit learning condition), no reminiscence effect was seen in either condition upon suspension of the secondary task. It was concluded that an easing of demands on processing resources, not a reminiscence effect, is responsible for post-secondary task surges in performance which may occur following suspension of secondary task restrictions during implicit learning.

Study's 3, 4, 5 and 6 explore the idea that 'reinvestment' of controlled processing may be a dimension of personality. In Study 3 it was hypothesised that individuals may have a predisposition towards 'reinvestment' of controlled processing, which will lead to skill failure under stress as a result of disruption of the automatic functioning of the skill. Factor analysis of a number of established personality measures related to the concept of reinvestment uncovered a reliable 20-item factor which appeared to be associated with reinvestment. In the fourth study a predictive validation of this 'Reinvestment Scale' was attempted. It was predicted that the motor performance of high scorers on the scale would be more likely to fail under pressure than that of low scorers, on the grounds that high reinvesters would be more likely to disrupt the smooth functioning of their own skill by investing it with controlled processing. High and low reinvesters learned a two-dimensional rod tracing task to a level of performance approaching asymptote and were then required to perform under conditions of stress. Despite highly significant increases in the levels of stress exhibited, performance was unaffected in both groups, thus providing neither support for nor refutation of the prediction. An explanation of this was that the rod tracing task was not complex enough to present the kind of demands that would lead to reinvestment. Hence, a fifth study was carried out in which a more complex, golf-putting skill was considered. In this instance support was found for the prediction that the performance of high scorers on the Reinvestment Scale would be more likely to fail under pressure than that of low scorers. Finally, a sixth study was carried out in which further validation was sought by exploring whether a relationship existed between the reinvestment scores of university team squash and tennis players and the opinion of informed raters on their tendency to 'choke' under pressure. A strong relationship was found, providing further evidence that high reinvesters are more likely to suffer from performance breakdown under pressure. It was concluded that the Reinvestment Scale does indeed assess a predisposition towards reinvestment of controlled processing, and may prove to be a valuable instrument in predicting skill failure in stressful situations involving complex, rule-bound skills.

Finally, in Chapter 5 issues and findings emanating from this research are discussed in the context of acquisition of skill, attainment of expertise and avoidance of skill failure, along with some debate on the possibilities for future investigation, and perhaps most importantly, insight into the practical implications and applications of the research.

Chapter Two

The role of explicit versus implicit knowledge in the breakdown of a complex motor skill under pressure*

2.1 An introduction to Study 1

The experiment to be described will test the proposition that disruption of the automaticity of a skill under pressure may be avoided if explicit knowledge of that skill is restricted; that is, should a performer have no pool of knowledge to consciously call upon when performing a relatively automatic skill then attempts to consciously run the skill would be expected to fail. In a sense the aim here is to block the path from procedural back to declarative processing, in Anderson's (1982) terms, or automatic back to controlled processing, in Schneider & Shiffrin's (1977) terms, or direct retrieval back to algorithmic processing, in Logan's (1988) terms, or even open-loop back to feedback-based performance, in the term's of Adams (1971) or Schmidt (1975).

The experiment will employ two phases. In the initial phase, individuals will acquire the complex motor skill of golf putting, either explicitly, through specific written instruction on how to putt, or implicitly, through a dual-task method (Baddeley, 1966) in which constant verbal generation of random letters at a specific rate is required whilst learning to putt. The rationale behind this is that the secondary task is a resource-limiting device which will place such demands on short-term memory capacity that accretion of explicit

* Based on Masters, R.S.W. (1992). Knowledge, knerves and know-how: The role of explicit versus implicit knowledge in the breakdown of a complex motor skill under pressure. *British Journal of Psychology*, 83, 343-358.

putting-skill knowledge will be virtually nil. A variety of control conditions will also be run.

This generates a strong prediction that individuals receiving written instructions will have a greater pool of explicit knowledge than those not receiving written instructions. A more instructive prediction is that individuals learning implicitly will have a smaller pool of explicit knowledge than those learning for themselves, that is, by discovery.

In the second phase, the differently acquired putting skills will be tested under conditions of stress. Stress is to be induced using Cottrell's (1972) evaluation apprehension paradigm, which posits that apprehension will arise in situations where there is anticipation of positive or negative outcomes contingent on evaluation by an audience. Anticipation of a negative outcome will be caused in the present experiment by emphasising that the evaluator (a supposed golf professional) will have instructions to reduce payments should performance be poor. A point favouring the use of evaluation apprehension in this way is that the presence of an audience has been argued to induce a self-attentive state in which attempts are made to conform with correct standards of performance (Wicklund & Duval, 1971; Carver & Scheier, 1981). In other words, reinvestment of controlled processing is more likely to take place in an effort to modify performance with one's explicit knowledge of how it should be executed.

A number of checks will be made on whether apprehension does arise. The state scale of the State-Trait Anxiety Inventory (Spielberger *et al*, 1970) will be administered under stressed and unstressed conditions, thus yielding a repeated measures view of each subject's apprehension. Heart rate will also be monitored under stressed and unstressed conditions, yielding a second indication of the effects of stress. The state-anxiety scale assesses immediate feelings of worry, tension, apprehension and nervousness. Heart rate reflects the physiological response to such state anxiety. One further check will be made on whether evaluation apprehension has been successfully induced. The time taken to complete each putting session will be recorded. According to Zajonc (1972) and Innes & Young (1975), if the subject endeavours to gain the maximum positive outcome from an evaluative situation in which he or she has been asked to work on a complex task as errorlessly as possible, then performance will slow down in order to minimize errors. In a meta-analysis of some 241 studies, Bond & Titus (1983) agreed that, in the presence of others, complex tasks "seem to be performed more slowly" (p.282). In the present case, subjects will be required to hole as many putts as possible out of one-hundred attempts during each session; in other words, to perform as errorlessly as possible. It is therefore hypothesised that, given the absence of time constraints, apprehension will be indicated by slower performance.

The Cognitive Failures Questionnaire (CFQ), devised by Broadbent *et al* (1982) to assess the tendency to have 'slips of action', will be administered. The result of such slips is "a departure from the normal smooth flow of function, and events do not proceed in accordance with intention" (Broadbent *et al*, 1982, p.1). This would appear to relate to the breakdown of motor skills in that the reinvestment of conscious processing may cause events not to proceed "in accordance with intention". In addition, Broadbent *et al* argued that a high CFQ score may reflect a high 'vulnerability' to stress. They felt this to be reasonable "in terms of the view that stress has its major effects on those who cannot cope cognitively" (p.13). A similar view is held by Reason & Mycielska (1982). They say that "the tendency to make a lot of these errors in all circumstances suggests that the person in question lacks some degree of resistance to stressful situations which is not shared by those who are less error-prone" (p.36). The question surfacing in the present context is, will such vulnerability to stress manifest itself in failure of skill? That is, will a high CFQ score predict a high likelihood of skill breakdown under conditions of stress, and, *vice versa*, will a low CFQ score predict a low likelihood of breakdown.

2.2 Method

Subjects

Forty paid volunteers, novice to golf putting, were randomly assigned[1] to one of five conditions: implicit learning (IL), explicit learning (EL), implicit learning control (ILC), stressed control (SC) and non-stressed control (N-SC). Each group consisted of 8 subjects. Ages ranged from 18 to 46 years (M = 27.22).

Apparatus

Standard 'Ping' golf putters were used by all subjects. These were 35 in. (88.9 cm) in length with standard angle of lie and loft for a Ping 'Anser' putter. White 'Ping Eye' golf balls of standard dimensions (size 1.68 in. [4.27 cm]) were used by all subjects. Putts were made from a distance of 150 cm at a hole 10.8 cm in diameter (the size enforced by the United States Professional Golf Association [PGA]). Task difficulty was increased by requiring putts to be struck up a shallow incline (1:4). The putting surface was green, short-tufted artificial grass of the type known as 'astro-turf'.

Heart rate was monitored by means of a computerised finger attachment system, which produced a continuous plot for 180 s. An electronic metronome was used to emit 'clicks' at regular 1.5 s or 1.0 s intervals in the secondary task condition.

Design

The experiment had two distinct phases: a skill acquisition phase followed by a test phase. In the skill acquisition phase, taking place over four sessions of 100 putts, subjects acquired the complex motor skill of golf putting implicitly, explicitly or in one of the three control conditions. In the test

[1] It was not possible to pre-test and match subjects on initial skill level for reasons to be discussed in the results section.

phase, taking place over one session of 100 putts, subjects in the IL, EL and SC conditions, were subjected to stress while they performed, whereas those in the ILC and N-SC conditions were not subjected to stress while they performed.

Procedure

At the beginning of each session subjects, who participated individually, were required to sit quietly for a period of 5 min. to allow their heart rates to return to base line. The five sessions took place on consecutive days at the same time. In each session subjects made two sets of 50 putts separated by an inter-trial interval of between five and seven min. A global performance measure - the number of putts entering the hole - was used as the dependent variable.

No time constraints were imposed on subjects. The total time taken to complete the two sets of 50 putts (task-completion time) was recorded each day in order to provide information regarding the expected slowing of performance of the stressed groups in the test phase. The state scale of the State-Trait Anxiety Inventory (STAI) was presented in the inter-trial interval of the third and fifth sessions, while the Cognitive Failures Questionnaire (CFQ) was presented in the inter-trial interval of the second session.

All subjects were required to read a standard statement explaining that they would earn £12.00, and requesting that they not think about, rehearse or practice putting while away from the experiment.

Additional instructions, tailored to each condition, were also given. In the EL condition a set of very specific instructions on how to putt a golf ball were presented [see Appendix 1]. These were extracted from two reputable coaching sources (Saunders & Clark, 1977; Stirling, 1985), and presented in each of the first four sessions during the 5 min resting phase prior to heart rate measurement. It was impressed upon subjects that they should read these carefully and follow them as specifically as possible.

In the IL and ILC conditions, subjects received no instruction on how to putt, but were required to carry out Baddeley's (1966) random letter generation task in parallel with the putting task. The instructions, borrowed, almost verbatim, from Baddeley's (1966) experiment, required subjects to call out a random letter each time an electronic metronome 'clicked' [see Appendix 2]. In the two initial sessions, clicks sounded every 1.5 s. In the two latter sessions, clicks sounded every 1 s. It was hoped that by maintaining the difficulty of the secondary task in this way suppression of explicit knowledge would continue throughout the four sessions. Inter-click intervals of 1.5 and 1 s were too short to afford subjects the opportunity to divert attention away from random letter generation to the putting task. It was impressed upon subjects in both groups that they must not stop generating random letters at any stage of the putting session, and they must give priority to maintaining the randomness of the letters at all times. Immediately prior to the first session they received one minute of practice at this task. They were required to reread the instructions each day during the 5 min. rest period prior to heart rate measurement. The two groups differed in that the IL group was placed under stress during the final session whereas the ILC group was not.

Subjects did not receive putting instructions in either the SC or N-SC condition, nor did they carry out a secondary task while putting. The only proviso was that they improve as much as possible. These groups differed in that the SC group was placed under stress during the final session whereas the N-SC group was not.

In the fifth and final session the EL, IL and SC groups were placed in a stressful situation involving a combination of evaluation apprehension and financial inducement. Subjects in the EL condition were not required to reread the putting instructions, while those in the IL and ILC conditions were not required to carry out the secondary task. As in the previous four sessions, subjects sat quietly for 5 min. prior to heart rate measurement; however, during the middle 60 s phase of the 180 s monitoring period they were required to read a standard statement [see Appendix 3] explaining that the original payment of £12.00 could increase to £15.00 or decrease to as little as £1.00, depending on evaluation of their performance by an expert in golf. The suggestion that the sum of £12.00 could increase to £15.00 was introduced as a defensive measure against subjects feeling they had performed so poorly that they might as well make no further effort. It was felt that motivation to perform well would remain high if subjects believed they could win back money they lost. Ten seconds after presentation of the statement the evaluator arrived and was introduced to the subject before going behind a one-way mirror. To emphasize the evaluator's status as an expert he wore a golf pull-over and it was mentioned, quite erroneously, by the experimenter, that some years earlier he had played the British Open at St Andrews. As heart rate was still being monitored, it was possible to obtain an indication of the subject's physiological response to the prospect of such evaluation, and to the threat of losing almost all of the £12.00. This was done by comparing the initial 60 s of the 180 s monitoring period with the final 60 s. A significant increase in heart rate was accepted as indicating an increase in apprehension. The final session of 100 putts then began. In an effort to maintain the level of apprehension in the three stressed conditions, the evaluator was heard to cough at irregular intervals throughout the session. This coughing was prerecorded. Once the evaluator had retreated behind the one-way mirror he was free to leave by a hidden exit. In reality, no evaluation was made; all subjects received a lump payment of twelve pounds. *Neither the* ILC *group nor the* N-SC *group was placed under stress.* The ILC group was run to determine whether any change in the performance of the IL group in the fifth session was due to stress or to dispensation with the secondary task. Hence, in the fifth session, this group performed the putting task without the secondary task and without stress. Any difference between the two implicit groups could then be compared. The N-SC group was unstressed in order to determine whether performance continued to improve in Session 5 or reached asymptote.

On completion of the final session, subjects were required to write down all the factors they had become aware of over the five sessions, which they felt were important in hitting a perfect putt. In this admittedly primitive way the degree of explicit knowledge available to each subject was elicited. These written verbal protocols were scored by summing the number of explicit rules each subject wrote down. An explicit rule was understood to be any rule drawn from the explicit written instructions received or specifically relating to the technical and mechanical aspects of holing a putt. For instance, "I placed the ball in line with the inside of my left ankle" or "I pointed my left index finger down the shaft at the ball" would be classed explicit rules. Statements not referring to the technical and mechanical aspects of putting, such as, "I did it by feel", were excluded.

2.3 Results

Analysis Strategy

The main measures were analysed using analyses of variance, supported by analysis of simple main effects in instances of an interaction, Tukey's tests of honestly significant difference and orthogonal contrasting of *a priori* predictions. Pearson product-moment correlation coefficients were also computed where appropriate. Initially, the verbal protocols were considered to determine whether accretion and suppression of explicit knowledge were successful. Analysis of state-anxiety scores, heart rate and task-completion times followed, to determine the success of the stress intervention condition. Once this was established, the skill acquisition phase was analysed with regard to trends in the learning curves, which linked directly with analysis of performance changes in the test phase. Finally, it was asked if the Cognitive Failures Questionnaire would predict vulnerability to skill breakdown under pressure.

Verbal Protocols: Did the different conditions result in different degrees of explicit knowledge?

The verbal protocols were scored by counting the number of explicit rules written down by each subject. Figure 2.1 illustrates these in the form of a bar chart.

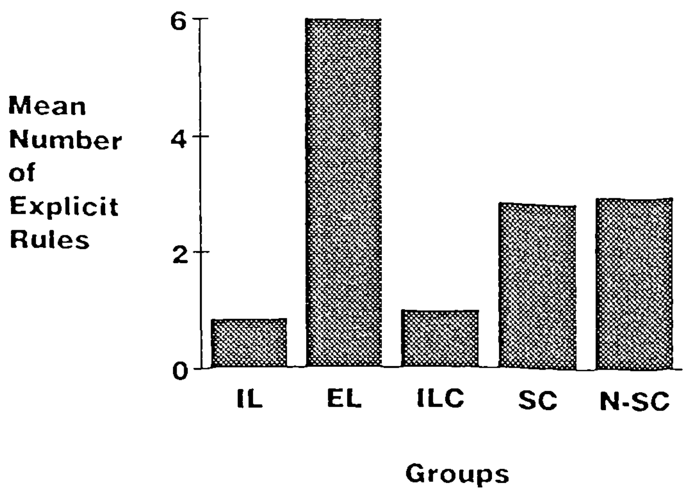

Figure 2.1. Mean number of explicit rules reported in the Implicit Learning (IL), Explicit Learning (EL), Implicit Learning Control (ILC), Stressed Control (SC) and Non-stressed Control (N-SC) groups

It was predicted that as the EL group's pool of knowledge was artificially enlarged by explicit instructions during learning, it would have a greater number of explicit rules than any other group. It was also predicted that due to the implicit nature of their learning the IL and ILC groups would have a smaller pool of explicit knowledge than the SC and N-SC groups, despite the fact that the SC and N-SC groups received no explicit instruction. One-way analysis of variance showed a highly significant main effect of the five learning conditions [$F(4,35) = 10.24$, $p < .001$]. Two orthogonal contrasts tested the specific predictions. Firstly, the EL group proved to have a significantly larger pool of explicit knowledge than the IL, ILC, SC and N-SC groups combined [$T(35) = 5.60$, $p < .001$]. Secondly, the IL and ILC groups combined held a pool of explicit knowledge far smaller than the SC or N-SC groups combined [$T(35) = 3.08$, $p = .004$]. These findings show that the different conditions were effective in controlling accretion of explicit knowledge during learning.

Test Phase: Was the stress intervention effective?

Two-way analyses of variance with repeated measures were carried out on each measure of anxiety level, followed by analysis of simple main effects in instances where a significant interaction occurred and on occasions where it seemed warranted (Howell, 1982). It was expected that the three stressed groups would exhibit greater increases in anxiety level than the two unstressed groups.

State Anxiety. Figure 2.2 displays the mean State Anxiety Inventory scores in Sessions 3 and 5 (pre- and post-stress intervention). A highly significant main effect was found over sessions [$F(1,35) = 15.32$, $p < .001$], but not groups. No significant interaction was evident [$F(4,35) = 2.05$, $p = .108$]. Normally, this lack of a significant interaction would prohibit further analysis; however, given the graphic impression that a substantial state anxiety increase occurred from Session 3 to Session 5 in only the three stressed groups, analysis of simple main effects was carried out. Highly significant increases were found in the three stressed groups - IL, EL and SC

- [F(1,35) = 7.57, p < .01, F(1,35) = 7.84, p < .01 and F(1,35) = 7.57, p < .01 respectively], but not in the unstressed groups - ILC, N-SC - [p > .05].

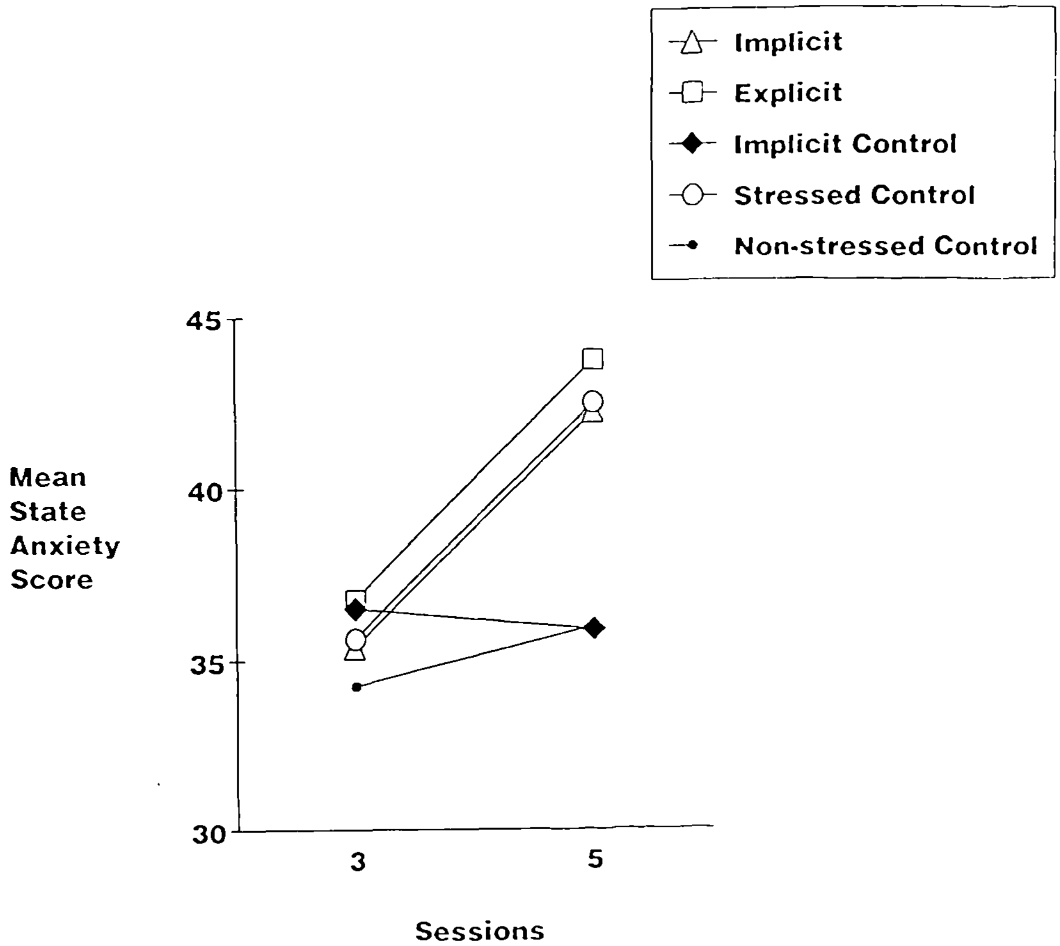

Figure 2.2. Mean State Anxiety scores in Sessions 3 and 5 [Stressed groups have clear markers and unstressed groups filled markers]

Heart Rate. Mean heart rates pre- and post-stress intervention in Session 5 are available in Table 2.1. A highly significant main effect of pre- versus post-stress intervention was found [$F(1,35) = 22.05$, $p < .001$]. Again, no interaction or main effect of groups was evident. For reasons identical to those in the state anxiety analysis analysis of simple main effects was again carried out despite the lack of a significant interaction. Heart rate increased significantly from pre- to post-stress in all three stressed groups: EL [$F(1,35) = 7.14$, $p < .05$], IL [$F(1,35) = 12.84$, $p < .01$] and SC [$F(1,35) = 10.29$, $p < .01$], whereas the unstressed groups (ILC and N-SC) showed no significant increase [$p > .05$].

Group	Stress Intervention	
	Pre-	Post-
Implicit	79.0 (13.0)	83.4 (13.2)
Explicit	81.4 (16.2)	84.7 (14.8)
Implicit Control	81.9 (9.9)	83.1 (9.3)
Stressed Control	81.8 (12.3)	85.7 (11.5)
Non-stressed Control	74.6 (11.5)	74.6 (10.9)

Table 2.1. Means and standard deviations (in parentheses) of heart rate (beats per minute) in groups pre- and post-stress intervention in Session 5

Task-Completion Times. Table 2.2 displays the mean time taken to complete the 100-putt task in Session 4 and in Session 5 (pre- and post-stress intervention). A highly significant main effect of sessions was apparent [$F(1,35) = 8.51$, $p = .006$]. The conditions by sessions interaction was also significant [$F(4,35) = 3.05$, $p = .029$].

Group	Sessions	
	4	5
Implicit	396 (96.6)	456 (103)
Explicit	471 (134)	490 (129)
Implicit Control	404 (99.3)	393 (92.9)
Stressed Control	409 (88.8)	456 (123)
Non-stressed Control	385 (70.5)	385 (69.2)

Table 2.2. Means and standard deviations (in parentheses) of task-completion times (seconds) in groups in Sessions 4 and 5

Analysis of simple main effects showed highly significant differences for only the IL and SC groups over sessions [$F(1,35) = 11.70$, $p < .01$ and $F(1,35) = 7.33$, $p < .05$ respectively].

It is clear from the three measures of anxiety that the stress intervention was effective. The stressed groups (IL, EL and SC) all experienced some degree of performance anxiety while performing during Session 5, whereas the unstressed groups (ILC and N-SC) did not.

Performance

Figure 2.3 displays the mean number of successful putts of each of the five groups over the five sessions. Split-plot analysis of variance (5 x 5: groups x sessions) revealed a highly significant main effect of sessions [$F(4,140) = 36.66$, $p < .001$] and groups [$F(4,35) = 6.49$, $p = .001$]. A significant groups x sessions interaction [$F(16,140) = 1.86$, $p = .029$] was also found.

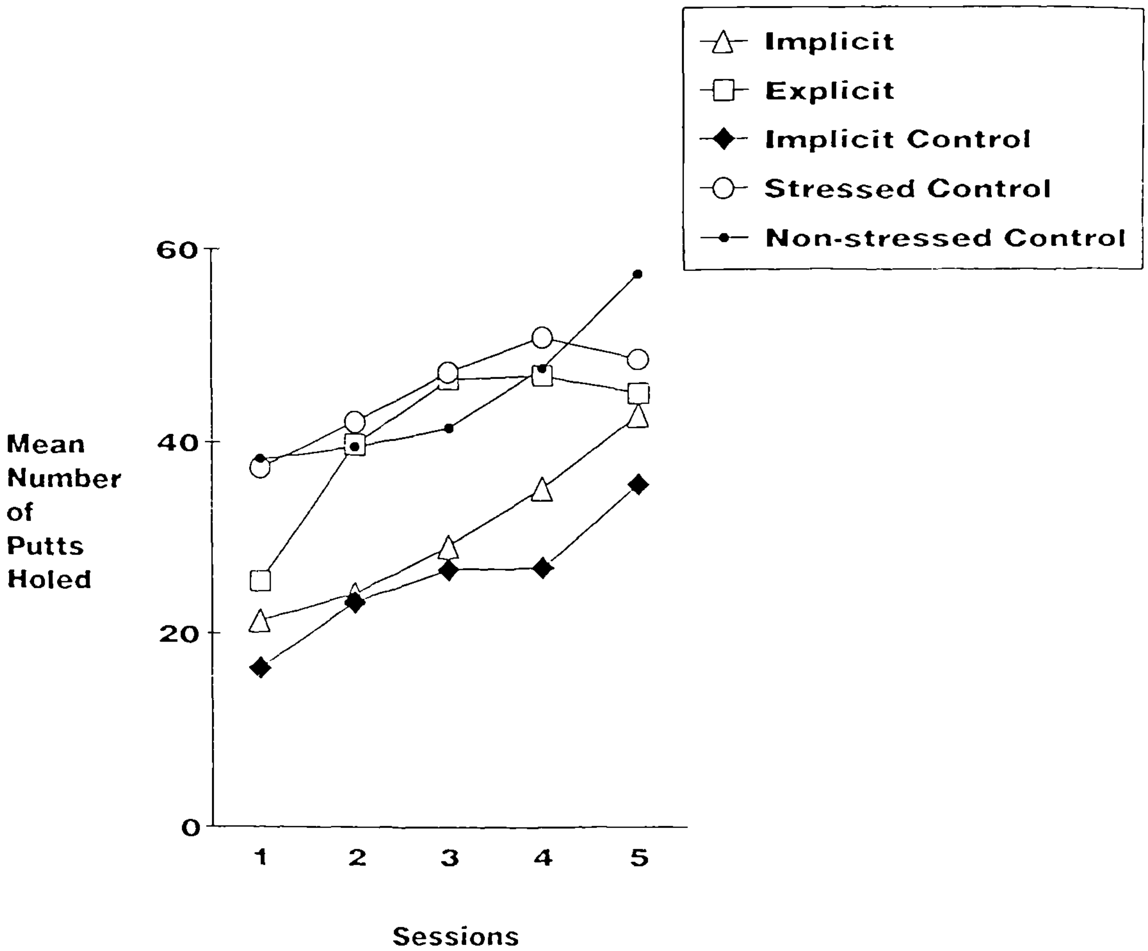

Figure 2.3. Mean number of putts holed as a function of the skill acquisition phase (Sessions 1 to 4) and the test phase (Session 5) [Stressed groups have clear markers and unstressed groups filled markers]

Analysis of simple main effects determined highly significant differences between groups in all sessions [$p < .01$]. Highly significant differences were also determined between sessions in all five groups [$p < .01$]. Following this, performances in the skill acquisition phase (Sessions 1 to 4) and the test phase (Session 5) were explored separately.

The Skill Acquisition Phase: Performance curves

An unavoidable difficulty in the design of the experiment was the implausibility of matching subjects on the basis of skill level. The need to ensure that neither implicit learning group had an opportunity to acquire explicit knowledge at any stage prohibited pre-testing. Involvement in a pre-test would have required these groups to forego the secondary task, thus lifting the embargo on short-term memory resources and providing an opportunity for accretion of explicit knowledge. As is normal in such cases, subjects were randomly assigned to conditions on the assumption that skill level would be equal across groups. In order to produce evidence that the groups were, indeed, matched, a one-way analysis of variance was carried out on the mean number of putts holed in the first five putts of Session 1 by each group. Little in the way of skill acquisition was expected over as few as five putts, and, indeed, no significant differences were found between the groups [$F(4,35) = 1.50$, $p = .222$][2] .

The general picture for the acquisition phase was that the two implicit groups, which learned under the dual-task burden, performed less well than the other three groups. However, the differences were not reliable in every case when Tukey's Test of honestly significant difference was employed to make *a posteriori* comparisons between groups in each of the first four sessions. In Session 1 the ILC group scored significantly worse than the SC group [$p < .05$] and N-SC group [$p < .05$]. In Session 2 the ILC group scored significantly worse than the SC group only [$p < .05$]. In Session 3 both the IL

[2] Means and Standard Deviations (in parentheses) of putts holed in the first five attempts in Session 1 were 1.0 (1.07), 1.0 (.54), .25 (.46), 1.5 (.93) and 1.13 (1.73) for the Implicit Learning, Explicit Learning, Implicit Learning Control, Stressed Control and Non-stressed Control groups respectively.

and ILC groups scored significantly worse than the EL and SC groups [$p < .05$], while in Session 4 the ILC group scored significantly worse than all groups other than the IL group, which in turn scored significantly worse than the SC group [$p < .05$].

The Test Phase: Performance under stress

Figure 2.3 seems to illustrate some distinct performance changes in the test phase. Analyses were performed on Session 4 to Session 5 differences between groups, rather than the differences between groups on Session 5 alone (as performance levels differed markedly at Session 4). The comparisons to be made entailed *a priori* predictions encapsulated in four orthogonal contrasts. Firstly, the performance change of the IL group (stressed) was predicted to be no different from that of the ILC group (unstressed); secondly, these two groups together were predicted not to differ from the N-SC group. Thirdly, it was predicted that under stress the performance change of the EL group would be similar to that of the SC group (both having a fairly large pool of explicit knowledge); and fourthly, these groups would differ from the combined IL, ILC and N-SC groups - with the former exhibiting degradation of performance. The first three predictions are for null effects, and so must be judged against the fourth prediction. It would be inappropriate to make claims on behalf of these predictions if the fourth prediction proved non-significant, as non-significance would show that, in fact, no effect of treatments occurred. As predicted, there was no difference between the IL and ILC groups [$T(35) = .24$, $p = .808$], both of which showed a substantial increment in performance. If the putting skill of the IL group had been affected by stress it would not have exhibited an improvement in performance identical with that of the ILC - its unstressed counterpart. Furthermore, the IL and ILC group differences were not significantly different from the N-SC group [$T(35) = .36$, $p = .721$]. Markedly similar gradients were exhibited by all three. This suggests both implicit learning groups improved over Session 5 when not required to carry out the secondary task (regardless of the fact that one group was under stress and the other not). The EL group performance decrement was not different from that of the SC group [T(35) = .11, p = .914], but the performance decrement of these groups was significantly different from the performance increment of the IL, ILC and N-SC groups [T(35) = 3.63, p = .001]. The continued improvement of the N-SC group, which acted as a control for both the SC and the EL groups, shows the degraded performance of these groups was not associated with reaching a ceiling in performance. However, despite the apparent degradation of performance in the EL and SC groups, Tukey's HSD test showed that the stress intervention did not result in significant deficits in either group from Session 4 to Session 5 (p > .05). Despite the significant differences shown by orthogonal contrasting, and in particular, the very obvious contrast between the stressed control group (SC) and it's unstressed counterpart (N-SC), which continued to improve, it must be emphasised that these results represent trends rather than statistically significant effects.

The Cognitive Failures Questionnaire: Does CFQ score predict likelihood of breakdown?

Mean CFQ scores were 42.5, 45, 46.13, 46.25 and 43.88 for the IL, EL, ILC, SC and N-SC groups respectively. One-way analysis of variance showed no significant differences whatsoever between the five groups [F(4,35) = .21, p = .931].

A Pearson correlation coefficient was computed between the CFQ scores and the change in performance in the SC group. This explored whether the CFQ could predict the tendency to break down under stress. The SC was the only stressed group that did not receive external manipulation which might have biased its ability to cope with stress. The correlation neared significance (r = .60, p = .057).

2.4 Discussion

This experiment was devised as a means of testing the hypothesis that disruption of the automaticity of a skill under pressure will be less likely if the skill has been learned implicitly (without knowledge of rules) rather than explicitly (with knowledge of rules).

The experiment produced evidence which can be seen to marginally support the hypothesis. Clear support is not available, due to the lack of a statistically significant decrease in performance in the explicit learning and stressed control groups. In Session 5 the implicit learning group (whose performance did not differ significantly, in Session 4 prior to stress intervention, from that of the explicit learning group) showed no degradation of performance under stress whatsoever, in contrast to the explicit learning group, which, as already mentioned, showed only a non-significant decrease in performance.

Verbal protocols collected from all subjects showed the implicit learning groups had far less knowledge of the 'rules for execution' available for conscious processing than the explicit learning group or, indeed, the stressed and unstressed control groups. The presence of explicit knowledge in these particular (discovery learning) control groups provides support for the Berry & Broadbent (1988) opinion that individuals can employ an explicit mode of learning even when there is an absence of explicit instruction.

The experiment has also shown it is quite possible to manipulate accretion of explicit knowledge when acquiring new motor skills. Baddeley's (1966) random letter generation task proved an adept suppressor of explicit knowledge, and the explicit putting instructions successfully parallelled common coaching mechanisms.

The success of the stress intervention was obviously of major importance in this experiment. It is unlikely that the stress levels were a perfect ecological match of those in real-world performance; however, with the amalgamation of evaluation apprehension, financial inducement, and the experimental situation itself, it was hoped to furnish a plausible facsimile. The non-significance of the trend towards a decrease in performance in the explicit learning and stressed control groups shows the facsimile fell short.

As the implicit learning groups were carrying out two tasks it is understandable that they generally performed at a lower level than the other groups during the acquisition phase. Nevertheless, Figure 2.3 seems to show the putting performance of both implicit groups improving. It is possible, however, that the learning curves are an artefact of learning the secondary task rather than the primary, putting task. As performance on the secondary task improved, its demands on processing capacity would have diminished, so easing depression of putting skill and giving the impression that the skill itself was improving. Clearly, it can be argued that if putting performance remained worse than its pre-test level, acquisition of putting skill was not taking place. For reasons already mentioned in the results section, no pre-test level was available for comparison. In solution, as the performance of the stressed control and non-stressed control groups was not manipulated in any way, their mean level of performance during the first five putts in Session 1 was taken as a pre-test performance base line for all groups. Expressed as a percentage, the 'assumed' pre-test level was 26.25%. The performance of the implicit groups in Session 4 surpassed the assumed pre-test level of 26.25 %, confirming that putting-skill acquisition did, in fact, occur.

In Session 1 the explicit learning group exhibits a performance level almost as low as the implicit learning groups. It seems reasonable to account for this in terms of the demands of processing written instructions on how to putt. This was clearly a less resource-limiting secondary task than random letter generation, but nevertheless, more limiting than putting alone. The dramatic improvement in the explicit learning group's performance from Session 1 to Session 2 may simply be a return to baseline performance, allowed by a rapid adjustment to carrying out such a simple secondary task. In some respects this is supported by the similarity of the explicit learning, stressed control and non-stressed control performance curves for the rest of the skill acquisition phase. Studies comparing discovery learning with instructed learning often show similar trends in the learning curves (den Brinker & van Hekken, 1982; Whiting *et al*, 1987; Vereijken & Whiting, 1990). An alternative way of explaining the dramatic improvement of the explicit learning group from Session 1 to Session 2, can be drawn from discussion of computational theories of motor learning and control. Whiting & den Brinker (1982) distinguished between the 'image of the act' and the 'image of achievement' in developing a general motor programme of performance. The image of the act defines the movement and coordination patterns required to execute the skill, while the image of achievement defines the external, environmental forces to be overcome. The novice performer must form both images if the task is to be completed satisfactorily, but Whiting & den Brinker suggested this is initially very difficult, as attention to either image will be at the expense of the other. It could be argued that in the present experiment written instructions in the explicit learning condition supplied subjects with a prefabricated coordination pattern with which to form an image of the act. Formation of the image of the act would therefore have demanded less attention at the expense of the image of achievement.

The very low degree of explicit knowledge held by the two implicit groups shows that despite the diminished demands of the secondary task on processing capacity, suppression of explicit knowledge still occurred. Had the acquisition phase perhaps continued for another five sessions, actual putting performance in the implicit learning groups may have shown considerable improvement, due to the easing of secondary task restrictions on putting skill acquisition. A wary eye would need to be kept on the extent to which accretion of explicit knowledge increased. However, if, as seems to be indicated, the embargo continued, the outcome of such additional learning would raise some interesting questions. For instance, would the skill remain or become even more strongly insulated against reinvestment of controlled processing under stress? Or, in terms of 'rehearsal', the tendency to rehearse emotional events (Roger & Nesshoever, 1987), would the lack of explicit knowledge mean there was less to rehearse, and hence, less distraction when performing, or more processing capacity available for rehearsal of potentially distracting information?

There is also a disparity between mean accuracy at Session 4 in this experiment and the mean accuracy of individuals who can be said to have fully automatic putting skills. For example, Cockerill (1975) gave figures for seven low handicap golfers (mean handicap = 6) putting from 150 cm on an artificial putting surface, which showed they had a 78 % success rate, as opposed to 42 % in the present experiment (although the uphill gradient of 1:4 did make the present putting task more difficult). The performance of the non-stressed control group was still improving in Session 5, which suggests the performance of the remaining groups was not fully automatic at Session 4. After all, only 400 putts had been made at the Session 4 stage - clearly too few to have attained automaticity of skill, if one agrees with Hammond (1987) that even 10 years of diligence may not be enough to achieve expertise. Nevertheless, the mere repetition of a skill in a consistent task environment is regarded as enough to warrant the development of some degree of automaticity (Logan, 1978, 1988; Schneider & Fisk, 1982; Schneider & Shiffrin, 1977), so the hypothesis that a reinvestment of conscious processing will disrupt automatic processing of the skill was valid.

There was a hint that the Cognitive Failures Questionnaire (Broadbent *et al*, 1982) might predict failure of skill under stress. The questionnaire assesses the tendency to have slips of action. If such slips are the result of an inherent flaw in automatic processing, it may be that disruption of automatic processing of skill under pressure is the result of the same flaw. Only a small number of subjects (n = 8) were eligible for the correlation between performance change under stress and CFQ score, so this question warrants further study.

In general terms, the results draw critical attention to long accepted methods of coaching, particularly the somewhat 'hit and hope' identification of potentially elite performers, followed by an earnest attempt to nurture them through to world class standards of performance with prolonged, explicit instruction in how to execute the skills of the sport. It is the contention of the author that such prolonged, explicit instruction can increase the chance that the skill of the potentially elite performer will not withstand the pressure accompanying performance in the world arena.

Chapter Three

Reminiscing about implicit learning

3.1 An introduction to Study 2

Study 1 showed that performance of a skill did not deteriorate under stress when the skill had been learned implicitly, that is, without accretion of explicit, verbalisable knowledge of the skill itself. A problem faced, however, when researching the effect of implicit motor-skill learning is that the only documented means of invoking implicit acquisition of skill is through enforcing secondary task restrictions on the learner. The basis of such restrictions is that dual-task methods such as Baddeley's (1966) random letter generation task are resource-limiting devices which can impede an individual's ability to consciously process what they are doing, and thereby prohibit accumulation of knowledge explicitly. As no other study has endeavoured to use such methods to investigate the implicit acquisition of motor skill teething problems are bound to occur.

A major problem signalled by Study 1 is that apparent improvement in performance of implicitly learned motor skill over time does not guarantee the skill is being learned. Initially, the secondary task may only depress the existing level of motor-skill performance, but as a result of acclimatisation to dual-task conditions its resource-limiting efficiency may lessen, so easing depression of performance by allowing increased resources to be directed to the motor skill. In such circumstances the increase in performance level may give a false impression of the amount of learning that has taken place. This would call into question the finding that an implicitly learned motor skill is less likely to fail under pressure than a motor skill learned either explicitly or by 'discovery' (that is, with no manipulation of knowledge accretion). Although not entirely convincing the study did confirm that learning took place by illustrating that performance after 400 trials was superior to the initial skill level[1].

Performance by the implicit learning groups in the study was depressed in contrast to that of the discovery learning groups. Furthermore, a surge in performance was seen in the unstressed implicit learning group following withdrawal of the secondary task load. It would appear that relaxing the demand on processing capacity allowed more resources to be diverted to the putting task, with a corresponding surge in performance. If this were true it would brace the argument that learning occurs but is masked by the presence of the secondary task.

However, this resource relaxing explanation is premature in that it is potentially confounded by a second explanation. The phenomenon of 'reminiscence' often mentioned in the motor-learning literature (Bakker, Whiting & van der Brug, 1990; Eysenck, 1985; Schmidt, 1982; Singer, 1982; Travis, 1936, 1937), involves, by definition, an unexpected increase in performance following a period of no practice (Ammons, 1947; Eysenck, 1985; Hull, 1943). It occurs in massed practice conditions where performance has been commonly documented to be depressed when compared to spaced or distributed practice[2] (Ammons, 1947; Eysenck & Frith, 1977; Kimble, 1949a; Kimble & Shatel, 1952; Reynolds & Adams, 1954; Schmidt, 1975). Surges in performance are common following a period of rest following on massed practice. The characteristics of the unstressed implicit-learning curve in Figure 2.3 parallel those seen in the phenomenon of reminiscence in that the depressed performance seen in the acquisition

[1] Calculation of an assumed initial skill level was required because pretesting of skill levels in the implicit learning conditions was not possible in the first experiment as subjects would have acquired explicit knowledge.

[2] According to Schmidt (1975, p.74) "One of the fundamental variables defining the make-up of the practice session is the scheduling of practice and rest pauses. When trials are separated by large amounts of rest, with the rest between trials being as long as or longer than the time in the trial itself, the practice session is said to be "distributed"; when the amount of rest is shorter than the practice, the session is said to be "massed".

trials was followed by a surge in performance after a rest period of 24 hours. What remains unclear, therefore, is whether this surge in performance is the consequence of the withdrawal of the secondary task or of the interposing of a significant rest period following on massed practice.

There has been considerable examination of the reminiscence phenomenon (particularly in pursuit-rotor performance), but it has no unanimously agreed explanation. Two opposing explanations have dominated the attention of the literature - an Inhibition theory (Hull, 1943; Kimble, 1949a,b) and a Consolidation of Memory theory (Eysenck, 1964b, 1985). According to the former, inhibition, in the form of physical or mental fatigue, develops during massed practice and prevents manifestation of the improvement normally evident following practice. Two types of inhibition can be responsible - reactive inhibition (I_R) or conditioned inhibition $(S^I R)$. The essence of both is that the inhibitory agent, whatever it may be, increases during massed practice to a point where it is depressing performance, but loses its inhibiting properties during rest, allowing performance to surge to an apparently higher post-rest level.

The alternative, consolidation of memory, explanation of reminiscence (Eysenck, 1965, 1966) argues that improved post-rest performance is the result of consolidation of previous learning. It is argued that performance leads to cortical events or 'neural fixation processes' which, in order to become available to the performer as learned behaviour, require a period of rest in which to consolidate. Consolidation functions to safeguard 'memory traces' against destruction via brain disturbances. A by-product is improved performance, which, according to Walker (1958) and Walker & Tarte (1963), occurs as a result of temporary inhibition of recall or "action decrement" while permanent memory is being laid down during the consolidation period. It follows that learning will only manifest itself in improved performance once consolidation has taken place, that is, following a period of no practice. Many failings, both theoretical and empirical, come with these explanations of reminiscence. They are irritatingly cumbersome in accounting for numerous questions raised in the reminiscence literature. Eysenck & Frith (1977) provide a thorough summary of this.

In spite of the difficulty in accounting for the reminiscence phenomenon, it is something that must be addressed if the explanation of the effects of stress on performance put forward in Study 1 are to be accepted at their face value. Of course, the whole reminiscence argument together with the potential confounding to which it can lead hangs or falls on whether the practice conditions in the study were truly massed. This can be accounted for by exaggerating the degree of massing and spacing of the practice conditions. This is done in the experiment to be reported which is designed to resolve the potentially confounding effect of reminiscence in the explanation of the effects found.

Put more succintly, the aim of the present study is to clarify whether surges in performance following withdrawal of secondary task restricitons in implicit learning situations can truly be attributed to an easing of demands on processing resources.

The avenue of exploration taken will be to contrast post-secondary task performance following massed versus spaced practice. If performance in massed conditions only is depressed during acquisition, and reminiscence occurs following rest in these conditions, then this would indicate the presence of a reminiscence phenomenon as a confounding explanation of the post-secondary task improvement of performance in the earlier study.

3.2 Method

Subjects

Forty-six paid, novice golf putters were randomly assigned to one of four conditions: implicit learning - massed (IL-M), implicit learning - spaced (IL-S), control - massed (CON-M) and control - spaced (CON-S). Both massed practice groups consisted of 12 subjects (mean age = 19.6 years, SD = 1.1), whereas both spaced practice groups consisted of 11 subjects (mean age = 20.3 years, SD = 2.4). Males and females were equally proportioned in each group.

Apparatus

A left or right handed 'Ping' golf putter was used by all subjects. These were 35 in. (88.9 cm) in length with standard angle of lie and loft for a Ping 'Anser' putter. 'Titleist tour 100' golf balls of standard dimensions (size 1.68 in. [4.27 cm]) were used. Putts were made from a distance of 200 cm at a hole 10.8 cm in diameter (as set down by the United States Professional Golf Association [PGA]). The putting surface was green, short-tufted artificial grass stretched on a level dais elevated 11 cm from the ground. An electronic metronome was used to emit 'clicks' at regular 1.5 s or 1.0 s intervals in the secondary task conditions. All secondary task responses were recorded on audiotape.

Design

The golf-putting skill was learned by the four different groups over an acquisition phase, consisting of two practice sessions on each day for two consecutive days. In each session participants made 125 putts (a total of 500 attempts). This was followed by a post-rest test session some 24 hours later, in which participants made a further 125 putts. The percentage of putts entering the hole acted as the dependent variable.

Procedure

No inter-trial intervals were allowed in the massed practice groups (IL-M & CON-M), whereas inter-trial rest intervals of 30 s were enforced following each subset of 5 putts in the spaced practice groups (IL-S & CON-S). A 5-trial block consisted of approximately 15-20 s performance time. The criterion for spacing of practice in these conditions was based on Schmidt's (1975) definition of spaced practice and on the fact that such spacing falls in the midground of spacing conditions employed in the reminiscence literature (Eysenck & Frith, 1977). During each interval the participant was required to fit pieces in a jig-saw puzzle. This was deemed a satisfactory method of prohibiting contemplation of the putting task. All participants were required to read a standard statement at initiation of the experiment explaining that they would receive a small payment, and requesting that they not practise or rehearse the putting skill outside the laboratory.

Additional instructions were given in each condition. In the implicit learning groups (IL-M & IL-S) participants were required to carry out Baddeley's (1966) random letter generation task whilst putting. As in Study 1 they were instructed to call out a random letter each time an electronic metronome 'clicked' [see Appendix 2]. Clicks sounded every 1.5 s during the first and second sessions of the acquisition phase, but every 1.0 s during the latter two sessions of the acquisition phase. It was necessary to decrease the time between clicks in order to avoid diversion of processing capacity to the putting task as participants became more efficient at random letter generation. It was emphasised that priority be given to maintaining the randomness of the letters in the secondary task at all times. One minute of practice at this was allowed at the beginning of the first session. The secondary task was discontinued in the post-rest test phase.

In the two control groups (CON-M & CON-S) participants were required to learn for themselves (discovery learning). Each group acted as a control for post-rest comparison with its related implicit learning group.

3.3 Results

Initial ability. Pretesting and matching of initial skill levels was not possible in the implicit learning groups. This would have required foregoing the secondary task and hence allowing an opportunity for accretion of explicit knowledge. Subjects were therefore assigned to the four conditions randomly (on the assumption that their initial skill level would be matched across groups) and the mean number of putts holed in the first 5 attempts was used as a surrogate pretest of initial skill level - on the grounds that little skill acquisition would be expected over so few trials. Computed as a percentage the means for the IL-M, CON-M, IL-S and CON-S groups respectively were 11.7, 31.7, 14.5 and 27.3 %. Individual percentages ranged from 0 to 80 %. One-way analysis of variance revealed no significant differences [$F(3,42) = 2.04$, $p > .12$], giving confidence that the groups were matched for initial putting ability.

Acquisition-Phase Performance. For general analysis purposes performance was computed over consecutive 25-putt trial blocks. Analysis of the performance trends over the acquisition phase only (500 putts) was carried out by split plot analysis of variance (groups x trial blocks; 4 x 20). Highly significant main effects were revealed for both groups [$F(3,42) = 7.22$, $p < .001$] and trial blocks [$F(19,798) = 14.47$, $p < .001$]. The lack of a significant interaction however [$F(57,798) = 1.05$, $p > .37$], shows that although significant improvements occurred in the groups over practice, the conditions did not have different effects on actual learning. The highly significant main effect of groups suggests there were overall differences in performance level. Consideration of Figure 3.1 reveals that the IL-M group performed at the lowest level throughout acquisition, hinting that massed practice of putting, in conjunction with the secondary task, may have depressed performance. Computation of Tukey's Test of honestly significant difference for the mean performance levels over the full 500 putts showed the IL-M group to have significantly poorer performance than both the CON-M and CON-S groups ($p < .05$), but not the IL-S group.

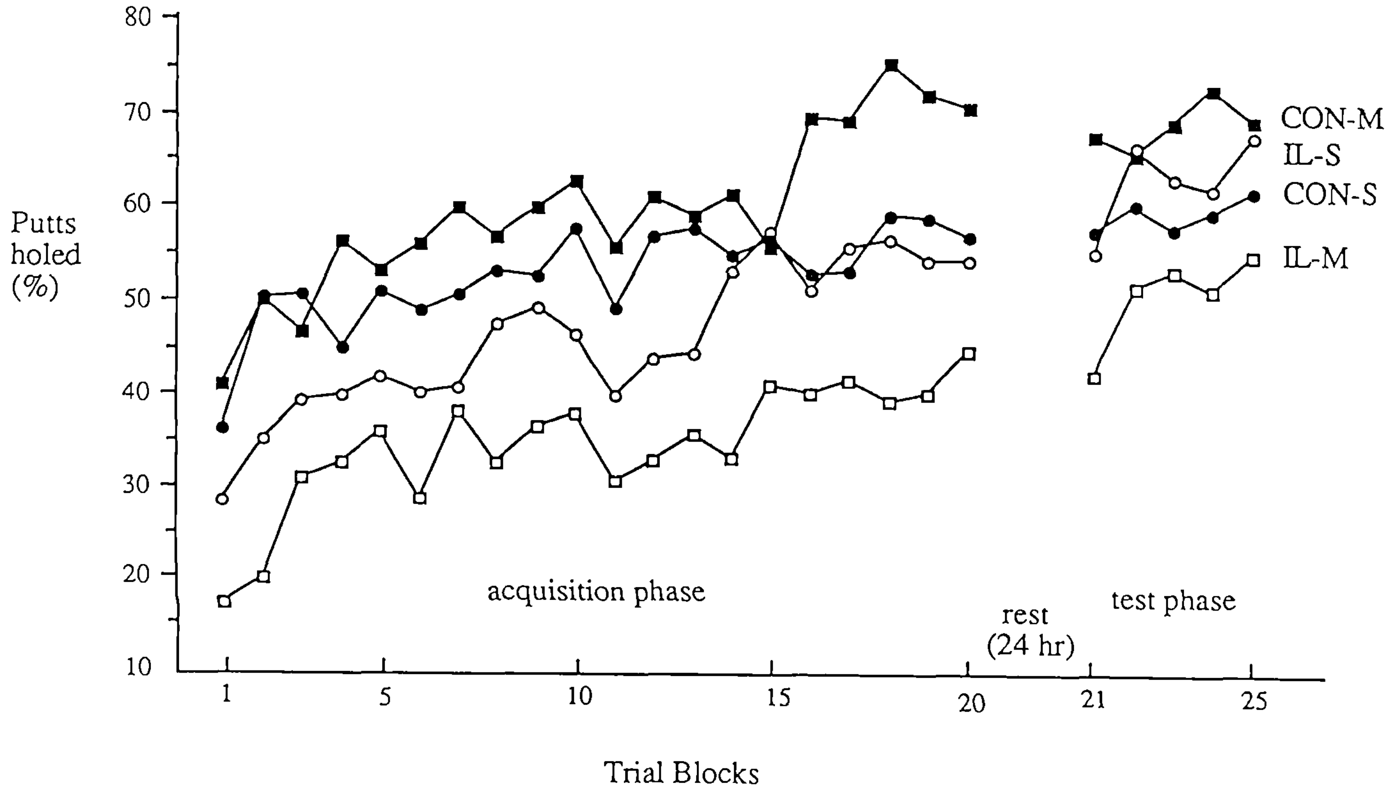

Figure 3.1. *Mean performance (%) for the Implicit Learning-massed (IL-M), Implicit Learning-spaced (IL-S), Control-massed (CON-M) and Control-spaced (CON-S) groups as a function of acquisition phase and test phase*

Reminiscence. Reminiscence scores were calculated for each group by finding the percentage difference between the last 5 trials in the acquisition phase and the first 5 trials after the 24-hour rest period. As is illustrated in Figure 3.1, the reminiscence scores were minimal (-5, -8.4, 9.2 and -12.8 % for the IL-M, CON-M, IL-S and CON-S groups respectively). The absence of a significant difference between the scores [$F(3,42) = .68$, $p > .57$], implies that although massed practice of the putting and secondary task resulted in depression of performance a reminiscence effect did not follow.

Test-Phase Performance. Split plot analysis of the performance trends over the test phase only (groups x trial blocks; 4 x 5) revealed significant main effects of groups [$F(3,42) = 3.03$, $p < .04$] and trial blocks [$F(4,168] = 3.13$, $p < .02$], but no significant interaction [$F(12,168) = .80$, $p > .65$]. Similarly to the acquisition phase, significant improvements took place in the groups over the test phase but the conditions involved did not have a different impact on learning.

3.4 Discussion

The purpose of the present study was to explore whether the surge in performance seen upon withdrawal of the secondary task in the unstressed implicit learning condition in Study 1 resulted from an easing of demands on processing resources or as a consequence of a rest period following on massed practice (the so-called reminiscence effect). It was argued that if massed practice caused depressed performance and was followed by a surge in performance after rest, but spaced practice did not, then this would indicate the presence of a reminiscence effect.

The similar performance of the spaced and massed control groups indicates that massed practice of putting alone is no more detrimental to performance than spaced practice. The slightly (although nonsignificantly) lower performance of the massed implicit learning group when contrasted with the spaced implicit learning group could, however, be taken to suggest that a combination of secondary task and putting task may be more affected by the massing of practice. This seems intuitively sensible if one accepts that putting is a discrete rather than continuous task. According to Schmidt (1975, p.78) "the practice time for a discrete task such as throwing a ball is very short for each trial, and it is apparently difficult for massing to cause a build-up of fatigue or boredom in so short a period". This may be the case when putting alone, but the addition of a continuous random letter generation task may well increase the possibility that massing will lead to fatigue or boredom.

Of greatest importance is the absence of a reminiscence effect in the designated massed practice groups. This suggests that the previously reported surge in performance following on the removal of the secondary task was not confounded by a reminiscence effect.

If anything, a slight degradation of performance is apparent in the two massed practice groups following rest. This can be explained in terms of the 'warm-up decrement' phenomenon (Schmidt, 1982), seen to occur in discontinuous skills - such as golf-putting - and purportedly related to the loss of a temporary 'activity-set' suitable for performance (Nacson & Schmidt, 1971; Schmidt & Nacson, 1980; Schmidt & Wrisberg, 1971). Suspension of the secondary task in the implicit learning groups may have exacerbated this warm-up decrement by altering the task and to some extent making the old activity-set redundant.

Although there is no increase in performance in any group immediately following rest it is relevant that both implicit learning groups, but not the control groups, do show a surge in performance over the next block of trials. This suggests that lifting the embargo on processing resources by withdrawing the secondary task was indeed responsible for the surge in performance in the unstressed implicit learning group in Study 1.

It must be concluded that although the presence of a secondary task in implicit learning may depress performance it is the easing of processsing demands that leads to surges in performance upon withdrawal of the secondary task, and not reminiscence. Having said this, it can be argued, somewhat anecdotally perhaps, that of the two implicit learning groups the most superior performance came from the spaced practice condition and the worst performance came from the massed practice condition, so a speculative recommendation for future research employing secondary tasks in implicit learning paradigms is that a spaced practice structuring of acquisition sessions be used.

Chapter Four

'Reinvestment': A dimension of personality implicated in skill breakdown under pressure*

4.1 An introduction to Studys' 3, 4, 5 & 6

Study 1 explored the stress resistance of skills learned either implicitly (with a small pool of explicit knowledge) or explicitly (with a large pool of explicit knowledge). Although the findings were not conclusive, evidence was produced that suggested an implicitly learned skill may be less likely to fail under pressure than an explicitly learned skill. This evidence was only trend-wise as the stress intervention did not result in significant decrements in performance in the explicit learning and stressed control groups. The trends were accounted for by arguing that in the latter condition 'deautomatisation' - the disruption of the automaticity of skilled performance - was more likely to take place as a result of purposefully endeavouring to run the skill with explicitly available knowledge of it, that is, by "*reinvesting actions and percepts with attention*" (Deikman, 1969, p.31). A number of examples from the literature support this view (Baddeley & Woodhead, 1982; Eysenck, 1982; Hammond, 1987; Henry & Rogers, 1960; Klatzky, 1984; Schmidt, 1982).

None of the cited writers, however, were led to suggest that reinvestment of controlled or conscious processing may be a dimension of personality; some

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* Based on Masters, R.S.W., Polman, R.C.J. and Hammond, N.V. 'Reinvestment': A dimension of personality implicated in skill breakdown under pressure. *Personality and Individual Differences*, (in press).

individuals having a greater or lesser predisposition than others to reinvest actions and percepts with attention - particularly when under pressure.

This idea has some face validity when viewed in the light of a conclusion by Henry (1960) that there are statistically reliable individual differences in the tendency to use sensory set or motor set when performing a motor skill; a motor set is a focus on the movement itself, rather like reinvestment, whereas a sensory set is a focus on external stimuli associated with the movement.

The first real hint of a reinvestment dimension emerged in the Study 1 when it was found that the Cognitive Failures Questionnaire (Broadbent *et al*, 1982) tended to predict failure of a putting skill under pressure ($r = .60$, $n = 8$, $p = .057$). The CFQ assesses the tendency to have 'slips of action' - occasions on which ones actions "do not proceed in accordance with intention" (Broadbent *et al*, 1982, p.1). It was argued that if such slips of action are in some way the result of an inherent flaw in automatic processing or if the automatic processing system in some individuals can be more easily disrupted than in others then this same flaw may be the root cause of 'deautomatisation' under pressure.

In relation to this, there is evidence that a greater predisposition to cognitive failure increases an individual's vulnerability to stress. For instance, Freeman, Weeks & Kendell (1980) found that student nurses failing their final-year examinations had higher CFQ scores. Although the strength of this finding was limited, Broadbent *et al* (1982) showed more conclusively that the state of health of nurses under highly stressed conditions was correlated with their CFQ scores, concluding that "high CFQ, in other words, is a vulnerability factor making the individual less able to resist the effects of stress" (p.11).

An additional component of reinvestment may be 'rehearsal'. Rehearsal is one of four factors surfacing in the Emotional Control Questionnaire (Roger & Nesshoever, 1987). The questionnaire (ECQ) was developed to assess individual differences in emotional control - "a cognitive strategy aimed at inhibiting the overt expression of emotional responses" (p.528). The rehearsal factor is described as a tendency to mentally rehearse emotional events. The link between rehearsal and reinvestment of conscious processing is self-explanatory; the former involves rehearsal of emotional events, whereas the latter involves rehearsal of rules associated with the skill.

There is also some evidence that rehearsal plays a role in the response to stress. That is, individuals with a greater predisposition towards rehearsal are more prone to high-level anxiety under pressure. For example, Roger & Jamieson (1988) presented evidence suggesting that rehearsal scores correlated with delays in heart-rate recovery following stress-inducing Stroop task performance, and Roger (1988) presented evidence that rehearsal scores correlated with increased cortisol levels amongst exam-pressured student nurses. These findings suggest rehearsal may be implicated in the stress/performance relationship.

Another component of reinvestment may be self-awareness, that is "...the existence of self-directed attention, as a result of either transient situational variables, chronic dispositions or both" (Fenigstein *et al,* 1975, p.522). Conscious attention to the self may be caused by any circumstance causing the individual to be 'self-evaluative'. Fenigstein *et al* (1975) constructed a 'Self-Consciousness Scale' (S-CS) to assess individual diferences in self-awareness. Factor analysis of the scale gave a view of three different factors; two different modes of self-consciousness (private and public) and a reaction to these (social anxiety). The private self-consciousness factor was defined in terms of the attention one gives to one's thought processes (e.g., I'm aware of the way my mind works when I work through a problem), whereas public self-consciousness was seen as an awareness of the self as a social object affecting others (e.g., I'm concerned about what other people think of me). The social anxiety factor was regarded as a 'by-product' of these two modes of self-consciousness, on the grounds that an inward focusing of attention is bound to give the individual something to be anxious about. It seems plausible that private and public modes of self-consciousness may be a component of reinvestment - the greater the individual's predisposition towards self-consciousness the greater the chance that that individual will think about what he or she is doing and hence the greater the chance that reinvestment of controlled processing will occur.

Fuel is added to the reinvestment-under-pressure perspective by the fact that self-awareness has been shown to increase in situations resulting in increased arousal (Fenigstein & Carver, 1978; Wegner & Giuliano, 1980). Evaluative stituations, for example, have been shown to induce a state of self-focus in individuals (Wicklund & Duval, 1971; Carver & Scheier, 1981). The presence of a camera (Davis & Brock, 1975; Duval & Wicklund, 1972) mirror (Carver, 1974, 1975; Scheier, 1976) or even an individual's own voice (Ickes, Wicklund & Ferris, 1973) have received validation as manipulators of self-focus.

Four studies will be described in the present chapter. The first abstracts a factor associated with reinvestment from the above-mentioned scales, and the second, third and fourth attempt to predictively validate it on the premise that those with a high predisposition towards reinvestment will be more likely to fail under pressure than those with a low reinvestment predisposition.

4.2 Study 3

Rather than construct a completely new scale to explore the existence of a reinvestment dimension, select items from the scales discussed were incorporated into one questionnaire. The entire Cognitive Failures Questionnaire (Broadbent *et al*, 1982) was employed, along with a revised version of the Rehearsal factor from the Emotional Control Questionnaire (Roger,1992) and the Private and Public factors from the Self-Consciousness Scale (Fenigstein *et al*, 1975). This gave a questionnaire numbering 75 items: 25 from the CFQ, 33 from the ECQ and 17 from the S-CS.

This corporate questionnaire was administered to a large body of the student population of York University and the returns factor analysed in a search for higher-order factors that might represent reinvestment.

4.2.1 Method and Results

Scale construction

A 75-item questionnaire consisting of 25 items from the CFQ, 33 from the ECQ and 17 from the S-CS was administered to 71 female students (mean age = 20.54 & SD = 4.36) and 73 male students (mean age = 21.28 & SD = 5.15) of the University of York, England. The sets of items were presented in random order. A dichotomised, forced-choice mode of response was required, with participants offered an option of TRUE/FALSE or YES/NO. This necessitated alteration of the Likert Scale response possibilities of the CFQ and S-CS. Determination of response frequencies showed that no item was endorsed in either direction by more than 80 % of the sample.

Factor analysis

Principal axis factor analysis was carried out on the data. Scree testing suggested a three-factor solution be sought. This was achieved with a varimax rotation. As is the norm, loadings of greater than 0.30 were taken as illustrating significance on the three factors. An oblique rotation was carried out in conjunction with the orthogonal rotation, yielding similar results.

The first and third factors were of little interest in reinvestment terms. Factor 1 was predominated by items from the CFQ (19 out of 24), and Factor 3 consisted entirely of items from the ECQ (15 out of 15). The items and loadings in each factor can be found in Appendices 4 & 5. The first factor accounted for 8.9 % of the variance, whereas the third factor accounted for 4.4 %.

The second factor, which accounted for 5.6 % of the variance, appeared considerably more relevant in reinvestment terms. Twenty items loaded on this factor, with a mixture of 12 from the S-CS, 7 from the ECQ and 1 from the CFQ. The items and their loadings are presented in Table 4.1. The highest loading of 0.50 was found for item 48 (I'm constantly examining my motives). This item belonged to the private self-consciousness subscale of the S-CS. The next highest loading of 0.48 was found for item 7 (I think about ways of getting back at people who have made me angry long after the event has happened). This item belonged to the rehearsal subscale of the ECQ.

Although the methods of categorising factors produced by factor analytic methods are somewhat subjective the use of the term 'reinvestment' for the second factor rather than the first or third seems justifiable for two reasons. Firstly, and most importantly, the factor is more robust than the others, in that it is made up of a mixture of items from all the scales, whereas, the third factor consists only of rehearsal items and the first factor consists mainly of cognitive failures items along with a few rehearsal items. The fact that this relationship exists between the different items from the different scales provides for greater breadth, and suggests a coherent, multi-dimensional construct - reinvestment. A second, more anecdotal reason, is that the items in Factor 2 are considerably more oriented towards internal thought processes than those of Factors' 1 or 3. That is, the items directly refer to the actual dynamic internal process of thinking about what one is doing. The items in the remaining two factors seem to be less specific and to refer more to the results of such processes.

Reliability

The three scales involved in the reinvestment factor have all been validated and shown to be highly reliable. The rehearsal factor, for instance, is reported by Roger & Nesshoever (1987) to have a highly satisfactory Kuder-Richardson (KR-20) coefficient of 0.86. In the present instance coefficient alpha (Cronbach, 1951) was employed to evaluate the internal reliability of the reinvestment factor. A suitably high value (0.80) was found.

Test-retest reliability was obtained by re-presenting the reinvestment scale alone to a subsample of 40 of the original population after 4 months. A Pearson product moment correlation coefficient of 0.74 was found between the original and repeated scores.

4.2.2 Discussion

It appears on the surface that a 20-item scale of reinvestment may have emerged from factor analysis of the combined cognitive failures, rehearsal and public and private self-consciousness scales. This reinvestment factor is dominated by rehearsal and public and private self-consciousness items and has a relatively robust internal and test-retest reliability. It remains for Studies 4, 5 and 6 to explore, via predictive validation, whether the scale actually does assess a predisposition towards reinvestment of explicit knowledge.

Item	Loading
Rehearsal	
I remember things that upset me or make me angry for a long time afterwards.	.32
I get "worked up" just thinking about things that have upset me in the past.	.41
I often find myself thinking over and over about things that have made me angry.	.36
I think about ways of getting back at people who have made me angry long after the event has happened.	.48
I never forget people making me angry or upset, even about small things.	.33
When I am reminded of my past failures, I feel as if they are happening all over again.	.32
I worry less about the future than most people I know.	-.32
Private self-consciousness	
I'm always trying to figure myself out.	.35
I reflect about myself a lot.	.40
I'm constantly examing my motives.	.50
I sometimes have the feeling that I'm off somewhere watching myself.	.33
I'm alert to changes in my mood.	.35
I'm aware of the way my mind works when I work through a problem.	.39
Public self-consciousness	
I'm concerned about my style of doing things.	.44
I'm concerned about the way I present myself.	.46
I'm self-conscious about the way I look.	.36
I usually worry about making a good impression.	.41
One of the last things I do before leaving my house is look in the mirror.	.32
I'm concerned about what other people think of me.	.46
Cognitive Failures	
Do you have trouble making up your mind?	.31

Table 4.1. Items and loadings on the second factor - Reinvestment

4.3 Study 4

An attempt was made in the present study to validate the new Reinvestment Scale by predicting that if the scale indeed assesses a predisposition towards reinvestment of controlled processing, then a skill such as the two-dimensional rod tracing task (Seashore, Dudek & Holtzman, 1949) will be more likely to fail or deautomatise under pressure in those individuals scoring high rather than low on the scale. In other words, the more likely the performer is to attempt to execute the rod-tracing task by consciously investing it with knowledge or rules the more likely that the performer's skill will be disrupted under pressure. If this were found to be the case it would provide validatory evidence for the Reinvestment Scale as a personality dimension.

4.3.1 Method

Subjects

Study 3 revealed scores on the Reinvestment Scale ranging from a low of 1 to a high of 20 (M = 9.81, SD = 4.37). Any score more than one standard deviation above the mean was designated a high score (> 14.18), whereas any score more than one standard deviation below the mean was designated a low score (< 5.44). Of the population of 144 who completed the original 75-item questionnaire, 22 scored high and 24 scored low on the reinvestment scale.

Three groups were drawn from the pool: a high reinvesters group (N=8; 4 females & 4 males), a low reinvesters group (N=7; 4 females & 3 males) and a control group, consisting of 5 high reinvesters and 6 low reinvesters (N=11; 5 females & 6 males).

Apparatus

A two-dimensional rod tracing apparatus (Seashore *et al,* 1949) was employed. This apparatus consisted of a length of copper rod 1 cm in diameter and 180 cm in length, bent into a rough vertical "M" shape 55 cm in height by 50 cm in width and mounted on a secure base. A hand held ring-stylus 2.5 cm in diameter encircled the copper rod. The aim was to move the stylus from one end of the rod to the other making as few errors as possible. A BBC computer recorded the time taken to complete each circuit of the apparatus, the number of contacts made and the length of each contact.

Measurement of changes in anxiety level under pressure were made using a portable heart rate monitor (HRM-2) attached to the waist. Electrodes were attached to the chest in 3 positions - one left of the sternum in the 4th intercostal space, one right of the sternum in the 5th intercostal space and an earthing electrode at the top of the sternum.

Procedure

In the first stage of the study participants in the control group were required to practice to asymptote on the rod tracing task. A spaced practice arrangement was employed, with each trial being separated by a 30 s rest interval in order to minimise fatigue effects. Spaced practice has generally been shown to result in more effective performance than massed practice (Eysenck & Frith, 1977).

The control group served two purposes. The first was to define the number of acquisition trials required for performance to reach asymptote. This allowed a target number of trials to be set for the high reinvesters and low reinvesters groups so that both achieved a similar level of performance prior to stress induction. The second purpose was to obtain a valid network of explicit rules associated with performing the task, in order that the two groups could be provided with a similar pool of explicit knowledge about the skill. This network of rules was obtained by requiring participants to write down any information they had gained about the task during each inter-trial interval. An added advantage was that it allowed inspection of whether high and low reinvesters accumulated equivalent amounts of explicit knowledge whilst acquiring the skill. It may be, for instance, that high reinvesters tend to accumulate more skill-related rules.

Once this subsidiary information had been gathered from the control group the second stage of the study, involving the high reinvesters group and low reinvesters group, was run. This stage consisted of an acquisition phase followed by a stress phase. In the acquisition phase participants made 15 practice trials, whereas in the stress phase they made 1 test trial. A spaced practice arrangement was again employed. During each 30 s rest interval participants were required to read a summarised list of the rules elicited from the controls, with the specific aim of applying those rules to their performance.

In all instances participants were told to make as few errors as possible, that is, not to make contact with the copper tubing. In the acquisition phase it was made clear that absolutely no emphasis was to be placed on time to complete a trial. During the stress phase this was again emphasised.

Upon completion of the 15-trial acquisition phase participants received a 5 min rest interval. During the final minute of this interval a brief stress induction statement was presented, explaining that one test trial was to be completed, and that each contact made with the rod would result in a reduction of 25 pence in the amount owed for participating in the experiment [see Appendix 6]. The apparatus was also altered so that upon each contact a 'buzz' emanated from the computer, further increasing the level of stress. In point of fact, money was not withdrawn. All participants received the same amount.

Assessment of the level of anxiety engendered by this method was made by monitoring the heart rate of each participant over the first trial of the acquisition phase (following 5 min rest) and over the test trial (again following 5 min rest), thus allowing comparison of rested heart rate pre and post stress-induction.

4.3.2 Results

The Control Group

Data were gathered from the control group (6 low reinvesters & 5 high reinvesters) for two reasons. Firstly, to determine the number of trials required for performance to reach asymptote, and secondly to form a network of rules with which to instruct the experimental groups.

Asymptotic performance. Performance, in terms of the number of contacts made in each trial, is plotted in Figure 4.1, for high and low reinvesters. It is apparent that by the fifteenth trial both groups were nearing an asymptotic plateau of performance. Therefore, it was decided that the experimental groups should also receive 15 trials.

A two-way analysis of variance with repeated measures (groups x trials; 2 x 15) showed there were no significant differences between the groups [$F(1,9) = .18$, ns], but revealed a highly significant main effect of trials [$F(14,126) = 5.39$, $p < .001$], confirming that performance improved over the 15 trials. A significant groups by trials interaction was also found [$F(14,126) = 2.10$, $p = .02$]; however, this appears to be due to the, perhaps quirky, difference between the two groups from Trial 1 to Trial 2.

Rules. For each subject the number of technical rules associated with performing the task was evaluated by two raters. Inter-rater reliability was 0.87. The mean number of rules produced by the low reinvesters was 5.25 as opposed to 4.25 by the high reinvesters. An independent *t*-test revealed that these were not significantly different, $t(9) = 1.02$, ns. Nine common instructional items were explicated from the pooled list of rules. These were rules such as, "rotate the ring with your fingers not your wrist" or "keep the ring perpendicular to the copper rod" [see Appendix 7 for the full list].

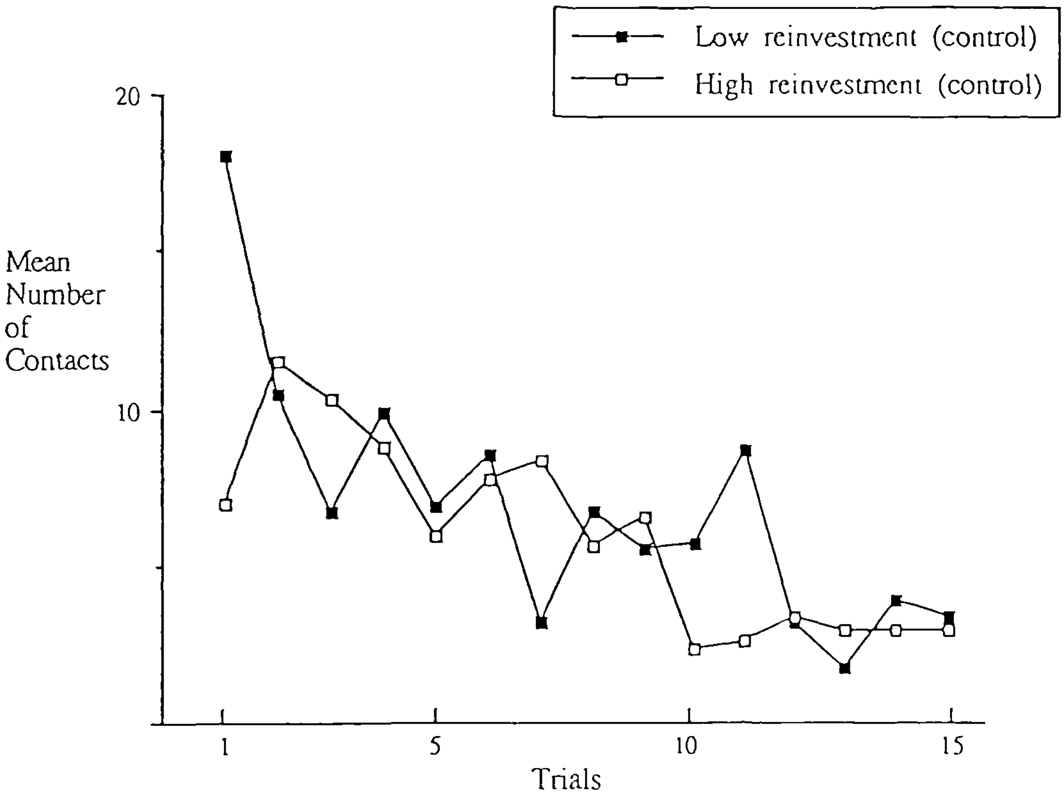

Figure 4.1. Mean number of contacts made on a 2-dimensional Rod Tracing apparatus by high and low scorers on the Reinvestment Scale (control groups) over 15 acquisition trials

The Experimental Groups

Stress Intervention. Heart rate was monitored over Trials 1 and 16 (pre- and post-stress). The means and standard deviations for the high and low reinvesters are presented in Table 4.2. Data from one subject in the low reinvesters group was lost due to equipment failure. A two-way analysis of variance with repeated measures (groups x pre- vs post-stress; 2 x 2) revealed a highly significant main effect for pre- and post-stress [$F(1,9) = 15.16$, $p < .001$], but not for groups [$F(1,9) = .06$, ns]. A significant interaction was not found [$F(1,9) = .18$, ns]. These findings show that heart rate in both groups increased significantly from Trial 1 to Trial 16 confirming that the stress intervention was effective for both high and low reinvesters.

Time taken. The mean times taken to complete trials 14 and 15 (pre-stress) and trial 16 (post-stress) were compared. These were 81.14 s pre-stress and 118.97 s post-stress for the low reinvesters and 65.31 s pre-stress and 87.95 s post-stress for the high reinvesters. In both cases there appears to have been a considerable slowing of performance under stress. This is supported by a two-way analysis of variance with repeated measures (groups x times; 2 x 2) which revealed no main effect of groups [$F(1,10) = 2.44$, ns] or group by time interaction [$F(1,10) = 1.24$, ns] but did reveal a highly significant main effect of times pre- and post-stress [$F(1,10) = 22.04$, $p < .001$]. Clearly, both groups were similarly affected by the stress intervention. Such slowing of performance is concordant with previous findings in the social facilitation literature which show that complex tasks are performed more slowly in situations where the subject is endeavouring to perform as errorlessly as possible in an evaluative or stressful situation (Bond & Titus, 1983; Zajonc, 1972).

Group	Stress Intervention	
	Pre-	Post-
High reinvestment	93.7 (9.4)	103.4 (9.7)
Low reinvestment	97.2 (6.3)	101.0 (10.4)

Table 4.2. Mean heart rate (beats per minute) and standard deviations (in parentheses) for high and low reinvesters prior to stress intervention (Trial 1) and after stress intervention (Trial 16)

Performance. From comparison of Figure 4.2 with Figure 4.1 it can be seen that the experimental groups shadowed the control groups over the 15 acquisition trials. Two low reinvesters and one high reinvester were excluded from the final analysis on the grounds that after 15 trials their performance showed no signs of reaching asymptote. In all three cases on Trial 15 performance was more than 3 standard deviations above the mean.

A two-way analysis of variance with repeated measures (groups x trials; 2 x 15) revealed a highly significant main effect of trials [$F(14,140) = 6.93$, $p < .001$] but no main effect of groups [$F(1,10) = .25$, ns] and no interaction [$F(14,140) = .94$, ns]. As in the control condition, both high and low reinvesters improved comparably over the 15 acquisition trials.

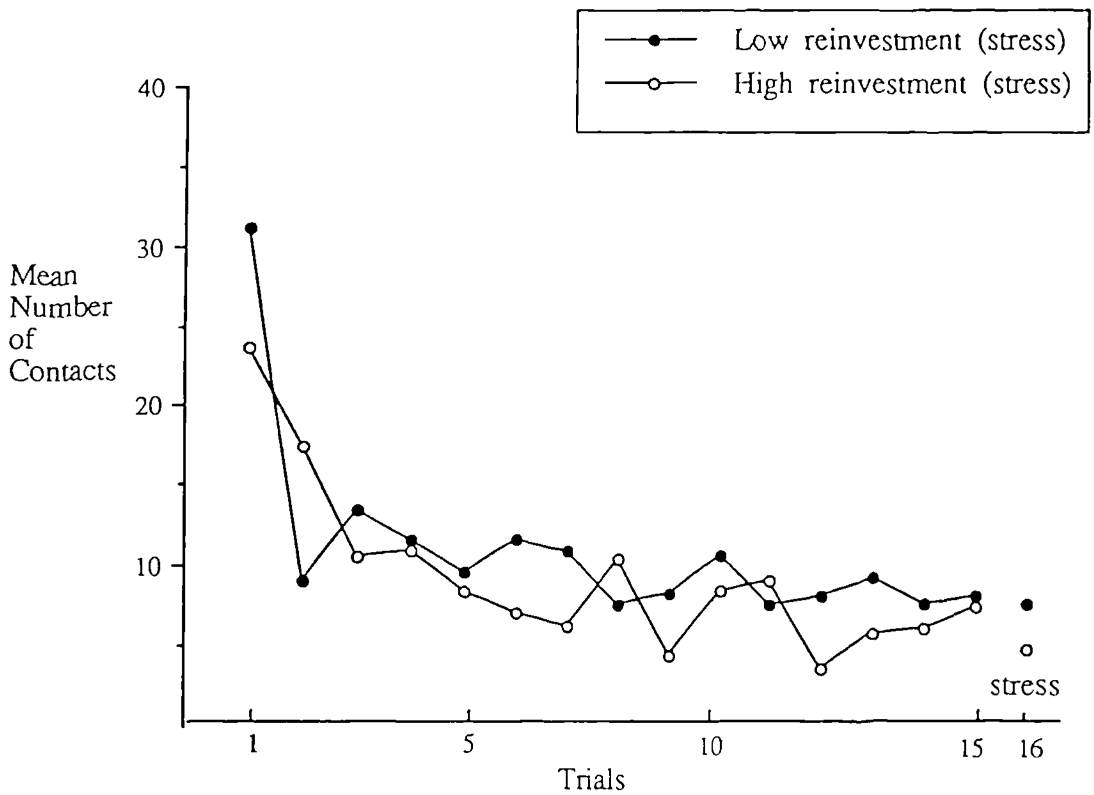

Figure 4.2. Mean number of contacts made on a 2-dimensional Rod Tracing apparatus by high and low scorers on the Reinvestment Scale (experimental groups) over 15 acquisition trials and 1 stressed trial

Stressed performance. For the purposes of assessing the effects of the stress intervention on performance in each group the mean number of contacts made in Trials 14 and 15 (pre-stress) was compared with the mean number made in Trial 16 (post-stress). The means and standard deviations are presented in Table 4.3.

	Stress Intervention	
Group	Pre-	Post-
High reinvestment	6.1 (3.3)	4.0 (6.4)
Low reinvestment	7.1 (4.5)	6.8 (5.6)

Table 4.3. Mean number of contacts and standard deviations (in parentheses) for high and low reinvesters prior to stress intervention (Trials 14/15) and after stress intervention (Trial 16)

A two-way analysis of variance with repeated measures (groups x contacts pre- and post-stress; 2 x 2) was again computed; however, no significant main effects or interaction were revealed ($p > .10$ in all cases).

A second dependent variable was considered at this point. The mean contact time of the stylus-ring on the rod was examined for each group pre- and post-stress. The mean contact times pre- and post-stress (Trials 14 and 15 versus 16) for the high and low reinvesters respectively were .30 and .55, and .20 and .30 seconds.

Analysis was again made via two-way analysis of variance with repeated measures (groups x contact time pre- and post-stress; 2 x 2), and again no main effects or interaction were apparent ($p > .10$ in all cases).

4.3.3 Discussion

There was no support for the prediction that high reinvesters would be more likely to fail under pressure. Neither the number of contacts nor the contact time was affected for high or low reinvesters under pressure. A number of explanations of the lack of differences are possible. For instance, the small number of subjects in each group may have been a restrictive factor, although different trends in performance under stress are not apparent. An alternative possibility is that the motor skill employed was not complex enough and did not create the kind of demands that would call for greater rule use. There is partial support for this explanation in the finding that although adoption of a motor set prior to performance (concentration on the movements of the skill itself) rather than a sensory set (concentration on the stimulus) will result in slower reaction times (RT) and motor times (MT) in complex skills the effect is minimal in simple skills (Henry, 1953; Pierson, 1959). If this was indeed the case it might be that an effect would be apparent for a more complex, rule-bound skill.

4.4 Study 5

Study 4 explored whether differences in performance under pressure arise between high and low reinvesters in more complex, rule-bound skills by contrasting the scores of participants in an earlier study (Study 1, Chapter 2) with their performance under pressure on a golf-putting task. Golf putting is a more complex motor skill than the two-dimensional rod tracing task, as is illustrated by the fact that in Study 1 learners of the putting task had not even reached a 50 % success rate after some 500 trials, whereas, in the present experiment asymptote occurred on the rod tracing task after a mere 15 trials.

4.4.1 Method

Reinvestment scores were obtained for participants from two similar stressed groups in Study 1 - stressed control (S-CON) and explicit learning

(EL). In Study 1 the S-CON group received no manipulation of its method of learning the putting skill, whereas, the EL group received explicit instruction in the correct putting technique. No differences in putting performance were apparent between the two groups either before or after stress, so for the purposes of the present study these groups were combined to give a more sizeable group, comprising 7 females and 7 males (one male and one female did not complete the scale). The method of invoking stress in Study 1 was similar to that employed in Study 4, in that, a monetary inducement was present; however, the earlier experiment enjoyed the security of an additional stressor - evaluation apprehension. As in Study 4, it was predicted that the putting performance of those scoring high on the Reinvestment Scale would be more likely to fail than of those scoring low.

4.4.2 Results and Discussion

A Pearson product moment correlation coefficient was computed between the reinvestment score for these 14 subjects and their putting-performance differences from pre- to post-stress. A significant correlation, in the expected direction, was found ($r = .59$, $p < .05$) .

The correlation between reinvestment scores and failure of skill in the putting task, but not the rod tracing task, supports the explanation that the latter task was too simple or too devoid of rules to result in reinvestment under pressure. That is, the skill involved so few technical components about which rules could be explicitly formed that there was little fuel for controlled processing and therefore little chance of deautomatisation. On these grounds it would be of interest to explore the relationship between reinvestment and performance failure in skills such as chess, which involve no motoric component but provide a rich source of failure under pressure. Study 5 was followed up by a further study in which the predictive validity of the reinvestment scale was, in a sense, tested in the field.

4.5 Study 6

It was posited that often participators in sports such as squash, golf or tennis gain an awareness, through experience, of whether their teammates tend to 'choke' or fail under pressure. If they were required to rate this tendency it could then be correlated with the reinvestment score of the teammate, hence providing a variation on the same predictive-validation theme. It could be argued that such a method of adjudging the strength of the predisposition towards failure of skill under pressure is more satisfactory because it does not rely on artificial modes of stress induction[1]. Employing two raters in order to ensure that the peer opinions are reliable should throw a little oil on any disquietude about the use of such a 'stress-failure rating' technique.

4.5.1 Method

The highest ranked 12 male members of the University of York Squash Club (mean age = 20.11 & SD = 3.97) and the highest ranked 12 male members of the University of York Tennis Club (mean age = 21.56 & SD = 4.32) were rated on their tendency to fail or 'choke' under pressure. These stress-failure ratings were made independently by the President and Captain of each club on a scale of 0 (never 'chokes' under pressure) to 4 (always 'chokes' under pressure) [see Appendix 8]. The Reinvestment Scale was administered to each player.

4.5.2 Results and Discussion

The means and the standard deviations for the reinvestment scores and stress-failure ratings in each sport are given in Table 4.4. Inter-rater reliability was very strong in both cases; squash (.90) and tennis (.84). The

[1] An anecdotal illustration of the fact that peer performers are well equipped to categorise the weaknesses of their teammates under pressure can be seen in a slang term coined during the author's own university tennis-playing days, and still heard on the courts today. The term, "a shummy", evolved as a direct result of general knowledge that a certain member of the club, carrying the surname Shum, often, if not always, tended to double fault on match point.

mean of the two stress-failure ratings given for each player was taken as an overall measure of predisposition towards skill failure under pressure. The data for the two sports were grouped together and a Pearson product moment correlation coefficient was computed between the mean stress-failure rating and reinvestment score of each player. A strong correlation was found ($r = .64$, $p < .01$)[2].

The high inter-rater reliabilities suggest that it was reasonable to use the opinions of teammates to assess the susceptibility of players to failure of skill under pressure, although ideally this needs confirmation via a more direct form of stress-failure rating. Most importantly, the correlation between the tendency towards reinvestment and the tendency towards skill failure under pressure broadens the support for the predictive validity of the Reinvestment Scale.

	Reinvestment Score	Stress-failure Rating
Squash	7.6 (3.7)	2.0 (0.8)
Tennis	7.8 (2.9)	2.3 (1.0)

Table 4.4. Mean stress-failure ratings and scores on the Reinvestment Scale with standard deviations (in parentheses) for tennis and squash separately

[2] The correlations for the two sports when taken independently were ($r = .70$, $p <.05$) and ($r = .63$, $p < .05$) for tennis and squash respectively.

4.6 General Discussion

Based on work in Chapter 2 it was hypothesised that individuals may have a predisposition towards 'reinvestment' of controlled processing, that is, a tendency to introduce conscious control of a movement by isolating and focusing on specific components of it.

In an attempt to establish a tool that would measure such a construct, existing personality scales, related to the concept of reinvestment, were administered to 144 students of the University of York. The scales were the Cognitive Failures Questionnaire (CFQ), the Rehearsal factor of the Emotional Control Questionnaire (ECQ) and the Public and Private factors of the Self-Consciousness Scale (S-CS). Factor analysis extrapolated three factors, of which the second fell within the confines of reinvestment. This factor consisted of 20 items drawn mainly from Rehearsal, and Private and Public Self-Consciousness and was dubbed 'The Reinvestment Scale'. A highly satisfactory test-retest reliability and internal reliability was evidenced.

It was argued that a high or low score on the Reinvestment Scale would be indicative of a predisposition that would manifest itself in altered performance under stress; specifically, high reinvesters would be more likely to fail under stress than low reinvesters, due to a greater likelihood that they would attempt to run their skill by consciously processing technical knowledge of its functioning. In order to test this a predictive validation of the Reinvestment Scale was carried out (Study 4). High and low reinvesters were selected from the population and required to learn a two-dimensional rod tracing test (with written technical instruction). The performance of the high reinvesters was similar to that of the low reinvesters both before and after stress intervention. In neither case was performance affected by stress, despite the fact that anxiety levels, in terms of heart rates, increased significantly.

On the grounds that the task employed in Study 4 may have been inappropriate a fifth study was carried out in which a correlation was found between reinvestment and the failure under pressure of a more complex, putting skill. This result can perhaps best be understood in terms of the idea that in simple skills there is simply less that can go wrong, whereas, in complex skills controlled processing has far more scope for disruption. For example, if a skill is achieved with the aid of a central executive to compute the necessary information and send the appropriate commands to the muscles for execution (Marteniuk & Romanow, 1983), then the more commands sent the greater the chance that disruption will occur.

A more sophisticated way to perceive this is the Neves & Anderson (1981) concept of 'composition' during the development of automaticity. As discussed in Chapter 1 composition is the chunking of "productions" to form single, direct representations of actions. If stress results in 'decomposition' of these direct representations and a regression to the use of the original lower-order productions to run the skill (as in the early stages of acquisition), then it follows that in a complex skill there will be more productions to coordinate, making it more likely that the skill will fail. A very similar account can be provided by Logan's (1988) Instance Theory, where stress might result in a return to an explicit, algorithmic-based control of behaviour through disruption of automatic retrieval of skill-based information from memory; the more algorithmic information to be retrieved the greater the risk of disruption. An analogy can be found in the often recounted, and somewhat tragic, tale of the centipede, who, when asked to disclose which foot moved when, never managed to walk again. The centipede's problem was compounded by a multitude of legs.

The sixth study broadened the scope of the support for the Reinvestment Scale as a method of identifying individuals more likely to fail under pressure with the discovery of a strong correlation between reinvestment scores and the stress-failure ratings of peer performers in tennis and squash. The strength of this relationship lends a certain practical appeal to the Reinvestment Scale in that coaches or managers could employ it in conjunction with their own opinions to identify performers likely to 'flop' on the big occasion.

The indications are that reinvestment as a concept is quite valid, although more research is required into the predictive power of the Reinvestment Scale. Even at this early stage, however, it does appear to have some potential as a method of identifying performers who may fail under pressure.

Chapter Five

Conclusions

The main intention in this the final chapter will be to provide an overview of the findings from the research, draw any conclusions warranted and discuss the implications and practical applications of the work.

5.1 A summary of the aims and findings

The aim in Chapter 1 was to build a framework from which to explore why the skill of apparently expert performers can sometimes fail under stress. This was constructed from reference to literature as far reaching as the implicit/explicit knowledge distinction (for example: Berry & Broadbent, 1984, 1987, 1988; Reber, 1967, 1976), skill acquisition theories (for example: Anderson, 1982; Fitts & Posner, 1967; Logan, 1988; Schneider & Shiffrin, 1977) and the role of stress in performance (for example: Baumeister, 1984; Hardy & Fazey, 1987; Hockey & Hamilton, 1983; Morris & Liebert, 1969; Parfitt & Hardy, 1987; Sanders, 1983; Weinberg & Hunt, 1976). It was seen that the route from novice to expert is one in which knowledge of the motor skill itself becomes less and less explicitly available to consciousness and more and more automatically accessed, but in certain circumstances this 'automaticity' can be lost. At such times, often when stress leads the performer to try consciously to exercise control over the execution of the skill, failure occurs. It was also seen that knowledge can be compiled implicitly and often has a strong influence on performance of the skill. Out of this framework came the idea that if consciously available knowledge can be reduced during the acquisition phase and accretion of implicit knowledge therefore encouraged the performer will be less able to consciously control the skill due to a lack of explicit knowledge of how it functions. This implies that under times of stress the skill will be less likely to fail.

The research set out in Study 1 (Chapter 2) to examine whether (a) it is possible to control the number of explicit rules compiled while acquiring a skill and (b) whether holding a small or nonexistent pool of such rules will mean skill failure is less likely to occur. Individuals acquired a putting skill either implicitly or explicitly. In acquiring the skill implicitly they were required to practise whilst carrying out a random letter generation task - a dual-task paradigm designed to limit the accretion of explicit rules or knowledge. In acquiring the skill explicitly individuals were given instructions obtained from well-known golf teaching manuals. These methods were found to be effective in inducing explicit and implicit learning - the implicit groups had few rules whereas the explicit group had many. Performance improved in both cases, and although it occurred at a slightly slower rate under the implicit learning conditions it was concluded that it is possible to acquire a motor skill implicitly. With regard to performance under stress there was a trend for implicit learning to be less likely to result in degradation of performance than explicit learning; however, it must again be emphasised that the stress intervention did not result in statistically significant decrements in performance in the Explicit Learning or Stressed Control groups. The argument that a trend existed was partly based on the fact that of the two control groups learning by discovery, the group not undergoing the stress intervention continued to improve in performance in Session 5, whereas that group involved in the stress intervention exhibited the opposite effect - a slight, but nonsignificant, decrease in performance. It was concluded that there is some suggestion that reducing the pool of explicit knowledge available to the performer will make it less possible for the automaticity of the skill to be disrupted by controlled processing, and hence the skill will be less likely to fail under conditions of stress.

The research in Study 2 (Chapter 3) removed doubts about use of a secondary task to cause implicit learning. A pall over Study 1 was the doubt about the improvements in performance exhibited by the implicit learning groups over practice. Although it was shown that learning occurred, there was a possibility that the secondary task held the performance level down and only allowed performance back to its initial level as the performer acclimatised to carrying out the two tasks at once. This would have given a false impression of learning. Initially, it was thought that the surge in performance of the unstressed implicit learning group upon withdrawal of the secondary task indicated that learning had occurred but had been masked by the presence of the secondary task; however, this explanation, despite its convenience, was felt to be premature in the light of a confounding explanation that 'reminiscence' (Eysenck, 1985; Schmidt, 1982; Travis, 1936) may have occurred.

An investigation of this confounding was launched on the grounds that to be fully confident of the effects of stress on performance in the implicit learning groups in the first experiment it was necessary to know whether reminiscence also had an influence on performance. It was argued that if both massed and spaced practice of the golf-putting skill and secondary task resulted in depressed performance followed by a surge in performance following withdrawal of the secondary task then reminiscence was not a confounding explanation - reminiscence is a phenomenon only associated with massed practice (Ammons, 1947; Eysenck & Frith, 1977). No reminiscence effect was found, suggesting that learning was not hindered, only masked, by the secondary task and allowing a conclusion that the easing of processing demands brought about by removal of the secondary task resulted in the apparent surge in performance.

With the dismissal of the reminiscence interpretation in Chapter 3 it was possible to explore further the idea of reinvestment of controlled processing first mentioned in Chapter 1 and expanded in Study 1 (Chapter 2). Study 3 (Chapter 4) argued that the tendency to try and consciously control one's skill with available explicit knowledge may depend on a predisposition to do so. A factor analysis of a number of relevant personality measures was carried out in search of a scale with which to measure such a personality dimension. The measures used were established scales, or part thereof, felt to be related to the reinvestment concept. They were the Cognitive Failures Questionnaire (Broadbent *et al*, 1982), The Emotional Control Questionnaire (Roger & Nesshoever, 1987) and the Self-Consciousness Scale (Fenigstein *et al*, 1975). A relevant 20-item factor was uncovered and was predictively validated in three further studies. In the first of these (Study 4), it was predicted that if the Reinvestment Scale is valid it should predict failures of skill - those individuals scoring high being more likely to consciously try to control their skill and hence more likely to fail than those scoring low. Unfortunately, the skill employed - a two-dimensional rod tracing task - showed no degradation under stress, and thus could not provide an adequate test of the hypothesis. It is likely that it was not demanding enough to result in greater rule use under stress so further studies were carried out.

Study 5 explored whether the prediction held for performance on the more rule-bound golf-putting skill used in Study 1. The majority of participants from two similarly stressed groups in Study 1 completed the scale in order that their scores on it could be correlated with their performance under stress. A significant relationship was found, showing that individuals with a predisposition to reinvest their skill with controlled processing were more likely to exhibit degradation of performance under stress.

A final study (Study 6) was carried out in an effort to further validate the scale. This was based on peer opinions in squash and tennis of how team mates perform under stress. Through experience, performers may gain an insight into the way their team mates respond to stressful situations; the penalty 'shoot-out' in football or 'match-point' down in tennis, for instance. Members of the University of York's squash and tennis clubs were presented with the scale and rated by each club's president and captain on their tendency to 'choke'. Again, evidence was provided supporting the predictive validity of the Reinvestment Scale - high reinvesters were more likely to be rated as tending to fail under pressure. It was concluded that reinvestment of controlled processing can be assessed by the Reinvestment Scale and is strongly linked with skill failure under stress.

5.2 Further Research

The research presented in this thesis explores implicit learning and reinvestment in human motor skill. A number of avenues worth exploring have been opened. Firstly, additional methods of enforcing implicit learning would need to be developed. One method would be to employ a binaural shadowing task, such as that used by Dawson & Schell (1982), Hicks (1975) and Kinsbourne & Cook (1971) rather than a random letter generation task. This would provide a number of stimulating possibilities. For instance, explicit rules could be submerged amongst the shadowed material (i.e., prose). This would make it possible to control the number and type of rules acquired by the individual. Comparisons could be made between the effect of stress on individuals acquiring twenty different rules as opposed to two, for example. Questions such as: do individuals become aware of the submerged rules, and do they employ those rules, would need verifying?

It would also be possible to explore the idea of 'deautomatisation' (Deikman, 1969; Henry, 1960; Klatzky, 1984) more thoroughly. For instance, it is usually argued that the physical characteristics accompanying automatic performance are that it is smooth, effortless and fast, whereas those accompanying novice performance are that it is effortful, erratic and slow (Fitts & Posner, 1967; Klatzky, 1984). It seems logical, then, that a deautomatised skill will be performed more slowly and less fluently. Indeed, as discussed in Chapter 1, Henry (1960) showed something similar when he found that motor times on a lateral arm sweeping task were significantly slower when one's attention was directed toward the motor response itself rather than towards the stimulus - recall, deautomatisation involves *"reinvesting actions and percepts with attention"* (Deikman, 1969, p. 31). This has support from a number of authors who have argued that direct execution of chunked procedures will be quicker than running an action with each individual procedure itself (Anderson, 1982; Klatzky, 1984). Salmoni (1989) took this further by suggesting that the the time taken to carry out a skill is proportional to the number of productions fired. In a sense, each production is an explicit rule used in executing a skill. If so, the time taken to execute the skill should be proportional to the number of rules employed to run it. Hence, reinvestment of controlled processing under stress would be expected to result in slower and less fluent performance on the grounds that additional explicit rules are being brought into play. A way to test this would be to have learners acquire a skill while shadowing prose containing different numbers of explicit rules. If reinvestment does occur under stress it might be that the time taken to execute the skill will indeed be proportional to the number of explicit rules shadowed. A less fluent skill might be indexed by a change in the amount of jerk, the rate of change of acceleration (Hogan & Flash, 1987).

A study was contemplated to investigate this, but difficulties in obtaining equipment prohibited it going ahead. The study was to have called upon skilled golfers, who can be assumed to have automatic putting skills, to perform under conditions of stress and no stress. Stress was to be induced by involving participants in a 'highly' competitive situation, achieved by offering the opportunity of foregoing the regular experimental fee in favour of competing against the other participants in the experiment for a first prize of up to £125.00 or second prize of up to £47.50. A minor variation on Cottrell's (1972) theory of evaluation apprehension was used as an additional stressor. Rather than employing specific coactive audience evaluation the situation was to have required performance in front of a professional film camera with a payment possible if performance was good enough. Exposure to a camera is an experimental manipulation that has been shown to increase levels of anxiety (Duval & Wicklund, 1972). The rate of change of acceleration of the putter (or magnitude of 'jerk') was to be computed by an acceleromotor as a measure of fluency of movement, with the expectation that jerk would be greater on putts failing in the stress condition. Furthermore, it was hoped that an insight may have been given into the component parts of the skill which break down under stress. For example, greater changes may occur in the follow-through than in the back-swing of the putt, or *vice versa*.

Along the same lines, although not making use of the shadowing technique, it would be of interest to draw the classic Chase & Simon (1973a,b) demonstration of chunking in chess experts into the reinvestment debate. A problem with discussing reinvestment in experts is that once the skill is automatic its execution no longer relies on the coordination of individually controlled productions; chunking of the productions occurs to form single, direct representations of the actions (Neves & Anderson, 1981). For reinvestment of explicit knowledge to occur these direct representations must somehow revert to their individual productions. Evidence from Fitts *et al* (1961) and Fuchs (1962) shows that when a learner is stressed he or she can regress to the use of simpler, lower level information. Fuchs (1962) called this the 'progression-regression' hypothesis. Such evidence supports the case for reinvestment as a major contributing factor to skill failure under stress, although more direct evidence would be valuable. Chase & Simon showed that expert chess players recalled more information at a single glance on a 5-second recall test than non-experts, but only if the material to be recalled conformed to realistic, as opposed to random, game situations. They effectively argued that this superiority was due to the experts' ability to chunk the material into meaningful units of information. This finding has been replicated in skills as varied as bridge (Charness, 1979), music (Sloboda, 1976), basketball (Allard, Graham & Paarsalu, 1980) and hockey (Starkes & Deakin, 1984). One way to investigate whether stress interferes with the chunking of information in some way would simply be to predict that under stress experts should perform worse on the 5-second recall test for material conforming to realistic game situations. Another method of investigating this would be to take highly cognitive skills, such as dart scoring, in which the scorer is required to calculate the total score made by three throws (e.g., triple 8 + double 19 + single 3) and then subtract the total from an starting score of 501. Chunking can occur in making mathematical calculations (Ashcraft, 1982; Zbrodoff & Logan, 1986). Early in learning calculating 'triple 8' might require the individual to make lower-order calculations such as 8 + 8 = 16 followed by 16 + 8 = 24, but with expertise the information will have been chunked into a more meaningful unit of 3 x 8 = 24 which is more rapid and requires fewer individual calculations. If stress interferes with chunked information by somehow fragmenting it one would expect the dart scorer to make more lower-order calculations and hence perform more slowly under stress than when not under stress. It would be possible to assay the number of higher- and lower-order functions by having the scorer make his or her calculations verbally or in writing.

A weakness in Study 1, signalled in that study's discussion, was that full automaticity of skill was not achieved. Although it was argued that a degree of automaticity was most definitely reached (Logan 1978, 1988; Schneider & Fisk, 1982; Schneider & Shiffrin, 1977), it would be most interesting to investigate the consequences of continuing skill acquisition in the various conditions - particularly the implicit learning condition - until asymptote was reached. Would an individual in the implicit learning condition become so expert at the secondary task that most of his or her available processing capacity could be given over to performance of the motor skill, hence allowing the possibility of accretion of explicit knowledge? Or would the motor skill somehow become immune to explicit interference, perhaps because over the initial sessions a prefabricated coordination pattern or 'image of the act' (Whiting & den Brinker, 1982) had been formed? If such a pattern was formed implicitly, explicit processing might never be required for its execution. If so, the practical application would be for those novice to a motor skill to initially acquire it implicitly. This would avoid the impracticality of having to maintain use of the secondary task in the field, over a long period of time and during competition. Another question is how would extended implicit learning affect the actual acquisition of the skill itself? Would the skill become better than an explicitly learned or discovery learned skill? Would it be less likely to fail under stress, or indeed would it even catch up to either the explicitly learned or discovery learned skill?

Future research might also consider some of the side issues arising from Study 1. For instance, more could have been done with the secondary task data, that is, the tape recorded random letters generated by each learner in the implicit learning conditions. No assessment was made of how well each learner maintained the randomness of their letter generation. It may have been that those participants who were less random were allowing themselves more processing capacity with which to acquire the putting skill. If so, they may have acquired a greater number of explicit rules and may have been more likely to fail under stress than those maintaining a greater degree of randomness in their letter generation.

There was also a weakness in the way in which the degree of explicit knowledge accumulated by each learner was accessed in Study 1. To merely ask the participant to write down anything they became aware of while putting was less than ideal. The debate on how accurately we can articulate our internal states or our actions has been a long one (for example, Titchener, 1912; Nisbett & Wilson, 1977; Ericsson & Simon, 1980; Sanderson, 1989). Most who wish to access the learner's verbal knowledge do so by question and answer, which, as Broadbent (1990) says, can be criticised on the grounds that "the particular questions chosen by the experimenter may not have been appropriate to the particular ideas of the person learning..." (p.47). The persons knowledge may simply not be accessed by the questions asked. The only alternatives appear to be to ask a variety of questions (Berry & Broadbent, 1984, 1987; Broadbent *et al*, 1986) or to ask the person to express their ideas on how they execute the action (Stanley *et al*, 1989). It is difficult to know what would have been the most appropriate method of accessing the explicit knowledge of the participants in Study 1. Perhaps it is of little consequence, as the information was accessed from all conditions in the same manner. More importantly, it must be noted that the ability to articulate one's skill is by no means a vital component of expert performance and may in fact hold performance back. For instance, Cooke (1965) showed that good verbal knowledge can accompany very poor performance, and Broadbent *et al* (1986), Morris & Rouse (1985) and Rouse & Morris (1986) showed that allowing a learner the opportunity to form strong memories for factual details about a skill does not necessarily mean they will perform better. It has also been seen that instructing the learner to try and become aware of the rules associated with the skill can slow learning (Berry & Broadbent, 1988; Reber *et al*, 1980). Furthermore, Berry & Broadbent (1984) even found, over all their studies, a significant negative correlation between good performance and the ability to articulate that performance - the worse the performance the more the performer seemed to know about it. Funke & Muller (1988) found this also.

This last finding can be explained in terms of the previously dicussed idea that reinvestment can cause a regression from higher-order to lower-order functioning (Neves & Anderson, 1981). The Neves & Anderson approach to skill acquisition suggests that as learning progesses lower-order productions are replaced by more complex, chunked, higher-order productions; however, only the lower-order productions can support verbalisable knowledge of performance - higher-order productions are more efficient and so disregard much of the information utilised by lower-order productions. It follows that the better the performance the more higher-order the performer's functioning will be and the smaller the involvement of verbalisable knowledge, but, the worse the performance the more lower-order the performer's functioning will be and therefore the greater the involvement of verbalisable knowledge. This implies that peak performances which involve almost entirely higher-order functioning will be accompanied by poor verbalisable recall of the performance, which is indeed one reported characteristic of peak performance (Browne & Mahoney, 1984; Murphy & White, 1978; Ravissa, 1977).

5.3 Practical Applications

It is clear from discussion so far that the value of implicit learning itself is that it restricts the possibility of reinvestment. Methods of enforcing such learning may be put into practice in the laboratory with relative ease, but they have some obvious restrictions in the field. For instance, even over a mere 400 putts in Study 1 the effectiveness of the dual task method of restricting resource availability was beginning to wear off - as subjects improved at executing the two tasks at once resources became available with which to become aware of the primary, putting task. This was not a particular problem in Study 1, but it would be over longer acquisition periods. Admittedly, it would be possible to change the secondary task each time the individual becomes accustomed to it, but eventually the variations on the dual task theme would become exhausted, or the overall effectiveness would be degraded by a general improvement in the ability to work under dual-task conditions. Finally, the impracticalities of using such methods in the field are obvious. Few coaches would have the time, resources or foresight to enforce implicit learning for all the years it takes to become an expert, and few 13-year old 'lads' would be prepared to shout random letters in time to an electronic metronome when out practising with their 'mates'.

A more simple, less rigorous approach would be for coaches to reduce their emphasis on the technical content of the skills they teach. This is a compromise and obviously would leave much room for acquiring explicit knowledge about one's skill by discovery learning, but the pool of explicit knowledge would at least not be unnecessarily enlarged. Additionally, there are methods available in sport psychology which are often used to prevent athletes focusing on specific parts of the skill. Preshot routines, for example, have been claimed to do just this by encouraging the performer to focus on the skill in a more wholistic way (Boutcher & Crews, 1987; Crews & Boutcher, 1986). Ultimately the coach must find a balance between providing explicit knowledge and encouraging accretion of implicit knowledge. If the learner is holding the wrong end of the pool cue, or using a fist rather than fingers to throw the dart, or bowling the cricket ball with a bent arm then the coach must offer explicit, technical rules to get the learner back on the right track[1]. On the other hand, the coach must remember that top performers often execute their skills in ways divergent from the stereotyped ways of doing them. Take, for instance, Borg's forehand, Ali's shuffle, Florence Griffith-Joiner's stride. They work not so much because they are more effective techniques but because they are part of these performers' natural armoury, and therefore implicitly developed rather than explicitly learned. And yet, the [so called experts] blithely add these new techniques to their instruction manuals and attempt to explicitly teach them to novices. This is

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[1] The Reinvestment Scale is of great value to the coach in finding the correct balance, for it can provide information on the predisposition of the learner to reinvesting explicit knowledge in the skill itself. If the learner is a low reinvester the coach will know that he or she can afford to provide more technical advice about the skill than if the learner is a high reinvester.

so in all skills. For example, Louis Kenter (1976, p.48) discusses the very complaint in connection with the piano:

> "Altogether it is dangerous to put down cut-and-dried rules about technique. I have heard pianists who had 'impossible' hands which looked half crippled on the keyboard, and who did all the things condemned by almost everybody else, perform miracles of technical perfection. In matters of piano technique so much depends on imagination, temperament and imponderable things of the mind, and genius often proves that the impossible is the only right solution - in short in Art there can be no categorical rules and no simple solutions."

The problem is actually more complex than this if the modern learner is to attempt to attain expertise the implicit way. 'Normal' participation in modern Western culture requires a dominance of logical, rational, analytical and verbal modes of consciousness, and as a result, explicit knowledge is prized above all. Polanyi (1957, 1966) and Bruner (1960) both agree that explicit knowledge is so much easier to deal with and so much less subjective that Western societies in particular, place far greater emphasis and value on it than implicit knowledge. Certainly, there is support for the idea that society pushes the learner towards an analytical, logical mode of functioning predominated by accretion of explicit knowledge. Ornstein (1972, p.162) writes:

> "Western educational systems largely concentrate on the verbal and intellectual. We do not possess a large scale training system for the other side...."

Corballis (1976, p.104) agrees:

> "Some writers have urged that our materialistic Western culture has forced too great an emphasis on the rational, analytic mode of thought, to the neglect of the intuitive and the wholistic."

In sport there are further blocks to implicit learning. For example, talented young performers come under pressures and expectations to conform to the stereotyped methods of performance promoted by coaches, administrators, parents or peers. It is almost always that when a young performer is first touted as a future star or potential champion that youngster has been noticed while performing in a state of 'play' in which performance lacks reference to anything analytical, logical or explicit[2]; however, the moment coaches, administrators or parents begin applying pressure to practise more, play better, try harder and so on, there is ignition and acceleration of 'striving activity':

> "The receptive mode is aimed at maximising the intake of the environment, and this mode would appear to originate and function maximally in the infant state. The receptive mode is gradually dominated, if not submerged, however, by the progressive development of striving activity...."
>
> (Deikman, 1973, p.69)

The ability of youngsters to perform outside the analytical, logical or explicit mode of functioning is often alluded to in Eastern writings. For instance, Herrigel (1953) cites his Zen master on this:

> "...a child doesn't think: I will now let go of the finger in order to grasp this other thing. Completely unselfconsciously, without purpose, it turns from one to the other...."
>
> (Herrigel, 1953, p.33)

As an adult this is not necessarily an easily achieved goal, as Suzuki (in Herrigel, 1953, p.VII) reveals:

> "Man is a thinking reed but his great works are done when he is not calculating and thinking. "Childlikeness" has to be restored with long years of training in the art of self-forgetfulness."

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[2] This is supported in part by Mandler (1984), who described the learning of pre-verbal children as unselective and non-analytical, and Parkin & Streete (1988), who found that implicit memory develops earlier than explicit memory.

One wonders if Bjorn Borg achieved this state of 'childlikeness':

> "A hundred per cent of my game is instinct. I never stop and think I'm going to hit a ball cross-court or down the line. I just do it."
>
> (Borg, 1980, p.86)

One effective method of bridging the gap between implicit learning and explicit knowledge has been developed by the author and is employed in his capacity as a professional tennis and squash coach. This method he describes as 'coaching by analogy'. The aim is to get the performer (often a novice) to perform the to-be-learned skill using one general analogical rule which in fact encompasses many technical rules necessary for successful execution of the skill. The learner follows the simple analogy and inadvertantly employs these rules. This appears to be a very effective method[3]. The author has been heard to boast, on many occasions sadly, of the fact that he can teach the most uncoordinated tennis hopeful to hit a top-spun forehand in less time than it takes to claim "Bjorn Borg was the *only* tennis player". This rather grand boast is accomplished by employing the right-handed triangle as an analogy. The learner is asked to describe a right-handed triangle with his or her tennis racquet and to bring it squarely up the hypotenuse. Figure 5.1 illustrates this. Once accomplished with reasonable accuracy and consistency - most people manage it immediately - the learner is told that every time he or she hits the ball to concentrate on nothing other than bringing the racquet squarely up the hypotenuse. The physical implication of making such a movement with the racquet is to impart top-spin to the tennis ball.

Disguised in the analogy are explicit rules often taught to beginners. For example, brush up from beneath the ball, complete the swing with the racquet above the ball, keep the wrist firm. The excerpt presented below

[3] The method also negotiates the value-for-money problem which would raise its head if the coach tried to avoid providing the torrent of explicit rules learners are used to paying for.

(Cox, 1975, p.39) gives an example of the traditional way in which the top-spun forehand is taught:

> "...take the racket head back parallel with the ground. In this shot, as all others, the wrist has to be locked rigid, absolutely firm, or the end product will be messy. Then move your left leg in front of you, at an angle of 45 degrees, to a comfortable position. The body should be at 90 degrees to the net and sideways on. Keeping the racket at the same level at which it was taken back, move it forwards and intend to meet the ball in front of the left toe. Don't tuck the elbow right in and don't have your arm straight out. The elbow should be slightly bent and once more remember to keep the wrist locked. The more rhythm the better but this will come in time. To finish the forehand, the racket should continue over your left shoulder in the direction in which you have hit the ball."

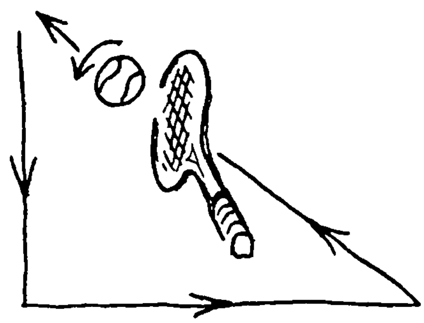

Figure 5.1. An illustration of the 'Analogical Forehand' method employed by the author in teaching a top-spun forehand in tennis

Clearly this method requires the learner to become aware of a far greater number of explicit rules. Furthermore, there are obvious drawbacks in terms of comprehending the instructions and achieving a desired result. In fact, Annett (1988) argues effectively that translation from the action mode to the verbal mode can only be made through imagery, as the verbal system does not have direct access to the action mode. This suggests that to successfully translate verbal instructions into action requires the instructions to stimulate formation of appropriate imagery. It is debatable that traditional methods of instruction such as those above succeed in this.

One of the most interesting applications of an implicit learning technique such as the dual task method is that it may provide a treatment for problems such as the 'yips' in golf or 'dartitis' in darts. Despite the many strange stories which surround these afflictions they appear to be particularly severe forms of reinvestment. Take for example the following description of the 'yips':

> "...instead he [the putter] may suddenly become acutely conscious of the movement he is about to make. What should be an automatic unified movement, becomes a complicated problem of consciously co-ordinating many separate small movements."
>
> *(Cochran & Stubbs, 1976, p.135)*

As has been shown, implicit learning can restrict much of what the performer would normally become aware of when making the movement. It may be possible to treat expert performers with problems of this nature by getting them to relearn their skill implicitly. It may well be somewhat time consuming to accomplish this, as individuals with such problems have usually been performing for many years and have often acquired a very large pool of explicit knowledge about the skill in an effort to cure it. However, the time taken to relearn the skill implicitly may be seen as time well spent, for this dreaded affliction has ended the career of many fine performers.

Finally, this thesis commenced with the words of a great novelist, Boris Pasternak, so it seems appropriate to end with those of another great writer, the Zen philosopher, Daisetz Suzuki. His words now require no explanation:

> "Thinking is useful in many ways, but there are some occasions when thinking interferes with the work, and you have to leave it behind and let the unconscious come forward. In such cases, you cease to be your own conscious master but become an instrument in the hands of the unknown. The unknown has no ego-consciousness and consequently no thought of winning the contest. It is for this reason that the sword moves where it ought to move and makes the contest end victoriously."
>
> (Suzuki, 1959, p.133)

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Appendices

Appendix 1: Instructions presented in the explicit learning condition (Study 1)

The following instructions in golf putting are borrowed in a slightly modified form from books entitled 'Golf: The Skills of The Game' (Stirling, 1985) and 'The Young Golfer' (Saunders & Clark, 1977). You will receive them at the beginning of each session. Always read them carefully and follow them strictly, as they will show you the correct way to putt a golf ball.

> *Set the clubface behind the ball with the face at right angles to the hole, and have all of the sole of the putter on the ground.*
>
> *Use the reverse overlap grip. This means that the forefinger of the left hand overlaps the little finger of the right hand. (Reverse this if you are left-handed). There is a feeling of more control with the dominant hand when using this hold, and this is an essential feeling to have when trying to roll a ball along a line to a specific point.*
>
> *Stand with the distance between the heels in the region of ten to twelve inches (25-30 cm)...The alignment of the shoulders, hips, knees and feet should be parrallel to the ball-to-target line.*
>
> *The body should be bent over until the eyeline is directly over the ball-to-target line. Ideally, the person should feel that a balanced stillness can be maintained in the body as the arms and putter make the stroke.*
>
> *Ball position is also critical, as the ideal point of contact is when the putter is travelling at the lowest point of its swinging arc. At this stage, it is square and travelling through to the target....Placing the back of the ball at a point opposite the inside of the left heel gives the best opportunity of achieving ...this.*

The actual swing of the putter is made by the arms with the hands serving as the connecting link. Because of the forward bending at address, the arms bend slightly and it is vitally important to maintain this degree of bend throughout the stroke.

Another very important feeling is that of moving the top of the shaft and the putter head back and through together. This cancels out wrist action....

In a good putting stroke, the putter should move back and through smoothly, with the putter very low to the ground.

The most important thing about the putting stroke is to take a fairly short backswing so that you can push the club firmly at the hole. Never take a long backswing with a putt so that you have to slow down. Short back; firm through.

Keep your head absolutely still. This will help you make the club travel in a perfectly straight line. If you move your head, you will find the putter travels off its line in the throughswing and is pulled in towards your feet. Never look at the ball as it reaches the hole....Always keep your head perfectly still until you hear the ball drop in. Only look up once you hear it drop, or once you're sure it's missed!"

Appendix 2: Instructions presented in the implicit learning conditions (Study 1 & Study 2)

The following instructions are to be carried out while you are putting. You will receive them at the beginning of each session. Always read them carefully and follow them strictly.

> "Imagine drawing letters of the alphabet from a hat one at a time, calling them out, and replacing them. On each draw any of the 26 letters will therefore be equally likely to be selected. Such a sequence would be completely jumbled or random and would not be likely to comprise English words or alphabetic sequences such as ABC or XYZ. You must call each randomly generated letter each time you hear the click."

Appendix 3: Stress induction statement presented in Study 1

Today is the final session. As explained at the beginning of the experiment, this session will decide what payment will be made to you. You will begin with a sum of £12.00 which can increase to £15.00 or decrease to as little as £1.00. You will lose varying amounts for missed putts or poor putts, and may gain lesser amounts for good putts. The amount you gain or lose will be decided by an expert in golf who will evaluate your performance from behind this one-way mirror.

Appendix 4: Items and loadings on the first factor - Factor 1 (Study 3)

Item	Loading
Rehearsal	
I remember things that upset me or make me angry for a long time afterwards.	.37
If I have to confront someone, I try not to think too much about it beforehand.	.30
I seem to remember things that have upset me much less vividly than other people.	.42
I tend to get over upsets more quickly than most people.	.30
I never worry about my past failures.	.35
Cognitive Failures	
Do you find you sometimes forget why you went from one part of the house to the other?	.65
Do you ever fail to notice signposts on the road?	.64
Do you bump into people?	.54
Do you ever find you forget whether you've turned off a light or a fire or locked the door?	.39
Do you fail to listen to people's names when you are meeting them?	.31
Do you ever say something and realise afterwards it might be taken as insulting?	.45
Do you fail to hear people speaking to you when you are doing something else?	.42
Do you sometimes lose your temper and regret it?	.39
Do you leave important letters unanswered for days?	.38
Do you ever find you forget which way to turn on a road you know well but rarely use?	.50
Do you sometimes fail to see what you want in a supermarket (although it's there)?	.51
Do you sometimes find yourself suddenly wondering whether you've used a word correctly?	.42
Do you find you forget appointments?	.30
Do you occasionally forget where you put something like a newspaper or a book?	.42
Do you find you accidentally throw away the thing you want and keep what you meant to throw away - as in the example of throwing away the matchbox and putting the used match in your pocket?	.60
Do you ever daydream when you ought to be listening to something?	.34
Do you find you can't quite remember something although it's "on the tip of your tongue"?	.47
Do you find you forget what you came to the shops to buy?	.54
Do you drop things?	.59

Appendix 5: Items and loadings on the third factor - Factor 3 (Study 3)

Item	Loading
Rehearsal	
I find it hard to get thoughts about things that have upset me out of my mind.	.53
If I see something that frightens or upsets me, the image of it stays in my mind for a long time afterwards.	.37
Thinking about upsetting things just seems to keep them going, so I try to put them out of my mind.	.49
If I lose out on something, I get over it quickly.	.48
Even though I try to forget about things that have upset me, they keep coming back into my mind.	.42
I often feel as if I'm just waiting for something bad to happen.	.53
When I am reminded of my past failures, I feel as if they are happening all over again.	.40
Upsetting things quickly lose their power to affect me.	.43
Sometimes I have to force myself to concentrate on something else to keep unpleasant thoughts out of my mind.	.41
Intrusive thoughts about my earlier unpleasant experiences make it difficult for me to keep my mind on a task.	.43
Any reminder about a past failure brings back emotions related to it.	.55
I wish I could banish from my mind the memories of past failures.	.43
Sometimes I get so involved thinking about things that have upset me I am unable to adopt a positive attitude towards anything.	.59
I worry less about the future than most people I know.	.40
It takes me an unusually long time to get over unpleasant events.	.36

Appendix 6: Stress induction statement presented in Study 4

YOU WILL NOW MAKE ONE TRIAL ON THE APPARATUS. THIS WILL BE A TEST TRIAL. EACH TIME YOU MAKE A CONTACT A BUZZER WILL SOUND AND 25 PENCE WILL BE SUBTRACTED FROM THE SUM OF 5 POUNDS OWED TO YOU.

Appendix 7: The list of rules for executing the two-dimensional rod tracing task (Study 4)

1. Hold the stylus firmly in your fingertips and close to the loop

2. Take up a firm footing with your legs spread to the width of your shoulders or greater.

3. Hold your arm with the elbow bent roughly at right angles to your body.

4. Support your wrist with your free hand.

5. Move the stylus at a constant speed.

6. Rotate the loop with your fingers and not your wrist.

7. Always keep the loop perpendicular to the copper tubing.

8. Rotate the loop slowly and with great care at the corners.

9. Move your upper body in the same direction as the stylus without moving your feet.

Appendix 8: The Stress-failure Rating Scale employed in Study 6

In the following spaces please rank who you feel to be the top 12 players in your club. On the scale alongside indicate your opinion of how likely the player is to 'choke' or fail when performing under pressure.

	Never	Seldom	Occasional	Often	Always
1. ------------------------	0	1	2	3	4
2. ------------------------	0	1	2	3	4
3. ------------------------	0	1	2	3	4
4. ------------------------	0	1	2	3	4
5. ------------------------	0	1	2	3	4
6. ------------------------	0	1	2	3	4
7. ------------------------	0	1	2	3	4
8. ------------------------	0	1	2	3	4
9. ------------------------	0	1	2	3	4
10. ------------------------	0	1	2	3	4
11. ------------------------	0	1	2	3	4
12. ------------------------	0	1	2	3	4