SKILLS ACQUISITION BY YOUNG DRIVERS:
Perceiving, Interpreting and Responding to the Driving Environment

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Abstract
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Keywords

DRIVING, YOUNG DRIVERS, SKILLS ACQUISITION

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EXECUTIVE SUMMARY

The majority of this report comprises a literature review of past research into the nature of perception, interpretation and skilled response in young drivers. Consideration of this research suggests that the development of mature driving can be illuminated by considering research into the fundamental nature of expertise, or expert performance, in other activities. The report concludes by raising a number of questions about driving skill acquisition considered within the context of the development of expertise.

It is recognised that driving is a complex skill but that error rates are remarkably low although frequently having serious consequences. Although these errors or crashes usually involve unique combinations of factors, the classes of cognitive or mental process responsible for it may be common to all crashes. Thus research into these cognitive processes is desirable.

Young drivers are over represented in crash statistics although their simple driving skills may be very good. However, the perceptual environment in driving is very demanding and many studies appear to show poor perceptual and attentional processes in young drivers as compared to mature, expert, drivers. Importantly, comparative studies of novices and experts in other domains show similar differences. Experts appear to have learned what to look for in the road environment, how to rapidly interpret it and how to simplify it, in comparison to novices. Experts do this in an automatic, immediate, and holistic way. In mature drivers one of the most important contributions of this expert perceptual process must be in the recognition of hazards and in their assessment. Past research shows that novices and experts differ in their assessment of hazards. It is the contention of this report that the perceptual and attentional procedural differences of novices and experts contribute importantly to this difference. However, the impact of these procedural differences on driving may be influenced by the greater discrepancy between novices' self-assessment and their performance than that of experts.

Past research also shows that driving is more demanding of mental resources in novices than it is in experts. Novices cannot handle as much information as can experts, nor can they switch attention between different sub-tasks as well as can experts. It is the contention of this report that these discrepancies are due to the automatisation of processes in mature drivers and this automatisation frees mental resources to better control and prioritise their skills. This automatisation does not, however, lead to inflexible driving in experts because they have developed effective and flexible prioritising strategies and can rapidly switch attention between sub-tasks because they have learned high level driving rules. So to do experts in other domains.

Research into the benefit of driver training programs is equivocal. Some small improvements have been found, often of a temporary nature, but these improvements are most often found in driving knowledge and in reduced violations but rarely in crash records. Drinking alcohol may have more serious consequences on novices than on experts because of differences in risky behaviour and in the appreciation of hazards between experts and novices. Programs designed to improve behaviour and attitudes to drinking and driving are similarly equivocal. This is mainly because behaviour and attitude may not be similarly affected by the program. However, driver education programmes must form a key part of attempts to reduce crash rates. An understanding of the means to improve driver performance is therefore crucial.

Highly skilled expert, mature drivers, are thought to have automatic procedures linking perception and attention to the environment and performance in fast and flexible ways. Novices, although familiar with the same rules, have not developed these procedures, and function at the level of booklearned knowledge. As novices develop these abilities they may go through a stage, before these abilities are automatic, when the amount of booklearned knowledge they have imposes even greater demands on their mental processes than does the more limited knowledge of the beginner. Then their performance may be even worse than that of the beginner; indeed crash rates do peak after two years of driving experience. The implication of this approach is that sheer knowledge of driving will not assist safe performance and reduce crashes unless it is automatic; indeed such knowledge may impair performance a little. What is required for safe driving is exhaustive practice of the skill, including perception, interpretation and response, to the point of automaticity of the procedures required. Research must therefore identify the range of skills needed in driving and then the nature of informative feedback required to correct deficiencies in those skills at all levels of their execution.

Research questions arising from the review focus on the nature of self-assessment and confidence in mature and novice drivers; the nature of expert perception of the driving environment; differences between the perception and attention of mature experts and novice drivers; the form a successful driving training program might take; and whether novices are impaired in task prioritisation by the demands of driving on their mental resources.

Driving is a complex skill involving continuous tracking movements by the hands and arms integrated with feet and leg movements, in response to an ever changing, varying and somewhat unpredictable environment. Considering the speed, precision and variable feedback conditions presented by the driving task, the error rates are remarkably low. However, errors are of great concern. For example, road statistics show that eight people are killed and another 80 are seriously injured each day in automobile crashes on Australian roads (Transport and Communications Report, 1988). What becomes clear from the literature is that crashes involve a complex interaction between many factors and that each crash is unique. **Nevertheless,** it is hoped that some principles of behaviour may be found that can be shown to have a central role in crash involvement. The present review examines mechanisms responsible for perceiving, interpreting and responding to the driving environment in an attempt to identify such behavioural principles, particularly those that may be responsible for the high crash rate among young drivers.

2. THE TARGET POPULATION

Young drivers are overrepresented in the road crash statistics (Jonah, 1986) and, as a result, much of the research on driving conducted within the last decade has studied characteristics of drivers between 16 and 24 years of age. For example, the mileage driven prior to a crash for young drivers is half the mileage per crash for older drivers (Kroj, 1981); teenage motor vehicle related fatalities are more than twice the rate expected on a population basis (Lewis, 1985); and young drivers are more likely than older drivers to be at 'fault' in fatal crashes (Lewis, 1985). Such startling statistics are documented one way or the other through out the literature. Perhaps the most revealing finding is that even when the amount and type of exposure are controlled for, young drivers are still overrepresented in crash statistics (Lewis, 1985; MacDonald, 1987; Brown and Groeger, 1988).

This rate of crashes cannot be attributed to a deficit in simple motor skills. For example, young drivers have better reactions than older drivers (Quimby and Watts, 1981); they are better at some driving tasks (e.g., accelerator release; Olson and Sivak, 1986); and they acquire simple motor skills at an extraordinarily rapid rate (Brown and Groeger, 1988). Rather, it appears that young or novice drivers differ from older, expert drivers in their perception and interpretation of the driving environment and also in their response to this environment, particularly when the environment is complex or stressful. For example, young drivers are slower to recognise hazards (Quimby and Watts, 1981) and underestimate the threat which hazards pose (Brown and Groeger, 1988). Since recognition and decision errors are predominant causal factors in crashes (Rumar, 1985), it appears that these differences are sufficient to account for the high crash rate amongst the young.

The review presented below explores the possibility that the nature and development of driving expertise is similar to that in any other area. In effect, we examine the hypothesis that a novice driver is like a novice pilot or novice radiologist, and that the transition from novice to expert in both perceptual, interpretative and response skills is the same for both groups. One finding which suggests that such an hypothesis may be valid is that changes in performance as experience increases are the same for both groups: the rate of errors (crashes or misinterpretations) actually increases for a time and then decreases until true expert performance is attained. This is true of both radiologists (Lesgold, 1984) and of drivers (Brown, 1982; Cameron, 1982).

The review is divided into several sections. Firstly, we examine novice/expert differences in perception and examine hypotheses which attempt to account for these differences. Secondly, we examine differences in interpretation, both of the "hazard potential" of an environment (given veridical perception) and of the "hazard mediating potential" of the driver's response (the "overconfidence" hypothesis). Thirdly, we examine differences in response, particularly responses to environments which are complex and demand the prioritising and allocation of resources. We then review the recent theories which attempt to account for the nature and development of expertise and, in the final section, explore the implications of the above reviews for road traffic research and for the design of training programmes to improve the performance of young drivers.

2. PERCEPTION

2.1 PERCEIVING THE DRIVING ENVIRONMENT:

The driving environment is very complex and the demands placed upon the perceptual system are frequently quite heavy. In some cases the task is relatively easy: the veridical perception of distance is a prerequisite for driving but the environment overspecifies relative distances between objects with such cues as size, height, occlusion, motion parallax, etc. and the perceptual system seems automatically to use these visual cues additively (Bruno and Cutting, 1988). However, in some cases the task is quite difficult: the veridical perception of velocity is also a prerequisite for driving, but this is not an easy task for the perceptual system for two reasons. Firstly, velocity judgments are, in general, much less accurate than those for location and much slower than those for direction and location (Costermans and Cita, 1988) and, secondly, such judgments are very difficult to make from within a moving vehicle because they are confounded by the speed adaptation of the perceptual system (Casey and Lund, 1987).

Earlier studies of the perception of the driving environment attempted to discover covariations between general "perceptual skills and/or styles" and driving performance. Initial results were quite promising; for example, Mihal and Barrett (1976) found that measures of perceptual style and selective attention were moderately correlated with crash rate. However, these results could not be replicated

(McKenna, Duncan and Brown, 1986). In fact, McKenna et al. found that a 'typical intelligence test' (Cattell's Culture Fair Test) showed a higher correlation with driving performance (r = .64) than any of the measures of perceptual style and suggested that perception should be studied at the level of component skills rather than with global, overall measures.

A second approach has been to determine what aspects of the driving environment drivers attend to. It has been found that only 15-20% of a driver's attention is given to traffic control devices (which is insufficient) and about 30-50% of attention given to aspects of the environment which are irrelevant to hazard assessment or to vehicle control (Hughes and Cole, 1986). Note that in these studies, laboratory results (reports of what attracted attention while watching movie depicting route) closely paralleled those from field studies (reports of what attracted attention while driving same route).

In addition, it has been found that, in comparison to expert drivers, novices are particularly poor at attending to relevant aspects of the driving environment. This relative insensitivity has been illustrated many times. For example, they fail to detect hazards which are noticed by experts; e.g., they detect children less frequently than older drivers (Egberink, Lourens and van der Molen, 1986). And they do not use as many environmental cues even in simple tasks, such as the control of a vehicle in straight road driving; e.g., unlike experts, they tend not to use the cue of lateral speed (Riemersma, 1987).

The studies reported above describe what drivers do; they illustrate the difficulty of the task and identify attentional problems which are common to all drivers and to novice drivers in particular. However, they do not address the issue of how drivers do it; that is, they do not show how the perceptual processes of novices and experts differ nor how these differences develop. One early study which contributes to the understanding of these problems was conducted by Mourant and Rockwell (1972) when they studied eye movements of novice and expert drivers. They found that novice drivers had visual scanning strategies which were very different from experts. Firstly, novices did not search appropriate portions of the driving environment: they sampled their mirrors less frequently and did not scan as far in front of the vehicle as experienced drivers (confirmed by Laidlaw as reported in Brown, 1982). Secondly, the visual scan of novices and expert drivers was quite different: (1) novices made pursuit eye movements on a freeway route (perhaps concentrating on static objects as suggested by Soliday, 1974) while experienced drivers made only eye fixations and (2) novices scanned the environment more broadly than experts who tended to concentrate their eye fixations in a smaller area. Mourant and Rockwell interpreted these results as suggesting that the visual acquisition processes of novice drivers were unskilled and overloaded.

The same differences in visual scanning strategies between novice and expert drivers has been observed in studies of radiologists. For example, novice radiologists scan chest films more broadly, distributing their attention relatively evenly, while experts tend to examine those areas of the film most likely to contain abnormalities and to concentrate their eye fixations (Kundel, Nodine and Carmody, 1978; Lesgold, 1984). In fact, the visual sampling distribution of expert radiologists approximates the probability of finding abnormalities in chest films.

These detailed similarities in visual scanning strategies for the two groups of experts and novices suggest that the change from novice to expert perception of the driving environment is very similar if not identical to the change from novice to expert perception of chest films. The second part of this section of the review will consider research which examines the development of expert perception in a variety of disciplines with the aims of generating (1) hypotheses about the characteristics of expert driver's perceptions and (2) theories about how these characteristics are developed.

2.2 EXPERT PERCEPTION

Researchers have studied the characteristics of expert performance and the development of expertise of radiologists, computer programmers, accountants, jet fighter pilots, geologists and chess players. What is striking about this research is that characteristics and developmental sequence appear to be the same, regardless of the type of expert studied. Expert performance is found to be faster, more accurate and more flexible than the performance of novices.

Experience can change the way people perceive environments. For example, even space perception can be rapidly altered by perceptual learning (see Wallach, 1985). One explanation for this effect is that experience informs expectations, that experts "know what to look for" and "know where to find it" (see, Kundel, Nodine and Carmody, 1978). This explanation has received considerable support. For example, cuing the location of a stimulus improves discrimination (of form, orientation and luminance, see Downing, 1988) and improves the quality of the perceptual representation of features (Prinzmetal, Presti and Posner, 1986). In addition, providing drivers with expectations has been shown to improve hazard detection; for example, Shinar (1985) reported that the detection of pedestrians at night improved when drivers were told to expect a pedestrian and improved even more if drivers were told that the pedestrian would be wearing a reflective tag.

However, experience must have more complex effects on perception than simply creating expectations. Although the creation of expectations improves the perceptual processing of a single target, it impairs detection when there are many targets. In particular, the creation of expectations impairs the detection of a second target (Broadbent and Broadbent, 1987), especially when both targets are in close physical proximity (Downing, 1988). Also, as the number of potential 'targets' (categories) increases, performance in simple classification tasks is impaired, particularly for stimuli which differ in velocity, direction and location (Costermans and Cita, 1988). Thus, if the effect of experience on perception is restricted to (1) creating expectations and (2) sensitising people to new 'targets' (hazards), then the performance of experienced drivers should be inferior to that of novices since the driving environment is complex and filled with many potential, proximal 'targets' (see above).

Evidence that experience has more complex effects on perception comes from studies of expert perception, particularly the perceptions of expert chess players and expert radiologists. Chase and Simon (1973), for example, in their study of expert and novice chess players found that experts have better short-term recall of meaningful chess positions and distinctive patterns of reconstructing positions in plain view. Expert reconstructions were done in bursts punctuated by pauses and the pieces placed down in the bursts were found to consist of highly familiar stereotyped patterns. Both experts and novices produced patterns, but experts included many pieces in their patterns (about six patterns of six pieces) while novice players produce patterns consisting of only single pieces. These patterns were also evident in the short-term recall of meaningful positions by experts. However, when these patterns were not present on the chessboard (chess pieces placed randomly), the short-term recall of experts was no better than that of novices (de Groot, 1965). Chase and Simon suggested that these results demonstrate that experts perceive recurrent patterns in the chess environment holistically; that is, they perceive a pattern as a single entity, a "perceptual chunk". These results are quite general. For example, expert computer programmers show similar types of performance in short-term recall tasks (Bateson, Alexander and Murphy, 1987) and expert petroleum geologists evidence a better knowledge of the covariation of geological features as well as being better at identifying individual features (Hawkins, 1983). In addition, detailed studies of the perceptions of novice and expert radiologists have shown that novice radiologists perceive features piecemeal and independent of context while experts perception is holistic (Lesgold, 1984 and see Schwartz and Griffin, 1986).

These changes in perception are thought to be a consequence of the acquisition and, more importantly, the reorganisation of knowledge that comes with experience. Firstly, it is clear that experts know more about their domain (Kolodner, 1983) and that novices have less and more fragmented knowledge (Allwood, 1986). Secondly, most research has shown that expert knowledge is organised differently than the knowledge of novices. This is clear from studies of radiologists, pilots of jet fighters, and computer programmers. Experts have been found to have simpler (Schvaneveldt et al., 1985) and more abstract (Adelson, 1984) organisational schema than novices. In addition, the organisation of expert knowledge appears to reflect function (Wagner, Sebrechts and Black, 1985) and other higher order properties (Weiser and Shertz, 1983) of information while the organisation of novice knowledge appears to reflect 'surface' or literal features (Weiser and Shertz, 1983) of information. And finally, the implications of the content and organisation of knowledge for perception are clear and are best illustrated with an anecdote taken from Corballis (1988), who notes that even though an airplane with its wings missing might better fit the stored (featural) description of a submarine or fish, it would surely be recognised for what it was, presumably on the basis of the perceiver's knowledge of the interrelation among parts rather than features alone.

The major consequence of such holistic perception is that novices are able to process less information about an environment than experts, for novices must search for critical features of the environment and integrate the resultant featural description into a perception. Experts, on the other hand, do not have to search and integrate, for their perception is holistic. Even if the only difference between expert and novice drivers is that experts have a holistic perception, this gives experts a very considerable advantage, particularly in environments which are complex, stressful or ambiguous.

3. INTERPRETATION

3.1 ASSESSING HAZARD POTENTIAL

The literature describing the assessment of hazard potential is rather confusing because there is a lack of consensus about what is being assessed. There are at least three identifiable views. One, presumably based on a 'rational' consideration of the problem, is that hazard assessment represents a judgment of risk and that risk ought to include both the probability of loss or crash as well as the utility of a loss (Oppe, 1988). Intuitive arguments for this position are compelling. For example, Haight (1986) argues that the only reason for judging Russian Roulette to be riskier than a coin flip is that the utility of a loss is greater for Roulette. Additional support for this position comes from econometricians who argue that driving behaviour may be described in terms of the maximisation of some utility function (e.g., Blomquist, 1986), where the function integrates information about the utility of a loss and the probability of a loss into an overall measure of worth: expected utility. Such theories suggest that it is quite reasonable to presume that the subjective assessment of hazard involves the integration of probability and loss functions.

A second identifiable view is that hazard assessment represents a judgment of the probability of loss alone. Support from this position comes from studies of human judgment and choice behaviour. For example, Slovic, Fischhoff and Lichtenstein (1978) report that protective behaviour is influenced more by judged probabilities of a loss than by the magnitude of consequences. Additional support for this position comes from studies of gambling which show that utility models (even SEU) do not describe individual behaviour (see Slovic, Fischhoff and Lichtenstein, 1977, for a critical review) and that attempts to describe subjective risk assessment inherent in gambling in terms of the probabilities and outcomes of the gambles have failed.

A third identifiable view is that hazard assessment represents an assessment of stress and/or threat. Hoyos (1988) seems to be the main advocate of this position and he interprets previous research as suggesting that the assessment of hazardousness largely depends on mental load imposed by such factors as the amount of information to be processed, control to be exerted, etc. Another attraction of this view may be that it offers a new methodology for research and a theoretical explanation of driver response to hazards. The new methodology is based on Hoyos's work in industry where a total of 2230 hazard indicators were identified in detailed interviews of 138 people. The new theory is the Lazarus and Folkman (1984) model of psychological responses to stress.

Even though it is unclear just what hazard assessment is really assessing, it is clear that it is a complex process. It is obvious that the task must be learned (Benda & Hoyos, 1983) and that learning must be extraordinarily difficult, for the driving environment is notoriously poor for providing feedback about non-veridical assessment (Rumar, 1988). In addition, it is obvious that the task is difficult, for it involves the integration of information from many sources (see McKenna, 1988) and people are not particularly good at making holistic assessments when many factors must be considered (they may elect to use "simple" strategies which yield rapid but inaccurate assessments; Onken, Hastie and Revelle, 1985), particularly when the assessment involves consideration of very low probability events (Slovic, Fischhoff and Lichtenstein, 1978; McKenna, 1985). Another factor which contributes to the difficulty of the task is that these assessments frequently must be made in stressful situations, and it is well known that stress impairs virtually every higher order cognitive activity (Mandler, 1982); in particular, harassed decision makers tend to decide before considering all alternatives or relevant information and tend to be haphazard in their review of alternatives (Keinan, Frieland, and Ben-Porath, 1987).

In spite of these difficulties, hazard assessment appears to be accurate, at least in some circumstances. For example, Svenson (1978) found that subject's rating of degree of hazard coincides with objective estimates for some characteristics of the driving environment (hazard ratings based on a road's physical characteristics) but were inaccurate for other characteristics (ratings based on speed, black spots, night driving and narrow roads). However, there is some question as to whether such simple subjective ratings accurately reflect a driver's actual assessment of hazard. For example, Howarth (1988) found that the behaviour of drivers in presence of child pedestrians is more closely related to OBJECTIVE RISK (which is very low) than to SUBJECTIVE RISK (which is rather high for all age groups).

It is difficult to evaluate Howarth's argument that driver behaviour is a more appropriate measure of hazard assessment than subjective ratings, because driver behaviour is influenced by a large number of factors. One obvious problem, currently a popular topic in the driving literature, is that the maintenance of a particular level of risk may in itself be a goal; this is termed self-induced exposure to risk by Brown (1982) and risk homeostasis by Wilde (1986). Jonah (1986) suggested that it reflects a more general risk behaviour syndrome. The idea has been heavily criticised, both on theoretical and empirical grounds. For example, Janssen and Tenkink (1988) argue on the basis of a theoretical analysis that "homeostasis" is possible only under very restrictive conditions; Mahalel and Szternfeld (1986) point out that the "perverse compensation" which the theory predicts (see Haight, 1986) can be accounted for in terms of changes in environmental feedback; and Lund and O'Neill (1986) argue that "perverse compensation" has not occurred in situations where the theory predicts it ought to occur (e.g., there were no measurable changes in driving behaviour as a result of the introduction of mandatory seatbelt use) and so the theory is simply wrong. Whatever the case, researchers have clearly opted to use subjective ratings to study the problem of hazard assessment. The problem of how to measure hazard assessment will be discussed in more detail in section 5 of the review, below.

Research comparing the hazard assessment of novice and expert drivers has not addressed the question of whether there are differences in the procedures these groups use to assess hazard. Rather, such research has aimed to determine whether there are differences in the hazard rating of particular aspects of the driving environment. Generally, research has established that novice and expert hazard ratings differ considerably. For example, Finn and Bragg (1986) found that young male drivers fail to perceive specific driving situations as being as risky as older drivers where hazard assessment was measured with a variety of techniques (general questionnaires about crash involvement, ratings of still photographs with descriptive captions and ratings of videotaped driving situations). Typical ratings were as follows:

Z-scores of rated hazard: Pr(crash)

RATING young	RATING old	SITUATION
-.54	-.71	urban driving
-.55	-.71	slow driving (8-lane divided highway at 45 mph when everyone else is going 55 mph)
-.43	-.53	tailgating (following 1.5 car lengths at 30)
-.37	-.50	speeding (as above, 65 when everyone going 55)
-.35	-.47	driving on bald tires
-.30	-.42	nighttime driving
-.13	-.24	wet roads (driving on wet roads or rain)
-.76	-.73	rural driving (on undivided 2-lane road)
.39	.05	driving on snow and ice covered roads
1.45	1.59	drinking (after consuming 6 cans of beer)

Similarly, Matthews and Moran (1986) measured hazard assessment with a general questionnaire and with ratings of risk of "videotaped sequences depicting various elements of driving behaviour". They found that young drivers underestimated risk for several Vehicle-handling and Driving reflex sequences, but that young and old agreed on the risks inherent in Driving judgment. The particular elements which were rated were:

Vehicle-handling sequences: (Young underestimate risk)
:rainfall (heavy rainfall with oncoming traffic)
:front wheel blow-out (while in a R-hand curve)
:wheel slips to soft shoulder (in L-hand curve)
:speeding (in heavy traffic on a freeway)

Driving reflex sequences: (Young underestimate risk)
:another vehicle suddenly pulls in front of you
:another vehicle runs stop directly in your path

:another vehicle, struck from behind, is propelled into an intersection directly in your path
:tailgating (in light traffic on a freeway)

Driving judgment sequences: (Young and old agree on risk)
:stop (a proper stop at an intersection)
:caution (response as light turns to yellow)
:oncoming vehicle pulls into your lane (while passing)
:passing (a properly executed passing manoeuver)

Research comparing novice/expert performance in other disciplines has not addressed questions analogous to hazard assessment as such. What research there is suggests that experts have an easier time than novices in making these judgments because novices try to integrate more information than experts. For example, various authors assert that experts "know what to look for" (Ettenson, Shanteau, and Krogstad, 1987) and "know what to ignore" (Kundel, Nodine and Carmody, 1978). That is, experts tend to give a great deal of weight to a few selected aspects of the environment when making assessments and tend to give little weight to other (irrelevant) aspects. These conclusions were supported by Ettenson, Shanteau, and Krogstad (1987) who found that the judgement of expert auditors primarily reflected one source of information while no single cue was dominant in novice judgements and that, as a consequence, the experts exhibited greater consistency (similar cases received similar judgments) and greater consensus (experts all agreed).

One interesting possibility is that experts and novices assess total environmental hazard in very different ways. For example, novice radiologists appear to analyse each feature of a chest film separately and independent of other features (Lesgold, 1984); that is, novices make context independent judgments. If this is the case, then assessments made by novices could be described as a simple combination of the (assessed) hazard of each of the features in an environment, perhaps a simple linear combination. Thus for novices, it would make sense to study their assessments of each environmental feature because their assessment of total environmental hazard could be predicted from their assessments of features.

Expert radiologists, on the other hand, appear to respond to the environment holistically. Lesgold (1984) theorised that these responses were guided by specialised, derivative schemata which change with context. Such schemata are, in effect, mental models of very specific environments. Lesgold believes that experts have a very large number of rich schemata and that experts use them to guide their perceptions, assessments and responses. He theorised that schemata are used quite flexibly, that experts "plan opportunistically", and respond flexibly; they constantly test the applicability of schemata and push, tune and retreat from a schemata that currently guides their thinking (Schwartz and Griffin, 1986). Nowaczyk (1984) came to similar conclusions in a study of expert and novice computer programmers, concluding that schema knowledge may not be a critical component in the problem-solving process for novice programmers and that differences in the size and nature of schema knowledge may not appear until a later stage in a programmer's education. If this account is correct, then experts should be able to resolve ambiguities in an environment which novices cannot, for experts, unlike novices, reason flexibly. Other consequences of this description of the nature of expertise will be discussed in section 4 of the review.

A final possibility is that, as Brown and Groeger (1988) suggest, hazard assessment is not determined by the environment alone, but that it represents a balanced judgment which includes information about hazard potential of the environment and information on the joint abilities of driver and vehicle to prevent that hazard potential being transformed into outcomes. In other words, hazard assessment is mediated by a driver's assessment of their own skill. This possibility is explored in the next section of the review.

3.2 ASSESSMENT OF SKILL: THE OVERCONFIDENCE HYPOTHESIS

A second factor which plays a large role in determining driver behaviour is a driver's assessment of the possibilities of preventing potential hazard from being transformed into outcomes. This estimate is based on assessments of one's own abilities and the capabilities of the vehicle being driven (see Brown and Groeger, 1988).

It is a general finding that people tend to be overconfident in such judgments, that people judge themselves to be more skillful and safer than others (Svenson, Fischhoff and MacGregor, 1985). This is particularly true for novice male drivers. Support for this view comes from earlier studies of the confidence ratings of young men (Wallach and Kogan, 1961) which showed that this group had distinctively higher confidence ratings and that, when confidence is very high, judgments given by young men were more extreme than those given by any other group. Additional support for this view comes from a study conducted by Finn and Bragg (1986) who reported that both novice and expert drivers agreed that the probability of a crash was greater for young than for older drivers; however, the novices saw themselves as similar to older drivers rather than to their peers, and estimated that their own chance of a crash was equal to that for an expert.

These findings have been generalised by Brown (1982) who proposed that the overconfidence of young drivers would serve as a complete explanation of their high crash rate. He suggested that novice drivers have excellent and rapidly improving vehicle control (perceptual-motor) skills and that the confidence of novices is based on these skills. However, the roadcraft of young drivers is not excellent and improves more slowly. Brown believes that this is sufficient to explain why the young drive dangerously and, with a free interpretation of the rates of growth of skill and confidence, shows that such a model will predict that crashes will peak about two years after one learns to drive.

However, this 'overconfidence' may not be as pandemic as was originally presumed. Matthews and Moran (1986), for example, found that young drivers occasionally showed 'underconfidence' and occasionally were simply more accurate than experts. For example, their estimates of the probability that they would be involved in a crash within the next year were greater than those of experts ('underconfidence') and their estimates of their own driving reflexes was better than those of experts. However, they were 'overconfident' in other situations: they gave lower "probability of a crash" estimates for driving situations demanding SPECIFIC SKILL and were generally more confident in their own abilities than were experts. Matthews and Moran suggested that young drivers overestimate the crash risk in low to medium risk driving situations but underestimate risk of less frequent high risk situations; the effect of this would be that the young view themselves (but not their peers) as immune from effects of higher risk levels.

Within the psychological literature, the study of 'overconfidence' is called the study of calibration. People are said to be well calibrated if they are able to judge correctly their level of performance or accuracy. Although it appears that expert drivers are well-calibrated and although it has been claimed that experts in general are well-calibrated (Logan, 1985), the research literature on this topic does not support these claims. Rather, it appears that people are generally overconfident; they are certainly overconfident when asked to predict their performance on difficult tasks although there is some evidence that they are, perhaps, underconfident when asked to predict performance for very easy tasks (see review by Lichtenstein, Fischhoff and Phillips, 1982). These findings are consistent with those reported by Matthews and Moran (1986) and discussed above. Curiously, expert weather forecasters represent a rare exception to this rule (see review), but then most forecasters are required to express their forecasts probabilistically which, in effect, requires them to calibrate themselves as they make a forecast.

Unfortunately, the psychological literature also suggests that miscalibration is difficult to correct, that is, that 'overconfidence' is robust. Fischhoff (1982) reviews research which aims to find methods of improving calibration, but the results are quite gloomy: a wide variety of training strategies have been found to yield only minor improvements in calibration. One explanation for the apparent calibration of experts and for the difficulties found in improving calibration was offered by Pascoe (1986): when asked to report on performance, people report what they ought to be doing rather than what they are doing. Indeed, it has been found that as performance improves with practice, the ability of people to give accurate verbal descriptions of what they are doing actually gets worse (see, for example, Berry and Broadbent, 1984). Thus when questioned, both experts and novices will report what they ought to be doing; the experts will simply appear to be aware because their actual performance is closer to target performance. This would also explain why novice drivers appear to be overconfident: they report that they are doing what they ought to, which is to drive like experts (older drivers), and so appear to be overconfident.

4. RESPONSE

4.1 RESPONDING TO THE DRIVING ENVIRONMENT

There are a VERY large number of responses which a driver must master, and master at a level where these responses are smooth and error free, in order to respond appropriately to driving environments.

The focus of recent studies of driver responses have been guided more by intrinsic interest in the response than by any overall framework which describes the components of the driving task. For example, several studies have examined the average speed at which a vehicle is driven and, as one would expect, novice drivers are found to travel at faster speeds: novice USA drivers tend to travel at faster speeds (Seal and Ellis, 1979 cited in Fildes, Fletcher and Corrigan, 1987) although this preference may not be as strong in young Australian drivers (see Fildes et al., 1987 for relevant literature); they display a conscious preference for speed over safety (Evans and Wasielewski, 1983); and the preference for speed appears to decrease over the ages 16-24 years (Schuman et al., 1967). Another response which has received considerable attention is tailgating, with the results of all studies showing that novices drive closer to the vehicle in front (e.g., Evans and Wasielewski, 1983). Other responses which have received attention include seat belt usage which is presumed to be less frequent amongst the young (e.g., Kunreuther, 1985) and general knowledge of steering control manoeuvers, the lack of which is a prominent causal factor in crashes involving novice drivers (Shinar, McDonald and Treat, 1978).

One of the major difficulties we have in interpreting the results of such studies is that there is no descriptive framework or classification system which can be used to determine the relationship between these responses. Several classification systems have been proposed, but these are based on properties of the responses such as their function or purpose and do not refer to the response units themselves. For example, Risser (1985) proposed a schema for classifying driving errors based solely on functional properties of the driving response (e.g., blinker use, lane use, etc.). As another example, Lourens (1986, as cited in van der Molen and Botticher, 1988) proposed a schema based both on purpose and function: he distinguished fourteen types of intended manoeuvers and proposed that each manoeuver consisted of six basic tasks including visual orientation, speed adaptation, course control, etc. What should be immediately clear is that these classification systems do not describe the response units themselves and so are of questionable worth in developing a characterisation of the skills which drivers must master in order to respond to the driving environment.

As with most studies of driver perception, the above studies describe what drivers do; they illustrate the difficulty of the task and identify problems which distinguish novice drivers. However, they do not address the issue of how the drivers do it. As with all skilled tasks which have a large motor component, driving involves the integration of phasing, sequencing and gradation of diverse response units (Glencross, 1980). For example, bringing an automobile to a full stop requires the phasing and sequencing of smooth and controlled movements of the feet (on brakes and clutch), smooth and controlled movements of the hands (on the steering wheel and shift), etc. The studies reviewed above do not give any insight into the nature of these response processes, the process differences between experts and novices or the way in which these differences develop.

One early study which contributes to an understanding of these processes was conducted by Brown and Poulton (1961) who required drivers to perform two tasks: to drive through a variety of rural and urban environments and at the same time perform a mental arithmetic task. This is referred to as a 'dual-task' experimental design. They found that novice drivers performed poorly on the arithmetic task; it seemed that driving required so much effort that these novices were unable to perform even simple arithmetic. Experienced drivers, on the other hand, performed well. Performance on the arithmetic task was found to relate to the level of experience of the drivers and the complexity of the driving environment. Thus this early study showed that the responses of expert drivers were performed in an apparently effortless manner. Similarly, it has been found that novice drivers allocate more attention to the primary visual task of monitoring the forward scene (Mourant and Donahue, 1977) while more experienced drivers attended more to the information relating to the sides and rear of the vehicle. Again, it is as if driving requires so much effort that unskilled drivers were unable to attend to more than the task at hand. Perhaps the most striking demonstration of the effort free performance of expert drivers was given by Safren, Cohen and Schlesinger (1970) who examined drivers performing two tasks: speed control and steering reversal. For novices, there was a negative correlation between task performance but for experienced drivers, the correlation was positive, indicating that the two tasks were highly demanding for novices (they could only attend to one) but not so for experts (if they could do one task well, they did both well).

Even more generally, it appears that an identifying characteristic of skilled drivers is the ability to control attentional resources. One indication of this is that novice drivers make use of the rear vision mirror at more inappropriate times when attention resources would be best allocated elsewhere (Macdonald, 1987). Another indication is that skilled drivers are able to perform several tasks simultaneously. For example, it has been found that performance on a dichotic listening task predicts the performance of bus drivers (Gopher, 1982; Gopher and Kahneman, 1971) and even of pilots (Mihal and Barrett, 1973). Keele and Hawkins (1982) also report that the ability to switch attention is correlated across a variety of tasks. There is, however, some conflicting evidence (e.g. Wickens, 1989). Mckenna et al. (1986) reported no correlations for dichotic listening with driver performance measures, but nevertheless acknowledged that "the true correlation between dichotic listening and accident rate may simply lie somewhere between (their's) and previous research." (p.660).

Thus, recent research suggests that good drivers can allocate and time-share their resources, switching attention between several tasks, and still have spare capacity. In terms of the recent psychological literature, these findings suggest that driving is an AUTOMATIC PROCESS for skilled drivers and that they are better able to control and PRIORITISE their responses. These issues are discussed in the next section.

4.2 SKILLED RESPONDING: AUTOMATING AND PRIORITISING RESOURCES

A distinction is commonly drawn, by information processing theorists, between those cognitive processes which are AUTOMATIC and those which are CONTROLLED (e.g., Schneider and Shiffrin, 1977;

Shiffrin and Schneider, 1977; Hasher and Zacks, 1979; Schneider and Fisk, 1984; Schneider, Dumais and Shiffrin, 1984). An automatic process involves a sequence of operations which occurs without the need for conscious initiation, and without consuming attentional capacity, in response to some predetermined input configuration. Such a process functions through a relatively permanent set of associative connections which link component operations, and these connections are thought to result from extensive and consistent training. Since automatic processes do not require attentional resources in order to function, they are little constrained by capacity limitations and are particularly resistant to interference from any simultaneous distraction of attention. Furthermore, it is thought that numerous automatic processes may operate in parallel, permitting the development of highly complex skilled behaviour within this mode of processing. A controlled process, in contrast, is a temporary sequence of operations activated under the control of, and maintained through attention by, the subject. The execution of controlled processes demands considerable attention. Such processes are therefore tightly constrained by capacity limitations, and only one sequence of operations may proceed at any one time in this mode without interference (except when two sequences are performed so slowly that they can be serially interlaced). Thus a controlled process will be disrupted severely if attentional resources are distracted during its execution. Our understanding of how automaticities come about is far from complete (see Salmoni, 1989; Logan, 1985; Heuer and Wing, 1984); this issue will be discussed more fully in Section 5 of the review.

One of the major consequences of this account is we can overcome two of the major limitations on our abilities by making an operation automatic, limitations of capacity and time. Capacity limitations are all too evident -- there is a restriction on the number of processes or operations which can occur at the same time. At one extreme, Welford (1968) in his single channel hypothesis has proposed that at the decision-level `we can only do one thing at a time` and other signals or events occurring will be delayed or missed. However, this limitation is partially overcome by automatising a cognitive process, for automatic processes require no conscious attention and so may operate with only minimal demands on our information processing system, leaving much of the system free to 'attend' to other activities (like addition). Time limitations are also very apparent -- all information processing takes some finite time, but this limitation is partially overcome by automatising a cognitive process, for automatic processes are executed very rapidly and accurately. However, it is important to realise that these limitations cannot be completely overcome. For example, in emergency braking the latency of the information processes cannot be reduced beyond a certain minimal time (Hick, 1952).

There is, however, a price to be paid when processes are automatic. To quote Logan (1985): "the implication is that automatization should result in very specific ways of performing a task, which should produce a rather narrow generalisation gradient when transfer to other situations is tested". That is, automatization implies a loss of adaptability since a single, automatic operation has replaced the requirement, at some early stage of skill acquisition, of perhaps five separate operations. Salmoni (1989) has argued, on the other hand, that a skilled performer has gained many more operations than an unskilled performer and can thus choose among a number of operations. Thus, the skilled performer can choose from a large variety of highly learned operations, each one of which is not adaptable singly, but in total number make the skilled performer very flexible during actual performance.

Thus, in the acquisition of skills, recent psychological research suggests that we develop higher order strategies to overcome limitations of the cognitive system. One of these higher order strategies is to make certain cognitive processes automatic. Another, equally important strategy is to prioritise tasks, that is, to switch attention, sharing the resources of the system to cope with different demands, by assigning priorities to the various system activities for the purpose of resource allocation. If importance and priority is attached to the wrong signal or event, the skill will deteriorate. As has been noted above, the literature suggests that novice drivers have trouble prioritising appropriately and that skilled drivers have developed effective higher order strategies which represent some combination and coordination of the basic information processes (see also Colley, 1989; Glencross, 1978; Keele & Hawkins, 1982). It is as if novice drivers demonstrate a preoccupation with one problem while another gets out of hand; that is, novices are unskilled at allocating resources. This issue has been directly addressed within the dual-task paradigm described in the previous section. Other methods of addressing this issue are discussed in the Appendix.

One promising approach to the problem of automaticity and resource allocation which has been applied to driving was described by Hale et al. (1988), expanding on the model of Hale & Glendon (1987) with deference to Reason (1985). These authors asserted that the representation and control of action is hierarchically organised and they distinguished several levels in this hierarchy: a knowledge-based level, a rule-based level and a skill-based level. The knowledge-based level consists of a formal description ('book-learning'), the rule-based level of guides to action (controlled processes), and the skill-based level of automatic processes which guide actions. Hale et al. propose that when a novel situation presents, a driver reverts to a knowledge based level. Likewise, decisions to change the "operating parameters" and tradeoffs of the task are made at this level. They have described how errors of driving relate to each of these levels. Implications of this theoretical framework for the design of research into driver safety will be discussed in Section 6.

5. EXPERTISE: DEVELOPMENT AND TRAINING

5.1 TRAINING PROGRAMMES FOR YOUNG DRIVERS

It should not be a surprise that we find few reports of driver instruction programs that reduce crash frequency in newly licensed drivers. Furthermore, programs that do claim such effects rarely support their claims with rigorous evaluation. Nevertheless, several points of interest arise from the existing literature on driver training.

Most traditional training consists of time spent driving on the open road in real traffic conditions with the learner at the wheel. This may be supported by a brief period of theoretical instruction during which the learner is expected to spend time at home preparing for the theoretical components of the driving test. Such traditional training programmes emphasise the importance of vehicle control skills and this is reflected in several evaluation studies. For example, MacDonald (1987) notes that traditional programs appear to adequately prepare vehicle control skills which are clearly a necessary prerequisite for safe driving. Vehicle control skill is the most straightforward aspect of driver behaviour to measure, and failure on most currently used tests indicates inability to achieve a minimum level of safety on the road. After reviewing licence tests, MacDonald concludes that the most valid licensing tests incorporate a significant proportion of items measuring vehicle control skills.

Attempts to develop new training procedures which are superior to the traditional approach have not always been successful. Exemplary of many similar reports, Simmonet et al. (1982) report that the addition of classroom based theoretical instruction and "looking and learning" in the passenger seat has no added advantage above traditional training methods when vehicle control skills are assessed. These authors report use of an intensive (and fast) training method in which learners undertook increased theoretical instruction (it's precise nature is not described) in addition to on-road driving. Self report data collected at varying stages after qualification revealed little difference between the groups in attitudes to safety measures. There was also little difference between the groups on skills assessed during training. Unfortunately, the study does not report any crash or conviction data; nor does it report any objective measures of driver skill beyond those obtained during training (i.e., no indicators of long term effects).

Such training courses may be no more successful than traditional methods because they merely manipulate the period over which training occurs but do not offer different content (or experiences). That is, it may be unsuccessful because current course content either does not address higher order problem solving skills, or increased exposure to the existing cognitive content is insufficient to make an impact on crash frequency.

Reports of courses in which the primary objective seems to be development of a safe attitude toward driving similarly present marginal results. Many studies report increases in driving knowledge (e.g. Edwards and Ellis 1976; McKnight and Edwards 1982; McKnight and McPherson 1986; Mann et al. 1986); some report positive effects on violation records (Mann et al. 1986; Peck 1976); but few report positive effects on crash frequency. McKnight and Edwards (1982) reiterate that effects are small, and delayed, when reporting on the impact of written manuals and tests dealing with safe driving practices. New drivers using a newly developed manual and test had fewer crashes than users of previous materials, an effect which reached significance only after 12-18 months of driving. Such delays may not reflect training, but may reflect a developmental change. For example, Edwards and Ellis (1976) report no crash reduction effects except for 25-34 year old males. It may be that other life events motivate safer driving practices in this group.

Some results are rather more equivocal: Pelz (1976) reports that safety workshops appeared to produce a temporary, "mild infection of unsafe driving" in the young men who participated. Sondel (1978) notes that school programs have been criticised because they increase the exposure of younger drivers.

Studies of defensive driving courses (ie. courses concentrating on cognitive issues rather than advanced vehicle control skills) also abound (e.g., O'Day 1970; Payne et al. 1984). Lund and Williams (1985) report that methodologically strong evaluations of the Defensive Driving Course (a popular variant) are relatively few. However, these few studies demonstrate that:

(1) the course has a small but consistent effect in the reduction of violation records;
(2) only some of the studies demonstrate a small positive effect on crashes; and
(3) knowledge of driving skills is generally increased.

Lund and Williams suggest that in many studies trainees may not be motivated to change their driving behaviour, but take the course to avoid/ameliorate violation punishments or for insurance reasons. However, they note that the National Traffic Safety Institute offers a course that focuses on motivating behavioural change; it is no more effective than DDC. Reduced violations may result from re-enrolment to avoid recording of a violation, but if it does reflect a real change in driving technique, lack of corresponding reduction in crash rate needs explanation.

Lund and Williams suggest one explanation is that correlations between rare events like crashes and traffic citations are inherently low. Citations are issued less often for violations that correlate highest with crash experience (Gagliardi cited in Lund and Williams 1985). So changes in behaviour that are reflected in traffic violations may be insufficient to substantially modify crash experience.

In summary, then, reports to hand suggest that: (1) training programs have little effect on crash frequency; (2) reductions in traffic violations are reported but tend to be temporary and/or delayed; and (3) many programs appear to successfully increase knowledge; some change attitudes; but these do not translate into fewer crashes. Existing reports of training efforts may be most useful because they highlight methodological problems. For example, Lund and Williams (1985) suggest that studies of traditional instructional methods demonstrate the need for reasonable statistical power to detect small effects and suggest that different driver populations should be considered separately.

An alternative and promising approach to driver training has been to introduce such programmes into secondary schools. While most of these programmes focus on the introduction of courses intended to produce positive attitudes toward safe driving, some have focused on skills. However, skill focused programmes have been shown to be reasonably ineffective in reducing crashes in the young. For example, the House of Representatives report on Education, Training and Licensing of Drivers (1982) notes that teaching students to drive at school has not proven effective in reducing the road toll or violation frequency. It concludes that education in schools should not attempt to train to the level of obtaining a drivers licence without further post-school preparation or guidance. Minimising the skills focus will help to alleviate the problem of increased exposure of younger drivers which results from early licensing. In-car training should be intended as a teaching aid to show relevance of classroom activity and for motivational interest.

School based and other educational programmes which focus on changing attitudes seem to hold great promise. Mann et al. (1986) and Preusser and Blomberg (1987), for example, suggest that school-based prevention programs may hold significant promise for reducing the rate of crashes amongst the young. They argue that it is possible to achieve great changes in the safety behaviour of children because it is much easier to deliver the message to children who are a `captive audience' in school. Mann et al. (1986) argue that it may be possible to change the attitudes and behaviours of new generations of drivers at the time when such attitudes and behaviours are amenable to external influence and therefore commend school based programs. However, few of these programmes have been evaluated systematically. Most seem to be successful in inducing short-term positive changes in knowledge and attitudes (e.g. McKnight and McPherson, 1986) but these tend to dissipate over time (e.g. Mann et al., 1986). In addition, the impact these programmes have on behaviour and traffic safety indices has received little or no attention.

One of the problems commonly addressed in school programs is youth drinking and driving. The importance of this problem was highlighted by Mayhew et al. (1987) who noted that young people who drive after drinking experience a relatively greater risk of involvement in crashes than older drinking drivers. They suggest that alcohol may exacerbate behaviour that is already risky, and thus contribute to an even greater risk of a crash. It would seem, then, that changing attitudes through a school based educational programme may have a large effect on the rate of crashes amongst young drivers. However, research supporting this view has not come to light in this review of the literature. For example, McKnight and McPherson (1986) report positive effects from a programme which encouraged students to intervene in the drink-driving behaviour of their peers; students in a conventional alcohol safety programme did not report similar behaviour. Although the programme affected behaviour, it did not affect attitude. McKnight and McPherson note that the absence of any effect on attitude may reflect peer pressure to not voice such attitudes and observed that an already favourable attitude amongst those attending school based courses may lead to insignificant results.

Results such as these suggest that measures of attitude and self-report are not always reliable indicators of programme success. They also suggest that simply increasing knowledge through educational programmes may not change behaviour and, conversely, that behaviour may change even though knowledge (attitudes) may not. One possible explanation for this is offered by Lewin (1982), who notes that once the behavioural units that constitute driving reach the autonomous stage they become almost invulnerable to cognitive influences such as changes in knowledge, beliefs and attitudes.

Results such as these demonstrate that it is very difficult to design and evaluate an educational programme without a clear understanding of the relationship between knowledge, practice and performance. Without such an understanding, it is difficult to know what goals to set for a programme and difficult to determine what measures should be used to evaluate a programme's effectiveness in terms of its impact on driving practices. Research on driving and driver education programmes has not helped to clarify these relationships. But the nature of the relationship between these variables is a central issue for researchers studying the development of expertise. This research is reviewed briefly in the following section.

5.2 THEORIES DESCRIBING THE DEVELOPMENT OF EXPERTISE

The major characteristics which are associated with expertise are fast and accurate performance of a task in a narrow domain. For example, expert programmers are both faster and more accurate than novices (Wiedenbeck, 1985; Allwood, 1986). Performance of this type is termed 'automatic' and it is believed that the cognitive processes which are responsible for this type of performance require little conscious attention and are relatively resistant to interference (see Section 4.2, above). Other characteristics of expert performance which are described by various authors include: elimination of piecemeal application of operators, dropout of verbal rehearsal, fewer working memory errors, and power-law speed-up (Anderson, 1982 and Singley and Anderson, 1985). Logan (1985) suggested that experts have better control of their performance (e.g., expert typists can control their rate of typing); more awareness of their own capabilities (but see above); and more (metacognitive) knowledge about their respective domain.

Currently, the most popular and complete theory attempting to account for these differences was proposed by JR Anderson (1982). Anderson proposed that the above characteristics were the result of changes in cognition which occur with the acquisition of expertise. Anderson theorised that human performance is controlled by cognitive rules or procedures which he termed 'productions'. A production is a complete algorithm which specifies what action should be taken if certain test conditions apply (e.g., if there is a fire, then panic). Experts are reputed to have productions which are specifically tailored to control performance in their respective domain. Such expert productions apply only in the particular domain (highly discriminated), are used flexibly within this domain (generalised), and are automatic (strengthened). Thus, as Lesgold (1984) claimed, experts will recognise situations which might be encountered and have specific responses associated with each situation.

According to Anderson, novices do not have such specialised productions. They use formal or declarative knowledge (like "book learning") to guide their performance. These declarative representations of the skill are interpreted by general productions, that is, by productions which are used to control everyday performance.

Anderson identified these different types of cognitive control mechanisms as different stages, and labeled them the (expert) procedural stage and the (novice) declarative stage. Anderson also identified a transition stage, a halfway house between novice and expert performance. During this stage, a person is developing expert productions by compiling knowledge, that is, by developing new productions to control performance (proceduralisation of declarative knowledge) and by collapsing sequences of separate productions into single, highly specific productions (composition of productions).

By describing this transition stage in detail, Anderson in effect offered a theory of what it is that makes expert knowledge so special: it is complied knowledge, which has implemented booklearning into automatic productions and integrated separate productions so that complicated tasks are accomplished smoothly and holistically.

Another phenomena for which Anderson's theory offers an explanation is that people in the transition stage may perform more poorly than novices. This phenomena was observed by Lesgold (1984) in his study of radiologists and a similar phenomena was reported by Adelson (1984) in his study of computer programmers. And the same phenomena can be observed in automobile driving, for crashes peak one or two years after a permit is obtained, presumably when drivers are in the transition stage from novice to expert. Anderson's explanation is that people in the transition stage are attempting to use productions which are not entirely appropriate. Similar explanations are offered by Lesgold and Adelson: as skill develops, one sees complexities and uses deeper analysis of details which imposes a temporary increase in conscious processing, presumably because fully automatic productions are not available to control performance. To quote Britton and Tesser (1982):

> "... it may be that the greatest cognitive demands are made at intermediate levels of skill. That is, at low levels of skill the subject does not possess enough prior knowledge to make any use of it at all, and at very high levels the skill is automated and so does not use much capacity. It is only at intermediate levels, at which the requisite knowledge is present and is used but is not yet automated, that very high demands are to be found."

5.3 TEACHING EXPERTISE

As the above review makes clear, simply giving novices more information will not make them experts. Certainly experts know more, but their knowledge is organised differently: the organisation is simpler and more relevant to the task at hand. This suggests that one method of expediting the transition from novice to expert is to teach these organisational principles to novices. A research plan to study how expert knowledge is organised and to study methods of teaching this organisation to novices is outlined in the next section.

In addition, it appears that expert knowledge is organised into productions which are automatic. This suggests that another method of expediting the transition from novice to expert is to give novices extensive (very extensive) practice with the task, for it appears that exhaustive practice is the only way in which cognitive processes which are initially controlled can become automatic.

This automatisation of cognitive processes can have surprising consequences. For example, Lesgold (1984) notes that reading ability *can be improved by vocabulary training which emphasises the* SPEED of access of word knowledge and proposed that this improvement is due to the creation of recognition procedures that are automatic (can be executed without substantial conscious planning). Vessey (1985) expressed a similar view: unlike novices, experts can systematically plan activities into separate modules, where each module is a semi-autonomous, automatic process. Thus if SELECTED driving skills were improved and made automatic, this might improve driving on the whole for novices would (1) be able to perform some tasks at the level of an expert and (2) be able to plan activities better (some components of their activities could be treated as automated modules or chunks and would not require conscious attention).

This suggests that another avenue for research is to carefully analyse the cognitive skills identified in driving so as to identify productions or modules which are commonly used. If such a production was identified, then training novices until such a production became automatised would improve their driving skills on the whole to the extent that this production was shared by other driving skills (*Singley and Anderson 1985*). *One commonplace finding which suggests* this line of research may be profitable is discussed by Lesgold (1984): transfer of training from a primary to a secondary task is negative up to a certain point, after which transfer effects became more positive. This finding may simply reflect the course of automatisation of productions: once a production becomes automated, it can be used as a module in other tasks and hence transfer is positive, but until it becomes automated the introduction of a new production simply increases cognitive load and hence transfer appears to be negative.

Thus there are several approaches to be taken in attempting to teach expertise to novices. One of the main reasons why it is so difficult to design an educational programme is that is unclear just what kinds of information will affect what aspects of performance. This difficulty is illustrated by Adams (1987) in a recent review of the literature on skill acquisition. He found that there have been only a limited number of attempts to apply comprehensive theories to the practical situation, such as driver instruction and that even in the development and application of *sophisticated flight simulators*, the link between theory and practice is somewhat piecemeal. Cognitive psychology is, however, providing some renewed interest in skill learning but more importantly it is providing some new directions for both research and practice. A number of these recent proposals (Adams

1971; Glencross 1978; Schmidt 1975) have some contribution to make to the development of driver training programmes.

The essence of these models of skill acquisition is that a plan or schema generates a response, followed by error detection and error correction in which both feedforward and feedback processes play an integral part. We have already reviewed the literature describing how information is picked up and analysed (Section 2) and how and why strategies are developed (Section 4). In the remainder of this section we review the recent literature describing how generalised programs of action are developed and controlled. The aim of this review is to develop an understanding of what kinds of information will affect what aspects of performance and so to develop new approaches to driver education.

Current theory suggests that generalised programs of action are developed as the learner processes information from a wide variety of sources and in many forms to structure a hierarchical schema of the skill. Such a schema is analogous to a series of operations or productions represented in the brain and is usually described functionally: different parts of the schema are described in terms of the kind or level of activity which is organised. Most theories distinguish four levels:

(1) directive (where information is used to form an executive plan),
(2) general (where information relating to rules, strategy, and task constraints is associated with the other relevant data usually on the basis of past similar experiences),
(3) operational (where all of the information at the higher levels is used to produce a series of instructions which will initiate detailed sequence of movements of the response sequence) and
(4) motoric (where information is translated into response units and, as performance becomes more automatic, holistic responses).

Such programs of action are modified or controlled through feedback. Obviously, a comparison on the basis of feedback information is made between what was intended or planned and the actual outcome of action. The discrepancy between plan and response is fed back to all levels of the system. On the basis of this information, modifications are made so that on the next attempt the discrepancy will be less and performance will improve. This process continues during the execution of any task requiring motor performance. Gradually, as this process of plan-response-discrepancy-feedback-modification continues, performance becomes more accurate and more closely related to the desired outcome. And, as expertise develops, the control of the operational plan passes to the motor programme stage, at which time the skill is said to be under automatic control.

It may be argued that the most significant advance in our understanding of how action is controlled has been through the development of new theories which attempt to account for the feedback processes and in particular to determine the `information content` and the information needed at each stage of the learning process (Annett, 1969; Glencross, 1978). In particular, this process of gradual modification on the basis of the discrepancy between the schema and response can only be understood if the forms of discrepancy that exist between the different levels of the system can be precisely described. Discrepancy most obviously exists between the actual response and the operational plan. But it is also likely that some discrepancy exists between the higher levels of the hierarchy of plans. For example, discrepancies may exist between the following levels:

(1) directive and general (e.g., the wrong information is used in trying to achieve the directive plan);
(2) general and operational (e.g., common information that is not relevant to the new skill is used);
(3) operational and motor (e.g., the actual response does not conform to the demands of the operational plan); and
(4) motor and response (e.g., the actual observable response does not accord to the detailed instructions of the motor programme).

With practice, changes and modifications occur at all levels, but the most obvious changes occur between the general, operational and motor programme levels. It should be noted that even though a plan may be well formed, this does not always guarantee the production of an effective response. Fatigue, distraction, loss of attention may influence the final implementation. However, a well formed plan will result in relatively consistent performance.

The significance of such an analysis of levels of plans and the forms of discrepancy is that each level is formed on the basis of information of a different type and nature. It would seem that unless adequate information was available to the learner at all levels of the scheme, then a particular level may contain some false or erroneous detail that will have direct or indirect repercussions on actual performance and the rate of acquisition of the skill. Thus only by providing informative feedback, which provide the details of a fault at the appropriate level, can the learner modify and amend the plan for action and hence improve performance. One proposal to accomplish this is to establish a driver training environment. These details are elaborated in the Appendix.

6. RESEARCH IMPLICATIONS OF THE ABOVE REVIEW

The above review clearly supports the hypothesis that a novice driver is like a novice pilot or novice radiologist. In particular, it suggests that the transition from novice to expert in both perceptual and response skills is the same for both groups. It is also suggestive of many new ideas for research on driving and particularly for research on the driving practices of young, novice drivers. These are listed below in the form of questions.

QUESTION 1: What is the role of confidence in responses to the driving environment? In particular, is it the case, as the review suggests, that confidence has little effect on driving or is it the case that manipulations of confidence will result in changes in styles of driving, perhaps in particular situations?

The review suggests that all drivers are relatively unaware of their level of skill and, when asked, may report what they think they ought to be doing rather than what they are actually doing. In the young, this appears to be overconfidence. This and the fact that it is difficult to improve calibration suggests that it is unprofitable to try to teach young drivers to be less confident; rather, both their calibration and their driving will improve as they attain a higher level of skill. Thus it would appear to be more profitable to concentrate on improving driving skill and to let the confidence problem take care of itself. Research needs to be conducted to address this issue.

QUESTION 2: What is special about expert knowledge? In particular, do experts have a simpler representation of the driving environment than novices and are their very specialised models (schemata) of the driving environment the basis of this representation?

The above review also suggests that expert performance may be the result of the development of very specialised models (schemata) of the driving environment. In addition, these schemata may indirectly form the basis of hazard assessment; that is, hazard assessment may be a by-product of the way in which experts organise their knowledge. Thus, it is necessary to study novice/expert differences in the nature and organisation of their knowledge of the driving environment in order to provide a foundation for more detailed studies of skills.

QUESTION 3: Do expert and novice perceptions of the driving environment differ? In particular, do expert drivers perceive the driving environment holistically while novice drivers perceive the driving environment piecemeal, concentrating on individual features?

The above review suggests that one critical component of expertise in driving is in the way the driving environment is perceived. In particular, it suggests that expert drivers perceive the driving environment holistically while novice drivers perceive the driving environment piecemeal, concentrating on individual features and only slowly integrating these features into an overall perception of the environment. This hypothesis is highly conjectural and must be tested experimentally.

QUESTION 4: Will making selected driving skills automatic improve driving? Will the improvement, if any, be very specific and restricted to skills which are very similar to the one selected or will the improvement be very general?

If the above hypotheses are verified, it suggests a new approach to improving the performance of young drivers: teach them to become experts quickly by teaching them new, automated ways of perceiving the driving environment. This would be accomplished by teaching them to reorganise their knowledge, by teaching them the implications which this reorganisation has for the way the driving environment is to be perceived, and by giving them training which is extensive enough to make the new perceptual styles automatic. The extent of improvement in driving which would result from such training is open to question.

QUESTION 5: Do novice drivers assign the wrong priority to the sub-tasks involved in driving and essentially use their limited resources at the wrong time and in the wrong place?

The review suggests that even though warning and danger signals might be correctly perceived and that the response skills of steering, braking etc. are adequate, that the integration of all of this information into an effective sequence may be more difficult for novice drivers who assign the wrong priority to the various sub-tasks.

QUESTION 6: In time stressed situations do novice drivers fail to integrate the spatio-temporal patterns of action? In particular, are there differences in sequencing, phasing, gradation and timing of the pattern of action between the novice and skilled driver?

The review suggests that one of the consequences of extensive practice is that the action pattern gradually becomes more and more refined and that the most significant of these changes involve the precision of phasing and timing, essentially that the `internal and external` time structure of the task shows a remarkable consistency and stability, with an invariant temporal structure.

QUESTION 7: Do *novice* drivers *acquire driving skill through the* process of skill learning based on the proposed hierarchical models? If this is the case, then the manipulation and control of both the cognitive representations and specific feedback processes should facilitate the learning process. Is it possible to develop a training environment to provide a structured learning situation to accelerate and consolidate driver training?

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