SKILL ACQUISITION AND CUE-BASED PROCESSING

Sue Brouwers

PhD/Master of Organisational Psychology Candidate

Macquarie University, Sydney, Australia

BPsych (Hons), Department of Psychology,

Macquarie University, Sydney, Australia

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Declaration

This thesis has not been submitted for a higher degree to any other university or institution. The work is predominantly that of the PhD candidate. Components of the thesis that involved collaboration have been noted as such. The Macquarie University Ethics Committee approved the research reported in this thesis on the 11th of April 2014 (Reference No 5201400351) and 15th of September 2015 (Reference No: 5201500725).

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Summary

Over the last several decades, research across a number of practice domains has suggested that the advanced perceptual-cognitive skills or *cue utilisation* of experts enables these operators to excel in tasks that rely upon anticipatory decisions and the formation of rapid responses. Indeed, skilled performance itself has been characterised by rapid and accurate responses, often in complex and dynamic situations. These specialised associations, which represent situation-specific relationships between environmental features and outcomes or objects and which lie resident in memory, are referred to as *cues*. However, while cue utilisation is typically considered a pattern recognition or associational process, the specific cognitive mechanisms that underlie cue utilisation remain unclear. The present programme of research was designed to investigate the nature of cue utilisation and examine the mechanisms that underlie cue utilisation in the early stages of learning a new task/skill.

Study 1 was conducted with the aim of investigating the impact of cue utilisation on performance, using a simplified rail control task. The results indicated that there were significant differences in the performance of participants with higher and lower cue utilisation. Throughout the 20-minute rail task, the mean response latency of participants with higher cue utilisation remained significantly higher, compared to participants with lower cue utilisation. One explanation for these results was that the decision to re-route trains in the rail task could be initiated up to seven seconds from the appearance of a train, and therefore, participants with greater cue utilisation may have recognised this opportunity and utilised the additional time. To test this explanation, a similar methodology was adopted in Study 2, but with the inclusion of a secondary task to invoke an explicit cognitive load part-way through the simulated rail control task.

Throughout the initial stage of the rail task, the performance of participants was consistent with the results from Study 1, whereby the response latency recorded was higher for participants with higher cue utilisation. However, once the secondary task was initiated, the

response latencies of participants with lower cue utilisation increased, while the response latency amongst participants with higher cue utilisation remained relatively consistent. These results provided support for the view that participants with higher cue utilisation identified cues in the environment (e.g., decision-time availability) that allowed them some advantage, reducing the demands on cognitive load, and thereby enabling their performance to be less impacted by an increase in cognitive demands.

Study 3 was designed to examine whether the performance of participants with relatively greater cue utilisation during the simulated rail control task, reflected strategies *to* reduce cognitive load, or whether a reduction in cognitive load represented an *outcome* of the process to achieve cue utilisation. A primary difference in Study 3 was the inclusion of a pattern in the rail task. Trains were programmed to appear in a particular sequence, and trains on only two of the four tracks required a diversion. Importantly, this pattern was not disclosed to participants. The results indicated that, under higher workload conditions, participants with higher cue utilisation were least affected by the imposition of the secondary task (they made fewer errors and were faster to respond in the rail task). Further, the participants in the higher cue group were eleven times more likely than those in the lower cue group, to accurately report the rail pattern. The results of Study 3 suggested that greater cue utilisation during a novel, simulated rail control task, reflected pattern-recognition mechanisms which resulted in a reduction of cognitive load.

Extending these findings, Study 4 was designed to examine whether the relationship between cue utilisation and rail task performance depended upon pattern recognition (a moderating relationship) and whether individuals who have higher cue utilisation and who rapidly acquire task-related patterns, also have an increased tendency toward miscueing. Study 4 included three different patterns of rail movement and each was programmed to change abruptly during the course of the twenty-four-minute rail task. It was reasoned that if participants who acquired the pattern were reliant on the pattern to formulate fast and accurate train diversions, the initial, abrupt change to this pattern would represent a miscue, and result in a temporary reduction in performance evident in slower responses and reduced accuracy. The results provided support for this hypothesis. Participants with higher cue utilisation were 2.9 times more likely to identify the train pattern. Further, compared to participants with lower cue utilisation and for participants who verbally identified the rail pattern, higher cue utilisation was associated with an increase in mean response latency to the initial miscue. However, for participants who did not identify the pattern, no relationship was evident. These findings suggest that the capacity to detect and respond to task-related patterns acts as the underlying mechanism that explains the impact of cue utilisation on task performance. The results of Study 4 also suggested that a capacity for high cue utilisation and an ability to rapidly detect patterns of dynamic stimuli, can give rise to miscueing in environments that are typically marked by regularity and routine.

Chapter One

Overview

The way in which humans process information, acquire skills, and attain expertise has important, practical implications for a range of professions, including fire-fighting (Klein, 1998; Perry & Wiggins, 2008)[1] aircraft piloting (Gopher, Weill, & Bareket, 1994; Sohn & Doane, 2004; Wiggins & O'Hare, 1995; Wiggins, Stevens, Howard, Henley & O'Hare, 2002), medicine (Alberdi et al,. 2001; Maran & Glavin, 2003; Schmidt & Boshuizen, 1993) and sport (Fadde, 2009; Ward, Williams & Hancock, 2006; Williams, Ward, Knowles, & Smeeton, 2002). An understanding of the cognitive processes that underlie human mastery and skill acquisition provides a valuable guide for training and development, and enhances current theoretical perspectives concerning human performance and ability.

The pinnacle of skill acquisition is typically regarded as the achievement of expertise (Ericsson & Charness, 1994). Expertise is characterised by consistent, superior performance on tasks (Ericsson, 2009) that are highly domain-specific (Vicente & Wang, 1998; Voss & Post, 1988). While this provides a general definition of expertise, operational definitions are largely dependent upon established criteria within a particular domain of expertise. For some domains such as golf and chess, there are established criteria (i.e., a scoring system) to establish rank (e.g., Wulf & Su, 2007; Charness, Reingold, Pomplun, & Stampe, 2001). In other domains, expertise is determined by a certain level of professional achievement, such as becoming a professional physicist, ballet dancer, or a commercial airline pilot (Hoffman, 1996; Starkes, Helson & Jack, 2001). For those cases or situations that require expert opinion or panel experts, the criteria may be less clear (Baker, Lovell & Harris, 2006; Crisp, Pelletier, Duffield, Nagy, & Adams, 1999). A large number of empirical studies relating to expertise have recruited 'experts' as research participants, based solely on the individuals' years of experience within a field of practice (e.g., Ball, Ormerod & Morley, 2004; Holt & Beilock, 2006).

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[1] References for this section can be found in the Complete Reference List

Describing the expert

Expertise-related research has typically been conducted within a novice-expert paradigm (see Chi, 2006), whereby the performance characteristics of non-experts are compared with experts within domains of practice. Domains that have been the focus of empirical research include chess (de Groot, 1978; Chase & Simon, 1973a,b), aircraft piloting (Sohn & Doane, 2004; Wiggins & O'Hare, 2003), medicine (Alberdi et al., 2001; Patel & Groen, 1986), sport (Williams et al., 2002), music (Fumeaux & Land, 1999), typing (Salthouse, 1986), and problem solving in physics (Chi, Feltovich, & Glaser, 1981). Differences between experts and novices in a wide range of other, less focused domains have also been investigated, including card playing (Frensch & Sternberg, 1989), rifle and pistol shooting (Doppelmayr, Finkenzeller & Sauseng, 2008; Del Percio et al., 2009) and burglary (Frensch & Sternberg, 1989).

Together, this body of research has produced what might be described as a catalogue of expert performance characteristics. This catalogue consists of *what* experts do differently to non-experts and provides an important and fundamental basis upon which to explore *how* they do this (how individuals come to acquire expertise). A comprehensive summary of the expertise literature, spanning from 1966 to 2003, is provided by Wiggins (2005) whose catalogue includes a listing of authors (who conducted the research), domains (or fields such as radiology or chess) and the characteristics of expertise itself (such as reasoning, recall, performance accuracy and so on). What has emerged from the novice-expert research literature is a broad consensus on several key and measurable dimensions of performance. For example, experts have typically engaged in deliberate practice (Ericsson, 2007; Ericsson, Krampe & Tesch-Roemer, 1993) for a minimum period of ten years (Simon & Chase, 1973a; Bloom, 1985; Hayes, 1981). Deliberate practice consists of focussed, practice-related activities that are deliberately designed to improve performance in a specific domain (Ericsson, 2007). Experts, in comparison to novices, have a greater level of domain-specific knowledge (Chi & Bassok, 1989; Ericsson & Smith, 1991), typically use less information (e.g., Garcia-Retamero & Dhami, 2009; Reyna & Lloyd, 2006; Shanteau, 1987) and take action and make decisions faster and more accurately (Glaser & Chi, 1988; Larkin, McDermott, Simon & Simon, 1980; Wiedenbeck, 1985; Williams et al., 2002). The tendency for experts to take rapid and decisive action is articulated in the Recognition-Primed Decision making model (RPD: Klein, Calderwood, & Clinton-Cirocco, 1986; 2010, Klein, 1993; 1998).

Recognition-Primed Decision Making (RPD). The RPD model provides a theoretical, and largely descriptive account of how experts make quick, effective decisions when faced with complex situations (Salas & Klein, 2001). In the mid 1980's, Klein and associates were commissioned by the United States Army Research Institute to study how decisions were made by expert and novice fireground commanders under conditions of risk, ambiguity, and time pressure (Calderwood, Crandall & Klein, 1987).

Twenty-six fire commanding officers were interviewed, and were asked to recount a specific fire or rescue incident in which the officer made command decisions (Klein, Calderwood & Clinton-Cirocco, 1986; 2010). Officers were asked to recount the incident in their own words, constructing a detailed timeline of the event (i.e., what s/he had seen, heard, felt, and smelled) and were probed at each command decision as to their decision objective, the availability of other options, available resources, and so on.

Based on their analysis of these accounts, Klein and colleagues (Calderwood et al., 1987; Klein, Orasanu, Calderwood & Zsambok, 1993; Klein et al., 1986; 2010) concluded that experts do not compare a *list* of alternative decisions but rather, appear to identify critical patterns or indicators in an immediate situation and match these indicators to previous experiences from memory. These experiences form a repertoire of patterns describing the causal factors operating in the situation and highlight the most relevant cues. These patterns provide expectancies, identify plausible goals and suggest typical types of reactions in that type of situation. When field operators (such as fireground commanders) need to make a decision, they can quickly match the situation to these learned patterns.

Klein and colleagues (Klein et al., 1993) presented the case of an expert fireground commander who had witnessed smoke escaping from the eaves of a building, under the roof. The commander's immediate assessment of the situation was that the entire building was engulfed and, as a result, a search and rescue operation was ordered (rather than issue orders to control the flames). In this situation, the association between 'smoke-under-eaves' and previous experiences of engulfed buildings collapsing, triggered an assessment that initiated a straightforward course of action: cease attempts to extinguish the fire, commence search and rescue operations, and call in a second alarm.

The accounts from fire ground commanders also suggested that experts characteristically make rapid and sound decisions, yet are often unable to articulate retrospectively *why* they selected a particular decision (Klein, 1993; 1998). This led researchers to regard this as an implicit-based, rapid processing style termed *intuition* (Kahneman & Klein, 2009; Klein, 1993; 1998). The observation that field experts rely on a rapid pattern-matching process to make decisions in complex situations is generally consistent with the heuristic account of human reasoning provided by Gigerenzer and colleagues (Gigerenzer, Todd & ABC Research Group, 1999; Gigerenzer & Gaissmaier, 2011; Goldstein & Gigerenzer, 1996; 2002).

Heuristic reasoning. In what is referred to as ‘fast and frugal' reasoning (Goldstein & Gigerenzer, 1996), Gigerenzer argues that, in situations of uncertainty, humans use heuristics to make decisions, rather than complex calculations such as those proposed by expected utility theory (for an overview of utility theory see Fishburn, 1982 and Shoemaker, 1982). Heuristics (such as the ‘first good reason’) are argued to be more efficient and accurate than complex calculations (expected utility) as they are: (a) ecologically rational (i.e., they exploit information in the environmental context); (b) founded in evolved psychological capacities such as memory and the perceptual system; (c) fast, frugal, and simple enough to operate effectively when time, knowledge, and computational capacity might are limited; (d) precise enough to be modelled computationally; and (e) powerful enough to model both good and poor reasoning. Individuals facing a decision-making or judgement task will select the most ecologically valid of the heuristics for a particular task, which allows high levels of accuracy despite the use of simple strategies (Gigerenzer & Selten, 2001). Several simple heuristics have been identified, and several studies have corroborated their use (Dhami & Ayton, 2001; Gigerenzer et al., 1999).

Testing their claim that ‘less is more’ Goldstein and Gigerenzer (2002) performed multiple experiments where participants were presented with pairs of cities and asked to decide, ‘which is the larger city'? The researchers observed that individuals with less information (i.e., Americans with limited knowledge of German cities) consistently made choices in accordance with the recognition heuristic and made inferences that were slightly more accurate than those achieved from more complete knowledge. Computer simulations of the recognition heuristic have also shown that it yields highly accurate predictions despite limited processing requirements (Goldstein & Gigerenzer, 2002).

The heuristics account of decision-making has been criticized for its claim that *only one cue* need be taken into account in reasoning. For example, it has been debated whether recognition is the only cue that is considered in probabilistic inference (as was originally proposed by Goldstien and Grigerenzer) or whether it is one cue among others, albeit a very important one (e.g., Bröder & Eichler, 2006; Newell & Shanks, 2004; Oppenheimer, 2003; Pohl, 2006; Richter & Späth, 2006). The RPD model has also been the subject of scrutiny. There is some argument that cues are a 'triggering' response, made on the basis of recognition, and thus, the reason that expert field operators may not retrospectively recall the 'steps' they took to make a decision, is because there are no steps to recall. Newell and Shanks (2014) suggest that rather than being a 'non-conscious' or 'intuitive' event, these operators simply utilise a cue-triggered association that lacks intermediate cognitive steps.

Both the RPD account of naturalistic-decision making (by field operators) and the heuristic account focus on the characteristic decision-making of experts and provide a useful means by which to *identify* experts and expert performance. They do not, however, provide an explanation as to how these characteristics are developed. Nor do they explain the mechanisms that enable the transition from novice to expert.

Skill acquisition theories and models

A connectionist approach. Skill acquisition models are evidence-based attempts to explain the mechanism by which humans learn and acquire skills and knowledge. One way of classifying these models is by levels of analysis. For example, a connectionist account of skill acquisition represents learning at a neural level of cognition (or a microstructural level; Fodor & Pylyshyn, 1988; Crick & Asunama, 1986), and suggests that learning can be represented and modelled by neural networks consisting of a large number of simple but highly interconnected ‘units’ aggregated into nodes. Nodes represent knowledge or concepts and human processing occurs via patterns of activation across the network of these nodes.

This 'spreading of activation' is the mechanism proposed by a connectionist account of human cognition, learning and skill acquisition. The behaviour of the network as a whole is a function of the state of activation of units and of the weights on its connections, which serve as its form of memory. For example, when a part of the memory network is activated, activation spreads along the associative pathways to related areas in memory, which readies these related areas of the network for further cognitive processing (Balota & Lorch, 1986). The speed and probability of accessing a memory is dependent upon its level of activation, which, in turn, is determined by how frequently and how recently the memory was used (Anderson, 1995).

Spreading activation has been proposed as the underlying mechanism in tasks such as word recognition and episodic sentence recognition (Anderson, 1983a, 1983b), category exemplar production and sentence verification (Loftus, 1974), and perceptual word recognition

(McClelland & Rumelhart, 1981). Balota (1983), amongst others (Neely, 1977; Ratcliff & McKoon, 1981), demonstrated that the spread of activation is automatic or uncontrolled, rather than being under conscious or strategic control. Referred to as the semantic priming effect, words are named faster in the context of an associated word (Ratcliffe & McKoon, 1981). For example, people recognise the word COW faster when it follows the word MILK, than if it follows the word WALL (Meyer & Schvaneveldt, 1971). Balota (1983) reported that when a priming word (e.g., MILK) is flashed on screen for a very short duration (i.e., 350 milliseconds), the priming effect remained (e.g., COW was more rapidly recognised than WALL), but the individuals were not able to report the priming word (MILK). This suggested that while the prime activated related nodes within the network facilitating subsequent identification of a target word, the activation process was neither conscious nor controlled.

The connectionist approach has also been applied to models of reading. Arising from empirical efforts to understand and model reading behaviours in children and adults, several connectionist models of reading have been proposed to explain the computational mechanisms underlying this skill (e.g., the parallel distributed processing model of Seidenberg & McClelland, 1989; The triangle model from Plaut, McClelland, Seidenberg, & Patterson, 1996; and Harm & Seidenberg's reading for meaning model, 2004).

More generally, spreading activation has provided a useful basis upon which to understand automatic, associative cognitive processes. However, as it describes processes at a micro level of human functioning, it only presents an explanation of skill acquisition at a non-conscious and representative level of cognitive functioning. For this reason, spreading activation has often been incorporated into higher-level theories of human skill acquisition (i.e., Anderson & Pirolli, 1984).

At a higher or 'functional' level of cognitive processing, there are several psychological models that purport to provide an account of the mechanisms that underlie skill acquisition.

These include case or instance-based learning (Logan, 1988; Dreyfus & Dreyfus, 1980; 1982; 1986) and production or rule-based learning (Anderson, 1982; 1983a; 1993).

A case-based account of skill acquisition. The case-based account of skill acquisition suggests that individuals accumulate cases or exemplars (typical examples) in long-term memory (Logan, 1988; Dreyfus & Dreyfus, 1980; 1982; 1986). These typical examples become represented in long-term memory as 'wholes'. That is, individuals store the entire context of the situation, and not simply 'parts' of it. Subsequently, recollections of situations (i.e., solutions) occur when the conditions being experienced are matched to previously similar environments. According to Dreyfus and Dreyfus, with continued practice, individuals store and cognitively organise experiences (i.e., form mental models) in such a way as to provide a basis for the future recognition of similar situations viewed from similar perspectives.

Case-based proponents argue that expert performance is acquired as case-based information (or instances) is internalised, such that cases are triggered rapidly and *implicitly* by environmental stimuli (Dreyfus & Dreyfus, 1986; Logan, 1988). For example, if a cardiologist is facing a relatively common heart problem, but had to perform an exhaustive mental serial search through lists of symptoms to rule out illnesses, then Dreyfus and Dreyfus would likely place this doctor at a non-expert level of skill acquisition. If the doctor derived an accurate diagnosis quickly and with little conscious thought, then they would argue that the doctor is likely to have attained an expert level of diagnostic skill acquisition. In this respect, case-based models mirror Klein's RPD model (1998) which emphasises intuition and speed in expert performance.

Evidence for the instance or case-based account of skill acquisition is evident in laboratory studies, which suggest that *automatic performance* relies on memory retrieval rather than on rule application (Lassaline & Logan, 1993; Logan, 1990, 1992; Logan & Klapp, 1991; Schneider & Shiffrin, 1977). For example, Lassaline and Logan (1993) noted that memory for novel patterns led to predictably faster and more accurate identification (recognition) by participants. Changing some details, such as size and colour, did not influence recognition. However, changing the spatial relations (rotating the pattern 180 degrees) did influence recognition, suggesting that the configuration of the entire pattern was encoded, and not just 'parts of it'.

A production-based account of skill acquisition. Still within a functioning level of cognitive processing, a production-based account of skill acquisition developed by Anderson (1982; 1983a; 1993) suggests that the human mechanism for learning occurs through production rules. The Adaptive Control of Thought-Rational account (ACT-R and ACT-R*: Anderson, 1982; 1983a; 1993) is a production system theory that is intended to model the steps of cognition by a sequence of production rules that activate to coordinate the retrieval of information from the environment and from memory. The computational programs of the ACT-R and ACT-R* can be used to model some human cognition processes such as memory retrieval (Anderson, Bothell, Lebeire & Matessa, 1998).

According to the ACT-R, information is integrated into long-term memory in the form of rules or productions that combine a condition and an action statement. A condition is a cognitive contingency or an "IF" statement (i.e. IF the goal is to reverse the car). The action statement follows the IF statement and forms the action or response portion of the rule (i.e., THEN place car gear into reverse). According to the ACT-R, the transition from novice to expert performance is characterised as a transition from control by declarative knowledge to control by procedural knowledge. Declarative knowledge is defined as knowledge that describes a rule (i.e., knowing *that* a car must be in reverse to move it backward), while procedural knowledge is the application of the rule (e.g., knowing *how* to drive a car in reverse). With practice, an increasing frequency of declarative facts and multiple productions can be collapsed into a single production. For example, a novice driver may rely on several productions to reverse a car (i.e., IF goal is to reverse, THEN place the gear stick in reverse, IF goal is to reverse the car, and car is in reverse, THEN check mirrors, and so on). However, over time, the same task will require less declarative knowledge, as information is subsumed into the response portion of the production (i.e., IF the goal is to reverse, THEN place gear stick in reverse, check mirrors, release brake, accelerate, and so on).

Anderson (1982; 1993) refers to the processes of consolidating declarative knowledge into procedural responses as *compilation* and *proceduralisation*. These mechanisms act to reduce the demands on working memory (due to reduced reliance on declarative information) and reduce response latency and increase accuracy (due to the proceduralisation of responses). According to Anderson's ACT-R (1993) production-based processing account, skill acquisition relies on the construction of goal-driven rules. On facing a situation that requires a response (i.e., problem A), an individual's response (i.e., performance B) would be predicted by the mental production/s or goal-linked rules held (in long-term memory) for this event (i.e., If A, then B). Therefore, one's level of expertise is predicted by the extent to which his or her performance is controlled by procedural (and not declarative) knowledge.

The primary evidence for the ACT-R model is its utility in modelling human cognition processes such as memory retrieval (Anderson, Bothell, Lebeire & Matessa, 1998) and basic language processing (language analysis; Ball, 2011). ACT-R models how humans recall 'chunks' of information from memory by deconstructing them into subgoals and applying knowledge from working memory as needed.

Integrated models. Several versions of the ACT-R rule-based approach have incorporated both the recognition heuristic (Gaissmaier, Schooler, Mata & Planck, 2008; Taatgen, Lebiere & Anderson, 2006) and instance learning (Gaissmaier et al., 2008; Taatgen & Wallach, 2002; Taatgen et al., 2006). According to Berka (2011) and Golding and Rosenbloom (1996), the use of heuristics and case-based reasoning operate on rules because cases or remembered instances still require some process of indexing for fast retrieval. For example, according to the ACT-R, 'achieved goals' are stored in declarative memory in the form of IF-THEN productions, and items in declarative memory have an activation value that decays over time (lowering the probability of correct recall; represented as a power law of forgetting; Taatgen et al., 2006). Activations (i.e., the retrieval of certain items of information from memory) are tracked using log-odds programming equations, and repeated activations speed the retrieval process of the next activation. This has been referred to as the power law of practice (Anderson, Fincham & Douglass, 1999; Taatgen et al., 2006). This system is said to model instance-based learning due to its adaptive memory retrieval process (Taatgen et al., 2006). Similarly, a variety of Expert Systems developed in the artificial intelligence community, have incorporated both case-based learning and rule-based learning (i.e., Prentzas & Hatzilygeroudis, 2002; Dutta & Bonissone, 2013). In these systems, symbolic rule-based reasoning (IF-THEN productions) act as the *indexing* component for case-based reasoning, and cases are stored as rule templates. These attempts to integrate the two forms of reasoning and learning, suggest that the retrieval of cases relies on rules. Put simply, the case-based model ultimately relies on some 'rule' to define which case is most important and pertinent to the context or task at hand. The implication is that cases, heuristics, rules are perhaps not as distinct as would first appear.

Arguing for the integration of reasoning systems, Rissland and Skalak (1989; 1991) have provided a computer-based model for interpreting legal statutes (interpreting written laws) that combines case-based and rule-based reasoning into a heuristic approach. They argue that legal rules and parts of them (e.g., terms such as one's "principle place of residence" or "due care") are typically not explicitly defined by a statute and contain ambiguities, unspoken qualifications, and exceptions. To interpret a law, one must examine precedent cases and argue why a previous interpretation may (or may not) be applied to the new case. Cases therefore, enable rules to gain contextual meaning. Heuristics, according to Rissland and Skalak, provide a means by which expert systems can control and interleave reasoning rules and reasoning cases. Heuristics such as 'ways to deal with results opposite from that desired' or 'ways to broaden a rule' operate as controlling processes that determine how the system as a whole and the reasoning processes in particular, are to proceed (Rissland & Skalak, 1989). Heuristics can also provide and determine reasoning tasks, given the perspective and states of the co-reasoners. For example, in a specific legal case there may be various individual perspectives (the plaintiff, the defendant, the witness and so on) and a heuristic 'controlling rule' can determine reasoning from each of these perspectives.

Highlighted in this integrated model of law-interpretation, is the problem of *uncertainty* in expert decisions, and the necessity for computer models to define what is important to attend to in the first place. According to Plessner, Schweizer, Brand and O'Hare (2009), because decision makers and learners often do not have certainty in distal variables (i.e., doctors may not know that a patient has a particular illness for certain, and soccer referees may not know for certain if a foul has been committed), they have to rely on approximations or relevant cues instead (i.e., the disease symptoms or the response of the soccer crowd).

Chapter Two

Cue-utilisation

The various models and theories of skill acquisition mentioned thus far (i.e., the ACT-R, case-based accounts, the RPD model, heuristics account, along with integrated models), all embody differences that lie primarily in the method of retrieving information from long-term memory. For example, the RPD model (Klein, 1998)[2] and case-based account (Dreyfus & Dreyfus, 1986) argue for a holistic, pattern-matching retrieval approach, while heuristic models (Goldstein & Gigerenzer, 1996) and Anderson (1993) argue for a rule-based approach to retrieval and response. Integrated models (i.e., Dutta & Bonissone, 2013; Gaissmaier et al., 2008; Prentzas & Hatzilygeroudis, 2002; Rissland & Skalak, 1989; Taatgen, et al., 2006; Taatgen & Wallach, 2002) rely on rules such as rule templates or heuristic rules to index and access case-based information.

Aside from these differences, there are many commonalities between these models, particularly with regard the process of skill acquisition and the characterisation of expertise. All of the models assume that the development of skilled performance depends on the ability to: (1) attend to important features in their environment; (2) link these features to objects, events, or outcomes; and (3) subsequently retrieve these associations and respond accordingly. These three requirements correspond to those described by Wiggins (2006; 2012) as comprising *cue utilisation*. Cue utilisation encompasses the ability to identify key features relevant to a task or objective, create causal relationships between these key features and events, retain this information in long-term memory, and then apply this to different environments and contexts (Oaksford, 2000; Wiggins 2006; Wiggins & Bollwerk, 2006). Concepts of cue utilisation and more generally, cue-based processing, stem from the work of Brunswik throughout the 1930's to 1950's.

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[2] References for this section can be found in the Complete Reference List

Hammond and Stewart (2001) describe Egon Brunwik's work throughout 1930 until 1955, as 'probabilistic functionalism'. The probabilistic focus of Brunswik's work came during psychology's deterministic behaviourism reign of the 1930's to late 1950's (i.e., Hull, 1943; Tolman, 1932 & Kurt Lewin: See Schultz & Schultz, 2011 for an overview). Questioning the central tenets of behaviourism, Brunswik proposed a *probabilistic environment,* arguing that organisms existed in uncertain environments and acted on evolved, biological tendencies, rather than simply responding to immediate reinforcements (Brunswik, 1943; 1956). In this respect, Brunswik's ideas are not dissimilar to those of Herbert Simon (Simon, 1957; 1972; 2000) whose notion of bounded rationality reflected the view that human rationality is limited by factors such as human cognitive capacity, the available information and the time available to make the decision. Brunswik’s concept of a probabilistic environment formed the basis for his theories of perception. He saw the relationship between perceptions and objects in the environment as correlational rather than deterministic (Brunswik, 1955).

Brunswik examined how people use sensory cues (perceived environmental features) to reach 'perceptual achievements'. ‘Perceptual achievements’ refers to the alignment of perceptual judgements (i.e., approximations of an object's size based on cues) with environmental criteria (i.e., actual size of the object). For example, Brunswik (1943) provided a series of coin piles, each containing a different number of coins arranged in circular clusters. All coins in one pile were of the same type (e.g., Turkish coins worth 2.5 cents). Observers were then asked to compare these clusters and make judgements as to the value of a pile, the number of coins in the pile, the size of the coins, and the area covered. Brunswik observed that the perceived size of coins changed as their number and value varied (Hammond & Stewart, 2001). When told that a pile of coins in the distance was of a high value, volunteers increased their estimates of the individual size of coins in the pile. Brunswik noted that coins of higher value were, on average, larger (despite an imperfect correlation), and argued that the use of these cues enables 'perceptual compromises' that often serve functional purposes quite well.

Brunswik theorized that perception involves making inferences about the nature of the environment from a multitude of available cues, many (or all) of which are not reliable predictors of important outcomes. Therefore, part of the inaccuracy in human judgments is due to the uncertainty in the environment itself. Brunswik illustrated his cue-based perception model (Figure 1), in what resembled the familiar diagram of light passing through a convex lens, and thus it became known as the 'lens model' (Brunswik, 1952; 1956; Hammond & Stewart, 2001).

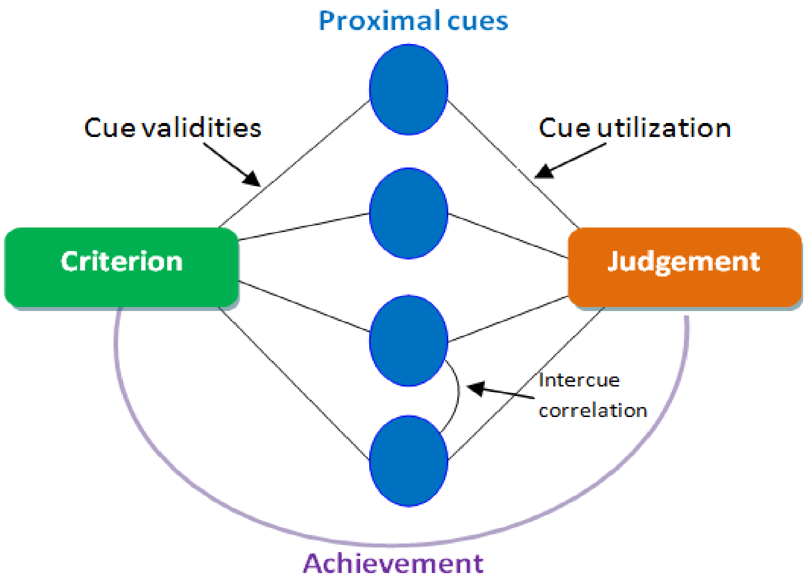

Figure 1. Human judgement modeled as the processing of imperfect sensory cues. Adapted from Brunswik (1952; 1956).

The *criterion* in the lens model represents the environmental criterion or distal variable of interest (i.e., the actual size of an object), and can also represent a dependent variable. There are features in the environment that should relate to this dependent variable. For example, the size, shape and orientation of an image on the human retina provide people with information, albeit imperfect, about an object's size. There are also other features such as reflections and nearby objects that can give an individual some indication of the size of an object. Brunswik referred to these features as *proximal cues* that provide individuals with approximations about a real object or variable that exists. Cues represent the independent variables in the lens model.

Individuals utilise cues to make judgements about the criterion. For example, judgements about the size of an object are made on the basis of cues that signal the ‘actual’ size (criterion). The right-hand side of the model (in Figure 1), therefore, represents perceptual-based judgements or conclusions by people, and can also represent a dependent variable.

The correlations between the cues and judgment provide an indication of the cue utilisation of individuals, or the relative importance of particular cues to the individual (i.e., the specific features that are given more attention than others). Similarly, the correlations between cues and the criterion describe the actual strength of the relationship between the cues and some event or object in the actual environment. Brunswik used the term ecological validity in reference to the relation between a cue and a criterion (not referring to generalisability as the term is used today). In Figure 1, this relationship is labelled ‘cue validities’. The correlations between individual cues and the criterion indicate the actual weight or importance of these features.

Since Brunswik, multiple regression has provided a means of comparing the relations between the cues and judgment to the relations between the cues and criterion (i.e., Bernieri, Gillis, Davis & Grahe, 1996). This provides an indication as to how well human judgements or decisions are calibrated to specific environmental criterion. The calibration between judgement and criterion is referred to as the *achievement index* (in the lens model), and can be used, for example, as a means of estimating the accuracy in practitioner diagnosis of illnesses such as pneumonia, based on multiple patient cues (Tape, Heckerling, Ornato, & Wigton, 1991).

Cues. Consistent with Brunswik's early work, cues can be defined as feature-event or feature-object associations in an operator's memory that can be used to interpret situations (Wiggins, 2006; 2012). For example, the arm movement of a ball being thrown (feature) and the location of the landing ball (event) form a feature-event/ object association, whereby the feature holds meaning to the catcher. Whether important features (such as the sight of a red traffic light, patient symptoms, or 'smoke under the eves') are accessed from memory in the form of *holistic associations* or *rule-based parts*, it is the ability to form these cue-associations, and draw on this information when needed, that appears to play a crucial role in the ability of an individual to acquire skills and progress toward expert performance (Wiggins, Brouwers, Davies and Loveday, 2014).

Cue utilisation and experts: Evidence. Experts utilise a relatively limited number of specific features to interpret a situation and make anticipatory responses (e.g., Williams et al., 2002; Williams & Ward, 2003; Fadde, 2006; Wiggins & O'Hare, 1995; Endsley, 2006; Lesgold et al., 1988). For example, Abernethy and Russell (1987) used eye-tracking and video-recordings of badminton strokes to examine the predictive decision-making of expert and novice badminton players. Employing a method of occlusion, (i.e., recordings shown with 4 missing frames per second, or with an opponent's racquet arm occluded), they found that expert players, compared to novices, were better able to utilise limited opponent movement information (i.e., position of arm), and predict where the shuttle would land. Consequently, expert players made earlier anticipatory predictions of the landing position of the shuttle (Abernethy, 1987; Abernethy & Russel, 1987). The ability of experts to extract visual information and make anticipatory judgements has been demonstrated in a range of other sporting domains including soccer (e.g., Savelsbergh, Williams, Van der Kamp, & Ward, 2002; Williams & Davids, 1998; Williams and Grant, 1999), tennis (e.g., Jones & Miles, 1978; Shim, Carlton, Chow, & Chae, 2005), hockey (Salmela & Fiorito, 1979), and squash (e.g., Abernethy, 1990).

Visual features have been of particular interest to researchers in the field of expertise. Expert operators pay more attention to relevant elements of visual stimuli, and interpret their observations with greater accuracy. This is evident for drawing artists (Antes & Kristjanson, 1991), chess players (Charness, Reingold, Pomplun, & Stampe, 2001), fish anatomists (Jarodzka, Scheiter, Gerjets & Van Gog, 2010), meteorologists (Lowe, 1999) and drivers

(Underwood, Chapman, Brocklehurst, Underwood, & Crundall, 2003). The tendency for experts to identify and focus on relevant visual features and produce more accurate interpretations has also been demonstrated in the medical domain such as in clinical and diagnostic tasks relying on microscopic slides, patient photographs, X-rays, and mammograms (e.g., Brooks, LeBlanc & Norman, 2000; Krupinski et al. 2006; Kundel, Nodine, Krupinski & Mello-Thoms, 2008; Lesgold et al., 1988). Lesgold et al. (1988) observed that expert radiologists attended to, and extracted important information from X-rays that went undetected by their non-expert counterparts.

There is also evidence to suggest that non-experts can be directed toward the cues utilised by expert operators, resulting in performance improvements. Wiggins and O'Hare (1995) examined the decision-making processes of pilots and reported that experienced pilots required less task-related information with which to formulate a decision, and required less time to do so. They subsequently created a cue-based training program for the recognition of poor weather conditions and noted that those pilots who received the cue training consequently made more optimal weather decisions during a simulated flight (Wiggins & O’Hare, 2003). Fadde (2006; 2009) adopted a similar strategy amongst baseball batters. Fadde examined observations of eye movements by expert and novice baseball players (Paull & Glencross, 1997) and suggested that the superior pitch-tracking skills amongst expert batters was due to their superior recognition of a limited number of key cues, extracted from the pitcher's arm movement. Using this information, Fadde (2006) designed a visual observation system for players, guiding their attention to these critical features. The introduction of this training system resulted in a significant increase in batting performance amongst trained players (Fadde, 2006).

Following Wiggins and O’Hare (2003) and Fadde (2006), Jarodza et al. (2012) examined whether directing attention towards key cues could be used to assist medical students to accurately interpret the diagnostic symptoms of infant epileptic seizures. Eye movements of expert models, superimposed onto audiovisual case recordings of infants in seizure, were used to guide learners’ attention to the relevant features of the infant (i.e., fingers, eyes). Based on the learners’ recorded visual search patterns and their interpretation of symptoms, the results indicated that this type of attention guidance was an effective learning strategy. The most effective condition in this study was a ‘blurred’ condition whereby the background to the cue was obscured so that learners were discouraged, or not able, to focus on irrelevant regions.

While the observation that cue-based learning can aid an individual's progress toward expert performance is useful, it does not explain *how* cues enable expert operators to respond rapidly with seemingly non-conscious processing. The ability of experts to rapidly respond to a situation has been referred to as 'intuitive pattern matching' (Kahneman & Klein, 2009; Klein, 1993; 1998), 'fast and frugal reasoning' (Goldstein & Gigerenzer, 1996), 'proceduralised responses' (Anderson, 1982; 1993) or triggered 'case-based matching' (Dreyfus & Dreyfus, 1986; Logan, 1988). To understand the *mechanisms* by which cue-based processing accounts for the rapid responses characteristic of expert performance, it is necessary to examine the principles and evidence relating to associational learning.

Associational learning

The elementary learning mechanisms of primates consist of basic associative processes which serve as the foundation for understanding many complex forms of behaviour and cognition (i.e., Pearce & Bouton, 2001; Wasserman & Miller, 1997). In animal behaviour, associative learning is defined by Mitchell, Houwer and Lovibond (2001) as "The capacity possessed by a broad range of organisms to learn that two or more events in the world are related to one another. That is, one event may refer to, signal, or cause the other" (p. 183). For example, pairing a tone with food leads to a tone-food association (Classical conditioning: Pavlov, 1927) while pairing a response (lever pressed) with a stimulus (food appears), forms a response-stimulus association (Instrumental conditioning: Skinner, 1938). Consistent with instrumental conditioning, Tolman (1932) argued that learning was a matter of discovering 'what leads to what'.

While associative learning has been the subject of philosophical speculation since the time of the ancient Greeks (Warren, 1921), it was not until the late nineteenth century, that associative learning was investigated experimentally (e.g., Pavlov, 1927; 1928; Skinner, 1938; Thorndike, 1911). Understanding the principles of instrumental and classical conditioning, primarily in non-human animals, dominated the work of Hull, Skinner, Spence and Tolman in experimental psychology throughout the 1930's to 1950's (Bower & Hilgard, 1981). The contemporary study of associative learning in humans has largely been replaced by research in higher-order cognitive activities that include beliefs, expectations, attention, mental representations, and conscious knowledge and processing (for example, see Holland & Wheeler, 2009; Lovibond & Shanks, 2002; Schachtman & Reilly, 2011). However, the concept of associative learning remains acknowledged as an elementary process that leads to human and animal behavioural changes (I.e., Mackintosh, 1983; Wasserman & Miller, 1997). According to Wise and Murray (2000), primates rely on a rich behavioural repertoire because of their ability to combine sensory stimuli with motor responses according to associative rules. Classical and instrumental conditioning procedures continue to be applied in a variety of experimental settings, to explore phenomena such as phobias and fear (Öhman, & Mineka, 2001; Veit et al., 2002), taste aversion (Logue, 1985; Welzl, D'Adamo & Lipp, 2001) and addictive behaviours (Everitt, Dickinson & Robbins, 2001; Lee, Di Ciano, Thomas, & Everitt, 2005).

Associational learning has been incorporated into neural network models of learning and decision-making (Green & Shanks, 1993; McLeod, Plunket & Rolls, 1998; Rumelhart, McClelland, & the PDP Research Group, 1986; Sun, 1994) and a primary reason for this relates to automaticity. Associational learning is argued to occur on a non-conscious processing level resulting in implicit, rather than explicit learning (Cleeremans, 1997; Sun, 1994). The distinction between implicit and explicit learning has been widely recognized (see, e.g., Cleeremans, Destrebecqz, & Boyer, 1998; Proctor & Dutta, 1995; Reber, 1989; Seger, 1994; Stadler & Frensch, 1998) and emerges from the more general idea that there are two cognitive systems that give rise to different forms of reasoning. Amongst cognitive theories of processing (in reasoning and decision-making), there is a distinction between processes that are nonconscious, rapid, automatic, and high capacity (System 1), and those that are conscious, slow, and deliberate (System 2) (see Evans, 2008 for a review). System 1 has been referred to as automatic (Schneider & Shiffrin, 1977), heuristic (Evans, 1989; 2006) intuitive (Hammond, 1996) and reflexive (Lieberman, 2003) while System 2 is referred to as higher cognition (Fodor, 1983; 2001), controlled (Schneider & Shiffrin, 1977), analytic (Nisbett, Peng, Choi & Norenzayan, 2001) and conscious (Wilson, 2002).

A question that might be asked is whether there is a ‘best system’? Or, more specifically, whether one of these systems is more conducive to expert performance. While the proceduralisation (or automaticity) of performance has been identified as characteristic of expert performance (e.g., Charlton & Starkey, 2011; Ericsson, 2006; Singer, 2002), automaticity has also been implicated in some types of human errors, including capture errors (Reason, 1990). Capture errors are a form of human error where more familiar action sequences in memory trigger or 'capture' an intended and less familiar action (Reason, 1979; 1990; Wickens & Hollands, 2000). A personal account of a capture error provided by Reason (1979) is the case where he intended to take his car out of the garage but, as he passed by the porch enroute to the garage, he stopped to put on his gardening boots and jacket, as though to work in the garden. The answer therefore, is that humans rely on both systems, and neither is infallible.

According to Evans (2003), individuals frequently determine their actions on the basis of past experience where intuitive responses rely on doing what has worked well in the past and where little reflection is required (e.g., System 1). However, decisions can also be made by constructing mental models or simulations of future possibilities, a process termed 'hypothetical thinking', which is a mechanism provided by System 2.

Two Systems

System 1 and System 2 reasoning systems have been described as dual processing theories (Evans, 2008; Kahneman & Frederick, 2002; 2005) and have been used to explain a range of decision making and reasoning phenomena (e.g., see Evans, 2003; Osman, 2004). For example, a great deal of literature has been devoted to understanding how people reason with the Wason four-card selection task (Almor & Sloman, 1996; Evans, 2003; Evans & Over, 1996; Griggs & Cox, 1983; Johnson-Laird & Wason, 1970; Lunzer, Harrison & Davey, 1972; Wason, 1968; Wason & Evans, 1975; Zimmerman, 2000). In this task, participants are shown four cards (see Figure 2) and told that each card has a letter on one side and a number on the other. They are given a rule, "*If there is a K on one side, then there is a 2 on the other side"*, and are then asked to select those cards that need to be turned over to assess whether the rule holds true or not. Most commonly, individuals will indicate cards showing *K* and *2*. The correct answer is *K* and *7*. While most people recognize the importance of selecting the *K* card (to ensure there is a 2 on the other side), it is also logical to select the *7*, because in the event that it has a *K* on the other side, the rule would be violated (thus falsified). As the rule does not stipulate what should be on the other side of a 2, this card might have anything at all on its opposite side, without confirming or disconfirming the rule.

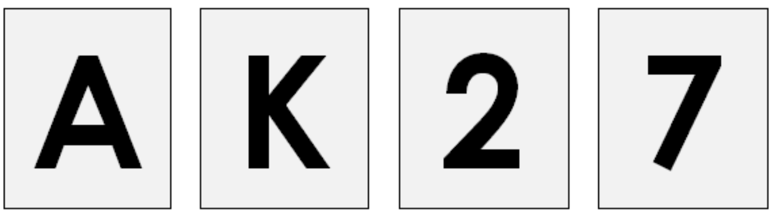

Figure 2. An example of the Wason 4-card selection task.

Given this abstract, card-based form of the task, few individuals correctly identify both the *K* and *7*, but given a concrete or deontic form of the same task, most participants are able to correctly solve the problem (e.g., Johnson-Laird, Legrenzi & Legrenzi, 1972). For a scenario where the rule is: *If a person is drinking a beer, they must be aged 21 or above,* the large majority of participants will correctly identify that, to test this rule, one must check (a) the age of any beer drinkers, and (b) the drink that is being consumed by under 21-year-olds. In this task, checking the drink of someone who is <u>not</u> 'aged 21 or above', is analogous to checking a number card that is <u>not</u> 'a 2' in the abstract task.

Evans and colleagues (Evans, 2008; Evans et al., 2003) have argued that the analytic and deductive reasoning of System 2 is required to solve the abstract form of the selection task. Support for this proposition is provided by evidence to indicate that ‘solvers’ have higher cognitive ability scores (as measured by Scholastic Aptitude Test Scores) than non-solvers (Stanovich & West, 1998). The concrete (beer-drinking) form, however, can be solved by the pragmatic or heuristic-based reasoning characteristic of System 1 reasoning (e.g., Newstead, Handley, Harley, Wright, & Farrelly, 2004). Despite the necessity of two different systems, both forms of the task do not *appear* to require lengthy, analytical-based responses (Evans & Curtis-Holmes, 2005). Thus, System 1 processing is likely to be evoked and actually applied by individuals in both forms of the task (Evans & Curtis-Holmes, 2005). Relying on System 1 processing will enable most individuals to correctly solve the situation-familiar, concrete form of the task, but poses challenges to the abstract form. Table 1 provides a summary of this rationale.

Table 1

Why individuals find the abstract Wason task challenging (Evans, 2008)

	Requires	Evoked/Applied	Result

Abstract task (letter-number cards)	System 2 reasoning	System 1 reasoning	Challenging
Concrete task (beer-drinking)	System 1 reasoning	System 1 reasoning	Less challenging

The two processing systems are consistent with existing models of skill acquisition and expert decision-making theories. According to Kahneman and Frederick (2003), "complex cognitive operations eventually migrate from System 2 to System 1 as proficiency and skill are acquired" (p. 51). For example, in Dreyfus and Dreyfus' (1980) case-based model of skill acquisition, novices begin with a laborious and rigid adherence to rules, (analogous to System 2 processing) and, as expertise increases, information is triggered implicitly by environmental stimuli (analogous to System 1 processing). Similarly, Anderson's production-based account (1982; 1993) suggests that learners begin by consciously manipulating declarative information, which then gradually shifts to procedures that rely on less conscious attention (System 2 to System 1 processing). The rapid, recognition-based decision-making amongst experts (Klein, 1999) as well as 'fast and frugal' reasoning (Goldstein & Gigerenzer, 1996) can be considered characteristic of System 1 processing (Evans, 2008).

Integrated models of learning such as those that combine case-based, rule-based and heuristics (e.g., Dutta & Bonissone, 2013; Gaissmaier et al., 2008; Prentzas & Hatzilygeroudis, 2002; Taatgen & Wallach, 2002; Taatgen et al., 2006) are also consistent with a dual-processing account. The two systems are argued to operate in parallel (i.e., Kahneman & Frederick, 2002; 2005; Sloman, 1996). For example, Kahneman and Frederick (2002) suggest that in the application of the recognition heuristic (Gigerenzer, et al., 1999), System 1 initially involves a rapid, intuitive assessment. This familiarity-based assessment may be monitored by System 2, which can then endorse, correct or override the elicited response. When information is simply lacking (e.g., an individual has not heard of a particular city), System 2 endorses the initial response (based on the recognised city). Thus, as Gigerenzer and Goldstein (1996) suggest, the recognition heuristic may also be viewed *in part*, as a deliberate strategy (Kahneman & Frederick, 2002). This is consistent with Sloman (1996) who argued that the two systems are complementary, with the associated, similarity path being one that operates without prejudice, whilst the more careful and deliberate path provides a logical filter for thought.

Cognitive load and chunking

As System 2 is relatively slow and deliberate, it may not be inappropriate under time critical conditions. Further, the cognitive load required may exceed the resources available to the practitioner (Kahneman & Frederick, 2002; Paas, Renkl, & Sweller, 2004). Cognitive load refers to the total amount of mental activity imposed on working memory at an instance in time (Cooper, 1998). Working memory is a conscious, short-term store that carries out planning and decision-making functions and requires cognitive resources (Baddeley, 2000). By contrast, long-term memory constitutes a rich, albeit imperfect store of information across one's lifetime (Cowan, 2008). A major limitation of working memory is its limited capacity to deal with approximately four elements (or chunks) of information simultaneously (Cowan, 2001) which thereby imposes limits on access to long-term memory (Baddeley, 2007; 2010). Due to its analytical and conscious processing, System 2 thinking is argued to require access to a central working memory system of limited capacity, whereas System 1 obviates this requirement (Evans, 2008).

The rapid, automatic or implicitly triggered decision-making of experts (Anderson, 1982; 1993; Dreyfus & Dreyfus, 1986; Goldstein & Gigerenzer, 1996; Klein, 1993; 1998), suggests that experts operating within their domain employ automatic processing (System 1) to a greater degree than novices. Furthermore, this system is less influenced by cognitive load (Evans, 2008). C*hunking*, a term coined by Miller (1956), has become recognised as a mechanism that explains how expert performers are able to circumvent working memory limitations (Chase & Simon, 1973a; 1973b; Gobet et al., 2001).

A chunk is a processing mechanism that enables units of information to be retrieved by a single act of recognition (Gobet & Simon, 1998). Chunking refers to the processing (storing) of information as groups, rather than as individual pieces of information. The use of chunks explains an increased ability to extract information from the environment, in spite of working memory limitations (Gobet, et al., 2001). Thus, cognitive chunking aids the ability to hold meaningful associations in long-term memory (Wickens & Hollands, 2000; Wickens, Lee, Liu, & Gordon Becker, 2004), which in turn, aids the retention and recall of the information (Gobet & Simon, 1998). For example, the string USAFBICIA represents only three pieces of information to those familiar with the terms USA, FBI and CIA (Wickens et al., 2004). Experts are able to rapidly retrieve information in long-term memory by recognising familiar patterns (i.e., chess piece configurations on a board), which act as cues that trigger access to the chunks (Chase & Simon, 1973b).

Chess expertise research (Chase and Simon, 1973a; de Groot, 1978; Simon & Chase, 1973) has illustrated the use of chunking amongst chess masters. In a classic expert–novice chess experiment, players are briefly shown an arrangement of pieces on a chessboard and asked to duplicate the arrangement on another chessboard. Chase and Simon (1973a) observed that when chess pieces were arranged randomly, there was little difference between the ability of expert and weaker players to reproduce the original arrangement. However, when the pieces were arranged in meaningful patterns (drawn from actual games), chess masters were far better at reproducing the arrangement of pieces. Chase and Simon concluded that by drawing on their knowledge of chess configuration patterns (i.e., castled-king, pawn chain, rook pair and so on) and *grouping* pieces into these meaningful chunks, chess experts were able to circumvent the normal limitations of working memory. According to Ericsson and Kintsch (1995), expert performers “acquire domain-specific skills to expand working memory capacity by developing methods for storing information in long term memory in accessible form” (p. 239).

To date, evidence for chunking is found predominantly in chess research (e.g., Chase and Simon, 1973a), computational chunking models (i.e., Gobet et al., 2001), and in the way that readers tend to group letter-symbols into words, sentences and paragraphs (Broadbent, 1975; Chase & Simon, 1973a; Chase & Ericsson, 1981; Gobet & Simon, 1998; Klahr, Chase & Lovelace, 1983; McLean & Gregg, 1967; Reitman & Rueter, 1980). Human chunking mechanisms and strategies have also been implicated in language acquisition and syntactic categorisation by children (Gobet & Lane, 2012; Hewlett & Cohen, 2011; Pak et al., 2005). Due to the importance of chunking to fundamental processes of perception, learning and cognition (Gobet et al., 2001), it is a capability that has been described (Gobet & Simon, 1998) and modelled (French, Addyman & Mareschal, 2011) as a pattern-recognition mechanism.

Pattern recognition

Pattern recognition involves identifying an object or event through feature extraction (i.e., object colour) and matching or classifying that object to a category within memory (DiCarlo, Zoccolan & Rust, 2012; Jain, Duin & Mao, 2000; Reed, 1972). Gonzalez and Thomason (1978) define pattern recognition from a syntactic-programming perspective as "the categorization of input data into identifiable classes via the extraction of significant features or attributes of the data from a background of irrelevant detail" (p. 1). Borrowing a human reasoning and decision-making definition, pattern recognition can be defined as the non-conscious recognition of situations as typical or prototype, that prime appropriate scripts in memory (Klein, 1989; Klein et al., 2010). What is known about pattern recognition has been derived broadly from three research domains: (1) vision, cognition and neuroscience; (2) computational programming and artificial intelligence; and (3) human judgement and decision-making.

From a visual neuroscience perspective, the process of visual pattern recognition is described as a solution undertaken in the brain via a cascade of non-conscious computational processes that culminates in a neuronal representation in the inferior temporal cortex whereby objects are assigned labels or categories (DiCarlo, Zoccolan & Rust, 2012; Gross, Rodman, Gochin & Colombo, 1993). The ventral visual stream (or 'vision-for-perception' pathway) originates in the primary visual cortex and extends along the ventral surface into the temporal cortex and is believed largely responsible for the recognition and discrimination of visual shapes and objects in primates (Miyashita, 1993; Orban, 2008; Rolls, 2000). The ventral stream produces an inferior temporal population representation (via the response pattern of a population of visual neurons) in which objects or objects features are responded to, and object identities are delineated (DiCarlo, Zoccolan & Rust, 2012). The algorithm that produces this identification and classification solution, however, remains poorly understood (Baron, 2013). Largely due to this lack of knowledge, a large body of research has emerged from the artificial intelligence and computer science communities that has focused on either establishing pattern recognition systems in the natural (human and animal) world (e.g., Tsotsos et al., 1995) and/or producing pattern recognition programs for applied, special-purpose hardware (Chellappa, Sinha & Phillips, 2010; Duda, Hart & Stork, 2012). Computationally, the proposed methods by which feature identification and extraction can be carried out include specific feature-extraction (rules), holistic representations (i.e., template matching), neural network classifiers, or a combination of these (Due Trier, Jain & Taxt, 1996; Hinton & Salakhutdinov, 2006; Nixon, Nixon & Aguado, 2012; Nosofsky, Clark, & Shin, 1989; Wiskott & Sejnowski, 2002).

In contrast to humans, for whom pattern-recognition comes naturally and effortlessly, machine-based programs for pattern and object identification have faced a number of key challenges over the last fifty years (Biederman, 1987; Thorpe, Fize & Marlot, 1996). Visual object recognition in particular, has posed numerous challenges for computers (Riesenhuber & Poggio, 2014), including, and most notably, the 'variability' or 'invariance' problem (Pinto, Cox,

& DiCarlo, 2008; Pinto, DiCarlo, & Cox, 2009; Ullman, 2000). For example, while individuals readily recognise that a person who has moved further away or who has turned his/her head is still the same person, this constitutes a potential new object identity to a machine. A vision system needs to generalise and classify accurately across large variations in the appearance of an object due to viewpoint, occlusions, background clutter or illumination. A similar challenge exists for the machine recognition of hand-written passages since machines must recognise all of the possible graphical variations of the same letter, and be able to recognise sentences that may lack clearly segmented words (Rehman & Saba, 2012). According to Zhao and Chellappa (2006), the attempt to mimic the face recognition abilities of humans for example, with existing technology, is futile. Computer systems, however, have memory advantages and outperform humans in their capability to accurately recall large numbers of images and scenes (Von Neumann, 2012).

Emerging from human judgement and expertise literature on pattern recognition is the proposition that experts tend to make judgements by engaging rapid, recognition-based decision processes (Klein, 1999; Norman, Young & Brooks, 2007; Schmidt, Norman & Boshuizen, 1990) which has also been referred to as System 1 processing (Evans, 2008). Klein and Hoffman (1992) have argued that experts are better able to judge typicality within situations and match these to their knowledge base of experiences. According to Larkin et al. (1980), an experts' recognition of a pattern evokes information previously stored from memory about strategies and actions that may be appropriately applied in a current context.

The differences between novice and expert clinical diagnostic performance suggests that medical experts rely on pattern matching whereby they rapidly retrieve solutions by matching existing salient cues (i.e., patient symptoms) to their repertoire of common medical problems or 'illness scripts' (Coderre, Mandin, Harasym, & Fick, 2003; Gilhooly, 1990; Groves, O'Rourke & Alexander, 2003; Norman, Young & Brooks, 2007; Schmidt, Norman & Boshuizen, 1990). Novice clinicians are more likely to utilise a hypothetico-deductive reasoning strategy that is considered more prone to error (Patel, Groen & Norman, 1991), more effortful (Evans, 2008) and a 'weak method' of problem solving (Newell, 1973; Groen & Patel, 1985). In attempting to solve physics problems, Chi, Glaser and Rees (1982) observed that novices grouped problems that were similar in *surface structure* (e.g., using the key words in the problem statement), whereas experts categorised the same problems on the basis of *deep structure* (using physic principles). Similar differences between experts and novices have been noted in the perceptual categorisation of mathematical problem solving (Schoenfeld & Hermann, 1982) and the reconstruction of circuit drawings by electronic technicians (Egan & Schwartz, 1979).

Knowledge structures

As pattern recognition relies upon a stored bank of associational features or categories, it might be argued that a *larger body* of stored information (referred to as declarative information: Day, Arthur & Gettman, 2001) would enable an individual access to a wider body of knowledge and proffer an advantage in assessing a current situation or making a decision. The observation that experts have typically engaged in focussed, practice-related activities (Ericsson, 2007; Ericsson, Krampe, & Tesch-Roemer, 1993) for a minimum period of ten years (Simon & Chase, 1973; Bloom, 1985; Hayes, 1981) gives some credence to the view that simply amassing 'more' knowledge or experiences may account for expert performance. However, individuals with the same number of years within a field, or having undertaken the same training, will often not achieve the same level of performance and expertise (Ackerman, 2007; Ackerman & Beier, 2007; Duncan, 1985; Hambrick et al., 2014; Scardamalia & Bereiter, 1991). This has led to the view that practice is a necessary but not sufficient condition for the attainment of expertise (Campitelli & Gobet, 2011).

The current rationale in cognitive science suggests that, along with the amount of knowledge stored in memory, of equal or even greater importance is the organisation of that knowledge (Chi, Glaser & Rees, 1982; Johnson-Laird, 1983; Kraiger, Ford & Salas, 1993; Rouse & Morris, 1986; Schank & Abelson, 2013). Also referred to as schemas, mental models, conceptual frameworks, templates and chunking, *knowledge structures* refer to the organisation of knowledge in memory (Chase & Simon, 1973b; Dorsey, Campbell, Foster, & Miles, 1999; Gobet & Simon, 1996b; Schmidt, Norman & Boshuizen, 1990). Knowledge structures are based on the premise that individuals organise information into patterns that reflect the relationships that exists between concepts, objects, events and features that define them (Johnson-Laird, 1983; Day, Arthur & Gettman, 2001). Novices are presumed to lack the specific knowledge structures that enable rapid retrieval of domain specific information held in memory (Chase & Simon, 1973b; De Groot, 1978). Consistent with the view that experts hold knowledge structures of information relevant to their area of expertise, experts demonstrate a remarkable memory for domain-specific material (Chase & Simon, 1973a; De Groot, 1965; De Groot & Gobet, 1996), suggesting that their vast amounts of knowledge are *structured* to enable rapid and accurate responses when required. After exposing chess experts (Master and Grandmaster players) to a previously unseen game board of chess for only five seconds, these players are able to retain almost complete memory for chess pieces and positions (Bilalić et al., 2010; Chase & Simon, 1973a; Gobet & Simon, 1996b). Disrupting the typical chess board patterns associated with a 'real game', by instead randomly assigning chess pieces across a board game, results in a significantly reduced memory advantage for game pieces by chess experts (i.e., Bilalić et al., 2010).

Chapter Three

Cue utilisation versus the multiple-cue judgement framework

Contemporary cue utilisation theory, as applied in diagnostic performance contexts (e.g., Wiggins, 2012; Wiggins & O'Hare, 2003; Loveday, Wiggins, Festa, Schell, & Twigg, 2013)[3] and multiple-cue judgement theories (e.g., Brehmer, 1994; Cooksey, 1996; Hammond, Stewart, Brehmer, & Steinman, 1975) both descend from the work of Brunswik (Brunswik, 1952; 1955; 1956; Hammond & Stewart, 2001). There are however, important differences in the focus and research application of these approaches, and to understand these differences, it is necessary to explore the multiple-cue judgement framework itself.

In many everyday situations, humans make judgments that estimate, infer, and predict the nature of unknown events. For example, individuals may form estimates of what the weather will be like tomorrow, the weight of an item of carry-on luggage, the strength of a resume for a job application or, in the case of a doctor, the likelihood that a medical patient has a particular disease. Multiple cue frameworks such as Social Judgement Theory (SJT; Brehmer, 1994; Cooksey, 1996; Hammond et al., 1975) investigate the processes involved in making such judgements. Multiple-cue approaches arose from Brunswik's lens model (1952, 1956), which provided a conceptual template for judgement processes.

According to the multiple-cue judgement perspective, individuals form estimates about a real object or variable of interest (a criterion), by relying on cues or perceived approximations about the criterion. These cues will vary in relevance to the criterion and vary in their perceived importance to the individual making the judgement. For example, the extent to which tomorrow will be 'sunny' (a judgement criterion) is indicated by a number of environmental factors that meteorology research typically addresses (e.g., based on weather patterns and so on). In every-

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[3] References for this section can be found in the Complete Reference List

day life however, an individual might rely on the weather the day before, the current season, how clear the sky is at present, or how warm he or she currently feels outdoors. These are all cues that the individual is utilising to form a judgement about tomorrow's weather, but these cues will vary in their relationship to the criterion (how sunny it will actually be tomorrow) and also vary in their relative importance to the individual (who may give more weight to 'current clear skies' than 'yesterday's weather').

The multiple-cue judgement approach relies on statistical analyses (Stewart, 1988) to describe the judgement processes involved in making specific judgements. As explained by Goldberg (1968), the multiple-cue approach to judgement represents an attempt to answer this question: "What model allows one to use the same data available to the judge and combine these data so as to simulate most accurately the judgement he actually makes" (p. 485). Typically, linear, additive regression models are used (by researchers) to produce and represent a profile of cues and judgement data, referred to as a judgement 'policy'. The nature of judgements is often investigated by presenting information (potential cues) to an individual participant (a 'judge') who makes a judgement. The judgement is typically a rating (e.g., a participant doctor may be asked 'from 1-10, how likely is this patient to have condition X?'). Repeated ratings are collected from the same judge (e.g. the doctor is asked '..and what about this patient?'). Subsequently, judgement estimates are collected and used for statistical analyses. The information available to the judge (i.e., each patient's information) is coded and also used for statistical analyses. This might include variables such as age, weight, the severity of reported symptoms and so on.

Correlation and linear regression is then used to calculate the weights that correspond to each of the cues' contribution to the judgements made by the individual. The regression of judgements on cue values produces a judgment ‘cue-weight profile' or 'policy' that provides an indication of the cue utilisation of individuals, or the relative importance of particular cues to the individual (i.e., specific patient symptoms that the doctor perceived as most important). Linear, additive models fit multiple-cue judgment data generally quite well (Hastie & Dawes, 2010) and according to Karlsson, Juslin and Olsson (2004), this is because it makes sense that individuals sequentially weigh the pros and cons of different aspects of a judgement. For example, in a decision to purchase a second-hand car, positive qualities (i.e., low mileage) *add* to and negative qualities (i.e., previous wear and tear) *subtract* from one's overall opinion.

Multiple-cue methodology has been used to describe judgements in a variety of domains including weather forecasting (Stewart, Roebber, & Bosart, 1997) medicine and clinical decision-making (Harries & Harries, 2001; Smith, Gilhooly & Walker, 2003; Wigton, 1988; 1996) and educational decision-making (Cooksey, 1988; Heald, 1991). Over the last few decades, extensions and modifications to multiple-cue methodology have enabled a range of judgement data to be represented, such as those described by non-linear relationships and binary judgements (see Goldstein, 2004).

Aside from its theoretical contribution in describing how cues can be weighted and combined in human judgements, the approach has had some utility in promoting human learning. If the criterion is known (i.e., a patient's actual disease), then the feedback of cue validities to research participants can be used to promote learning and improve judgement (Doherty & Balzer, 1988; Balzer, Doherty, & O'Connor, 1989; Gattie & Bisantz, 2006; Lagnado, Newell, Kahan, & Shanks, 2006; Plessner, Schwizer, Brand, & O'Hare, 2009). For example, a doctor participant can be informed of the patient symptoms (cues) on which he/she placed most importance, and what cues (of those available) *should* have been given priority in the diagnostic judgement.

Multiple-cue judgement research has revealed that generally, people tend to rely on between three to five cues to make judgements (Brehmer, 1994; Hastie & Dawes, 2010;

Stewart, 1988), and that individuals often lack insight into the relative importance they attach to cues in their own judgement policies (Einhorn & Hogarth, 1981; Wigton, 1996). For example, in multiple cue tasks, judges can be far from accurate in estimating their own cue weights (Brehmer & Brehmer, 1988) and may be unable to consciously identify the cue that was given the most importance (Lagnado, Newell, Kahan & Shanks, 2006; Smith, Brody & Wigton, 1986).

The multiple cue judgement approach, however, has also faced criticism. While it provides a descriptive account of the judgement by the weighting and combining of cues, it does not explain how the brain might search and retrieve cue information (Dhami & Harries; 2001; Gigerenzer & Kurz, 2001). In addition, the multiple cue judgement process has faced challenges in capturing the judgement policies of experts (e.g., Doherty & Kurz, 1996). The inability to describe expert judgements has been attributed to the inability of experts themselves to often report what it is (what cues or experiences) they are relying on, when making judgements (e.g., Evans, Clibbens, Cattani, Harris, & Dennis, 2003; Klein, 1993; 1998). The multiple-cue approach has also been accused of presenting a decision-making model, similar to expected utility (Fishburn, 1982; 1988), that relies upon explicit, computational processes which does not account for the limited cognitive processing capacity of individuals (e.g., Kahneman, 1973; Miller, 1956).

An important limitation of the multiple-cue approach concerns individual differences. The inconsistencies evident in the profile of cues and judgement between individuals (see Brehmer 1994; Cooksey, 1996; Hammond & Stewart, 2001), has been referred to as a "plague" on multiple-cue judgement research (Karlsson, Juslin, & Olsson, 2004, p. 648). The specific cues upon which individuals rely, varies from person to person and while one individual may rely on only a few cues, another may rely on a much greater number. The number of cues upon which individuals rely (according to multiple-cue regression and correlation calculations), is also, often fewer than the number that participants report using (Dhami & Harries, 2001; Evans, Clibbens, Cattani, Harris, & Dennis, 2003; Gluck, Shohamy, & Myers, 2002). This suggests that there are both individual differences in the utilisation of cues, and that the utilisation of cues may be largely nonconscious.

One of the reasons why multiple cue theory does not adequately characterise the cue utilisation of experts, is due to the automatic processes associated with cue utilisation. The rapid, automatic or implicitly triggered decision-making of experts (Anderson, 1982; 1993; Dreyfus & Dreyfus, 1986; Goldstein & Gigerenzer, 1996; Klein, 1993; 1998) suggests that experts employ automatic processing (or System 1 processing: Evans, 2008) to a greater degree than novices. This form of processing is less impacted by cognitive load (Evans, 2008).

Individual differences present a challenge to the aggregation of data in multiple-cue methodology. In general terms, the aggregation of data enables researchers to draw meaningful generalisations or inferences from their findings (Epstein, 1980; Horowitz, 1969). For example, quantitative research uses statistical methods that abstract from particular instances to infer general descriptions and trends that can then be replicated by other researchers (King, Keohane & Verba, 1994). However, due to their different life experiences, people have different degrees of importance associated with different stimuli (Feldman, 1995; Walker & Catrambone, 1993). In the context of multiple-cue research, this means that a focus on cue-content (*what* is being 'looked at') will give rise to discrepant, and often meaningless aggregated data. An alternative means of aggregating cue-related data and investigating the use of cues, concerns the examination of behavioural patterns of information acquisition from individuals (Loveday, Wiggins, Harris, O'Hare & Smith, 2013; Morrison, Wiggins, Bond, & Tyler, 2009). Experts and novices show specific patterns of behavioural phenomena, the subject of which has come to dominate much of the existing expertise research (e.g., Chi, Feltovich & Glaser, 1981; Durso et al., 1995; Sheridan & Reingold, 2014). Concomitantly, expertise and skill acquisition research has largely shifted focus from 'what' feature-cue is important, to 'how' cues are processed and responded to.

Behavioural patterns of information acquisition

Cue utilisation (Wiggins, 2012; Newell & Simon, 1972) has the distinguishing feature of focusing on the *way* that humans acquire and respond to information (their pattern of responses to features), rather than focusing on the specific cues or features themselves. For example, a batsman may move into position to return a ball toss, and may do so by the recognition that a particular arm movement (of the pitcher) is associated with a particular landing location of the ball. Another batsman, just as skilled, may make the same prediction based on a different feature (i.e., the position of the ball as it leaves the pitcher's hand). They both, however, are relying on feature-event associations that enable them to respond in an adaptive, and predictive manner.

In fast-ball sports, such as baseball and cricket, the flight time for a ball (or pitch) delivered at 145 km/h is approximately 500 milliseconds, while the time it takes a human to visually detect and then respond (in movement) to this information is approximately 700 milliseconds (Gray, 2009; Ripoll, 1994). As there is insufficient time for a batsperson to rely on ball flight information (e.g., Bahill & LaRitz, 1984; Gibson & Adams, 1989), the batter must extract *early* visual information from the pitcher's (or bowler's) body movements to successfully anticipate the ball's trajectory and strike the ball (Müller & Abernethy, 2012; Moore & Müller, 2014).

According to Müller and Abernethy's (2012) model of expert visual anticipation in striking sports, multiple sources of visual-perceptual information, including opponent body movement patterns and game features, are used for preparing and performing action-responses. For example, the wrist angle of the bowling arm in cricket (e.g., Müller, Abernethy & Farrow, 2006) and the location of the ball just prior to racket contact in a tennis serve (e.g., Jackson &

Mogan, 2007) are cue features that arise from the opponent’s movement patterns. Temporally placed features of a game itself can also provide players with important information. For example, the pitch count (number of pitches thrown by a pitcher) or the number of batters-on-base in baseball, provide cues as to the likely next type of pitch (Gray, 2002).

Over the last several decades, a range of methodologies have been employed for capturing behavioural patterns in response to specific visual information, including temporal or spatial occlusion, point-light displays and eye tracking analysis. With temporal and spatial occlusion (Abernethy, 1990; Scholl & Pylyshyn, 1999), various visual portions within a video or image (i.e., of a tennis serve) are occluded (e.g., the server's hand is hidden), viewers are given a task (for example, to predict ball landing locations) and their responses or behaviours are assessed to determine *what* sources of information are necessary and *when* this information is required (extracted).

Point-light displays (Johansson, 1973; Shim, Carlton, Chow & Chae, 2005) typically consist of twelve small lights attached to the joints of an otherwise invisible human body (or simulated human body). The visible lights provide information about the joint positions while the connections between them are absent, which limits information about the body's structure. Point-light displays can be used to investigate and test visual perception of biological motion or purely kinematic movement patterns. Eye tracking, which relies on a device to measure and record ocular behaviours (eye positions and movement), is another method used to investigate how individuals identify, acquire and respond to environmental information. Fixations, saccades, pupil dilation, and scan paths are used to investigate visual search characteristics such as fixation duration, number of fixations, visual search paths and quiet eye (Hoffman & Subramaniam, 1995; Mann, Williams, Ward & Janelle, 2007; Singer, Cauraugh, Chen, Steinberg, & Frehlich, 1996).

Tai, Loehr and Brigham (2006) examined the eye-gaze behaviours of secondary science teachers to examine whether gaze patterns differentiated the teachers' level of specialised expertise. The teachers were given a range of biology, chemistry and physics multiple-choice exam problems, and each test item consisted of a question accompanied by a graph, illustration or table. The teachers had varying degrees of training in specific science domains (i.e., some had majored in physics rather than chemistry) and, on this basis they were classified as either non-expert or expert within specific problem-solving topic areas. The results indicated that, while test scores and response latencies were generally indicative of expertise (for the most part, chemistry majors had higher chemistry test scores and completed chemistry items faster), eye gaze behavioural patterns appeared to clearly differentiate levels of expertise. Fewer fixations and saccades were associated with an individual's expertise, suggesting that when 'expert' science teachers solve problems within their specialty, they attend to fewer visual elements, and do so for a shorter period of time. Therefore, the results suggest that responses to cue-features (cue utilisation) may provide an insight into elements of performance beyond accuracy-based, single-test measures, and ultimately may be more indicative of levels of skill acquisition.

Assessing cue utilisation

In the context of expertise research, an example of the utility of focusing on *patterns of information acquisition* (or behavioural responses to cues), rather than the cues themselves, is demonstrated in assessment and diagnostic tools such as EXPERTise (Loveday, Wiggins, Harris, O’Hare, & Smith, 2013; Wiggins et al., 2014) and the Cochran-Weiss-Shanteau (CWS) index of expertise (Weiss & Shanteau, 2003). These tools are designed to differentiate operator expertise performance levels on the basis of decision-making *behaviour* in response to cues, rather than successful judgement outcomes or cue content. For example, the CWS protocol exposes operators to a range of stimuli (some or all of which is repeated) and operators are required to provide judgement ratings. They may be asked for example, to provide ratings of the likelihood that various patients suffer from heart disease. An index of expertise is calculated based on the ratio of discrimination (the degree to which ratings vary for different patients) to inconsistency (the degree to which ratings vary for the same patients). Therefore, the CWS index of expertise is equal to one's *discrimination score* divided by their *inconsistency score.* Typically, experts would be expected to have high discrimination and low inconsistency in their evaluations. For example, an operator with a relatively high discrimination score of 220, and a *low* inconsistency score of 5, would have an expertise index of 44. If a second operator with the same discrimination score (220) had a *high* inconsistency score, of perhaps 180, this would result in an expertise index of only 1.2.

Consistent with the CWS, EXPERTise (Versions 1.0 and 2.0: Wiggins, Harris, Loveday, & O'Hare, 2010; Wiggins, Loveday, & Auton, 2015) is an assessment tool that examines the responses of operators across a range of situational judgement tasks. The series of tasks within EXPERTise were specifically designed so that task stimuli could be customised and adapted to reflect the stimuli used in different operational domains. For example, EXPERTise tasks adapted to pediatric diagnosis (Loveday, Wiggins, et al., 2014), expose paediatricians to a range of patient symptoms and images of patient bedside monitors, while in the driving adapted version (Wiggins, Brouwers et al., 2014), the same EXPERTise tasks incorporate images of roads and driving-related hazards. Assessment stimuli are sampled from the specific operational environment of individuals to ensure that the assessment captures behavioural responses representative of those made in one's operational environment.

Amongst other response behaviours, EXPERTise uses an operator's response time and tendency to judiciously identify, select and rate features (regardless of the cue-related feature itself), to delineate the operator's cue-based performance across tasks. Clustered cue performance scores can reflect distinct levels of domain-related performance, such as novice, competent and expert (Loveday, Wiggins, Searle, Festa, & Schell, 2013; Loveday, Wiggins, Harris, O’Hare, & Smith, 2013). For both the CWS and EXPERTise assessment tools, evaluated performance levels will be relative to those captured from other operators in the same domain of practice. Norm-referencing is a critical component of these tools, as their utility relies upon capturing the variation within and between individual operators in judgement ratings, rather than absolute 'correctness' in decisions or feature ratings.

Cognitive interviews and critical incident techniques with subject matter experts (selected on the basis of peer reference and position for example) can provide information about available features (irrespective of his/her utilisation of them), event timing and sequencing, which can assist in developing domain-specific stimuli for tasks within EXPERTise version 1.0 (Loveday, Wiggins, Searle, Festa, & Schell, 2013).

Cue acquisition

The view that individual behavioural-response patterns can be used to infer cue utilisation, gives rise to a question as to whether there are individual differences in the initial formation of cues within memory. The formation of cues is referred to as *cue acquisition* (Perry & Wiggins, 2008), which is described as the construction of feature-event relationships. If individual differences exist in the propensity to develop associations in memory quickly, then these differences may be related to performance rates in specific learning tasks. In other words, one's capacity for cue acquisition may facilitate performance in novel skill acquisition tasks. In a recent study, Wiggins, Brouwers, Davies, and Loveday (2014) investigated whether the capacity to acquire and utilise cues is associated with skill acquisition in simulated aircraft and Unmanned Aerial Vehicle (UAV) landing tasks.

Participants in these studies were motor vehicle drivers who undertook a battery of situational judgement tasks (EXPERTise driving battery) which provided a composite assessment of cue-utilisation in the context of motor vehicle hazard detection and way-finding.

Subsequently, fifty-one of these individuals who had no piloting or flight simulator experience undertook a series of flight landing trials where they attempted to land a light aircraft as close as possible to a ground target. Similarly, fifty participants with no previous experience in remote control aircraft operations, attempted to land a UAV in a series of trials. The results of these two studies indicated that, controlling for driving experience (in months), higher levels of cue utilisation were associated with increased accuracy in aircraft landing (as measured by distance from target on the fourth trial), and with the proportion of successful UAV landing trials. In both studies, driving experience was treated as a covariate to ensure that the association between cue utilisation (in driving) and skill acquisition (in the flight and UAV landing tasks) was not explained by driving exposure. By doing so, the findings suggest that there may be a capacity for cue acquisition that generalises across similar (or even different) domains, and that one's capacity for cue acquisition may facilitate performance in novel skill acquisition tasks.

It is noteworthy that, in Wiggins et al. (2014), cue utilisation performance was assessed within a domain (car driving) different to that of the novel task (piloting a plane and operating a UAV), suggesting the possibility of a common underlying mechanism for cue utilisation across different domains of practice. This is consistent with the view that experience alone does not adequately account for performance expertise (Campitelli & Gobet, 2011). For example, Hambrick et al. (2014) reviewed a range of previous expertise studies in domains such as chess and piano and noted that an estimated 30% of the variability in the achievement of expert performance was explained by practice or experience. Therefore, while domain-specific experience is necessary, it is not sufficient, to explain variation in the attainment of expertise.

While cue utilisation is described as an associational or pattern recognition process (Banning, 2008; Juslin, 2000; Williams, Ward & Smeeton, 2004), the cognitive and neural mechanisms that underlie cue utilisation remain unclear. Given that cue utilisation encompasses the capacity to identify key features relevant to a task or objective, create causal relationships between these key features and events, retain this information in long-term memory, and then apply this to different environments and contexts (Oaksford, 2000; Wiggins 2006; Wiggins & Bollwerk, 2006), it has been argued that pattern recognition presents a likely mechanism that underpins cue utilisation (Smeeton et al., 2004).

Pattern recognition can be conceptualised as a rudimentary feature-event association mechanism consistent with the view that humans seek to make sense of their world and predict events, while operating with limited cognitive resources. Further, differences in the capacity of individuals to form associations quickly, may explain differences in the rates at which individuals move from novice to expert performers within a given field of practice. If pattern recognition underlies cue utilisation across similar (or even different) operational domains of practice, and explains individual differences in rates of cue acquisition, it is unclear whether pattern recognition would be conceptualised as a trait. If cues are acquired through the process of feature-event associations, and if the capacity for association is a trait, then the acquisition of these associations in one domain should predict the acquisition of associations in a related domain.

Cue acquisition and domain specificity

The proposition that cue acquisition may generalise across different domains of practice and facilitate the acquisition of skills is one that may appear contradictory to domain-specific principles of expertise. By definition, experts are individuals who exhibit consistent, superior performance (Ericsson, 2009; Vicente & Wang, 1998; Voss & Post, 1988) and do so typically within a specialised domain of practice (Ericsson & Lehmann, 1996; Shanteau, 1992; Weiss & Shanteau, 2003) such as brain surgery or spin bowling. If feature-event associations are acquired through experience, and experts have highly nuanced associations organised into mental models that enable them to predict and rapidly respond to situations (e.g., Chase &

Simon, 1973b; Gobet & Simon, 1996b; Schmidt & Boshuizen, 1993; Schmidt, Norman & Boshuizen, 1990), then it logically follows that the cues themselves cannot be separated from the domain of practice from which they were derived. Further, it makes little sense that an expert brain surgeon or chess player would be expected to have the expert spin-bowling skills of a cricketer. However, while the specific cues acquired by individuals will vary across different specialist domains, the mechanisms that underpin and enable feature-event associations to be acquired, may operate across different domains.

Cue utilisation by experts has been evident across a wide range of domains including sport (e.g., Abernethy, 1990; Savelsbergh et al., 2002) chess (e.g., Charness et al., 2001), meteorology (e.g., Lowe, 1999), driving (Underwood, Chapman, Brocklehurst, Underwood, & Crundall, 2003), medicine (e.g., Lesgold et al., 1988) and piloting (Wiggins & O'Hare, 1995) which, in itself, suggests that cue acquisition may be related to (or may facilitate) the perceptual skills necessary to achieve expert performance across a range of practice domains. This point is illustrated by Williams, Ward, Smeeton, and Allen (2004) who examined the effects of cue-based training with or without physical practice, on improved anticipation skills in tennis. After camera-recording a series of return-serves on a tennis court to establish individual performance baselines, novice tennis players were grouped into a 'perception-only', a 'perception-action', and a control-group training condition.

The perception-only group were given a training session with a tennis coach who highlighted the early postural cues of opponents' serves. Players in this group were then given a twenty-minute practice session, but instead of physically participating (actually returning serves), were asked to verbally predict the landing location of each ball (e.g., by saying 'right' or 'left'). The perception-action group were given the same cue-based training (that highlighted early postural cues of opponent serves) but within their 20-minute practice session, were required to physically attempt to return tennis serves made by the training coach. In the control condition, players were given technical instructions regarding how to return tennis serves, but without cue-based (anticipatory) training or a practice session. Following training, all players were recorded returning a series of tennis serves delivered by two county-level tennis players.

The results of the study indicated that, while cue-based training resulted in significantly faster response-initiation times (the time between the ball leaving the server's hand and the first step to return the serve) compared to the control group, there was no significant difference in response latency between the perception-only and perception-action group. This suggests that, irrespective of physical movements (self-action) in training, the formation of cognitive associations between 'external' or visual-perceptual features (e.g., body postures of the server) and outcomes (ball landing locations) enabled predictive, rapid responses by trainees in this study. Early, anticipatory behaviours by expert sports players (denoted as 'advanced perceptual-cognitive skill' and 'cue utilization': Jackson, Warren & Abernethy, 2006; Mann et al., 2007) have been evident in a range of other fast ball sports (Abernethy, 1987; Starkes, Edwards, Dissanayake, & Dunne, 1995), and suggest that expert players possess the ability to anticipate an opponent's actions based on partial sources of information (e.g., Aglioti, Cesari, Romani, & Urgesi, 2008; Smeeton, Ward & Williams, 2004; Williams et al., 1999; Williams, 2000). Together, this evidence suggests that the acquisition of cues may facilitate performance within any domain of practice or task that relies upon anticipatory decisions and the formation of rapid responses.

Overview of research questions

The aim of the present programme of research was to investigate the nature of cue utilisation and examine its impact on performance in the early stages of learning a new task/skill. The following portions of this dissertation include four studies, each of which was designed to investigate a specific research question. Given that cue acquisition appears integral to skill acquisition, and that individuals differ in their rates of learning and progression toward expertise, a key question is whether there are individual differences in the propensity to acquire cues and form feature-event associations. A further two questions pertain to the nature of cue utilisation itself: (a) *Is a greater propensity for cue utilisation associated with a reduction in cognitive load in task-related contexts*?, and (b) *is cue utilisation associated with pattern recognition processes*? The four studies conducted within the present thesis were designed to address these questions. As summarised in Figure 3, Study 1 was designed to examine whether differences in cue utilisation were associated with differences in performance during a novel, simulated rail control task. Study 2 was designed to test whether these performance differences reflected a reduction in cognitive load. In Study 3, a pattern of train movements in the rail control task was used to ascertain whether higher cue utilisation reflected a *deliberate* strategy of least cognitive effort or whether the reduction in cognitive load was an (unintended) *outcome* of cue utilisation. Finally, in Study 4, miscues were used to examine the relationship between pattern recognition and cue utilisation.

Study 1: PERFORMANCE

- **Research question:** Are differences in cue utilisation associated with differences in performance during a novel task?
- **How was this tested?** Participants undertook an assessment of cue utilisation and their performance was recorded in a novel, train control task

Study 2: COGNITIVE LOAD

- **Research Question:** Do the performance differences (evident in the novel, learning task) reflect a reduction in cognitive load?
- **How was this tested?** The workload demands were manipulated: A secondary task was included during one half of the train control task

Study 3: PATTERN RECOGNITION

- **Research Question:** Does higher cue utilisation reflect a *deliberate* strategy of least cognitive effort or is it an (unintended) *outcome* of cue utilisation?
- **How was this tested?** To enable participants to anticipate trains that required a diversion & provide an opportunity to reduce cognitive load, a 'hidden' pattern of rail movements was programmed into the rail control task

Study 4: MISCUES

- **Research Question:** Does pattern recognition moderate the relationship between cue utilisation and performance in a novel, train control task?
- **How was this tested?** The pattern of train movements in the train control task was programmed to abruptly change (a period of exposure was followed by a 'miscue')

Figure 3. A summary of the research questions in the present programme of research

STUDY 1 & 2

Publication history

Studies 1 and 2 were published as a single paper in the *Frontiers in Psychology* journal in 2016. This paper was entitled "Cue Utilisation and Cognitive Load in Novel Task Performance". Frontiers in Psychology has an impact factor of 2.463. The author of the present dissertation wrote approximately 80% of this paper.

Cue Utilisation and Cognitive Load in Novel Task Performance

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Sue Brouwers, Macquarie University, Australia
sue.brouwers@mq.edu.au

Mark Wiggins, Macquarie University, Australia
mark.wiggins@mq.edu.au

William Helton, University of Canterbury, New Zealand
deak.helton@canterbury.ac.nz

David O'Hare, University of Otago, New Zealand
ohare@psy.otago.ac.nz

Barbara Griffin, Macquarie University, Australia
barbara.griffin@mq.edu.au

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Abstract

This study was designed to examine whether differences in cue utilisation were associated with differences in performance during a novel, simulated rail control task, and whether these differences reflected a reduction in cognitive load. Two experiments were conducted, the first of which involved the completion of a 20-min rail control simulation that required participants to re-route trains that periodically required a diversion. Participants with a higher level of cue utilisation recorded a consistently greater response latency, consistent with a strategy that maintained accuracy, but reduced the demands on cognitive resources. In the second experiment, participants completed the rail task, during which a concurrent, secondary task was introduced. The results revealed an interaction, whereby participants with lower levels of cue utilisation recorded an increase in response latency that exceeded the response latency recorded for participants with higher levels of cue utilisation. The relative consistency of response latencies for participants with higher levels of cue utilisation, across all blocks, despite the imposition of a secondary task, suggested that those participants with higher levels of cue utilisation had adopted a strategy that was effectively minimising the impact of additional sources of cognitive load on their performance.

Keywords: Cue Utilisation, Cognitive Resources, Cognitive Load, Workload

Introduction

Skilled performance across a range of domains of practice is characterised by accurate and rapid responses, often in dynamic and complex situations (Beilock, Bertenthal, McCoy, & Carr, 2004; Ericsson & Lehmann, 1996; Salthouse, 1991)[4]. This is attributed to specialised routines or associations that have been established through repeated application across a variety of settings (Klein, 2011). These highly specialised associations, representative of situation-specific relationships between environmental features and events or objects, are often referred to as cues (Brunswik, 1955; Klein, Calderwood & Clinton-Cirocco, 1986; Wiggins, 2014), and their activation and retrieval from long-term memory has the advantage of imposing relatively fewer demands on working memory resources (Chung & Byrne, 2008; Evans, 2008; Norman & Shallice, 1986).

Differences in the rate at which individuals acquire skills have been attributed to various factors, including cognitive style (Cegarra & Hoc, 2006), motivation and self-regulation (Zimmerman, 2002; 2008), cognitive ability and intelligence (Ackerman, 1986; 2007; Ackerman & Beier, 2007), personality (Simonton, 2008; Singer & Janelle, 1999), and a range of general intrinsic abilities (Simonton, 2007; 2008; Thompson, Cowan, & Frieman, 1993). However, in some environments, the acquisition of skilled performance is also characterised by the capacity to rapidly and accurately extract and utilise meaningful information from features in the environment (Abernethy, 1987;1990; Bellenkes, Wickens, & Kramer, 1997), thereby enabling the discrimination of relevant from less relevant cues (Weiss & Shanteau, 2003).

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[4] References for this section can be found in the Reference List for Studies 1 & 2

Evidence to support the utilisation of cues in skill acquisition can be drawn from investigations involving fast ball sports, in which skilled performers anticipate the trajectory of a target by restricting their attention to a limited number of highly predictive features (Müller & Abernethy, 2012; Moore & Müller, 2014). These features include the wrist angle of the bowling arm in cricket (e.g., Müller, Abernethy, & Farrow, 2006) and the location of the ball just prior to contact with the racket following a tennis serve (e.g., Jackson & Mogan, 2007).

The rapid identification of a limited number of predictive features has a range of benefits for skill acquisition, including a reduction in the demands on cognitive load and an improvement in the rate of skill acquisition. For example, Perry, Wiggins, Childs, and Fogarty (2013) were able to demonstrate improvements in performance amongst novice fire fighters by restricting their information acquisition only to those features that were sourced by skilled fire commanders. Although the discrimination between relevant and less relevant features was contrived in this case, it suggests that a general capability to identify a limited number of highly predictive features may explain differences in rates of skill acquisition during unimpeded learning tasks.

Wiggins, Brouwers, Davies, & Loveday (2014) demonstrated a relationship between a general capacity for cue utilisation and skill acquisition in experiments involving learning to land an aircraft and learning to operate a line-of-sight Unmanned Aerial Vehicle (UAV). Using the situation judgement test EXPERTise (1.0) (Wiggins, Harris, Loveday, & O'Hare, 2010) to provide a composite assessment of cue-utilisation, higher levels of cue utilisation were associated with improved accuracy in landing the aircraft following four trials, and with fewer trials to reach criterion in learning to take-off and land a UAV. These improvements in performance occurred in the absence of any formal instruction. However, it was unclear whether these improvements were a consequence of participants' capacity to quickly establish feature-event relationships in the form of cues, and/or whether this capacity reduced the demands on cognitive load, thereby enabling learners to reinforce, revise, or refine the relationships that had been acquired during the initial stages of skill acquisition. The aim of the present study was to investigate, in the context of a low workload, novel task, whether differences in a general capacity for cue utilisation are evident in performance, and whether these differences reflect differences in the management of cognitive load.

Where there are multiple courses of action to achieve an outcome, humans will normally select strategies that are associated with the least cognitive effort (Kool, McGuire, Rosen, & Botvinick, 2010). This is referred to as Hull's (1943) law of less work, whereby mental effort is regarded as an aversive stimulus. Therefore, in responding to a novel task, the capacity to identify quickly the strategy of least cognitive effort, while maintaining performance, represents an adaptive approach that conserves cognitive resources.

When exposed to a novel task, participants with a relatively greater capacity for cue utilisation would normally be expected to quickly identify key features associated with the performance of a task which, in turn, reduces cognitive load, thereby providing an increased capacity for skill acquisition (Wiggins, 2015). The present study comprised two experiments in the context of rail control, in which participants were asked to respond to misrouted trains. Importantly, however, participants had seven seconds in which to formulate an assessment, and this represented a key feature that, when identified, would enable participants to minimise the cognitive load imposed by the task.

Consistent with actual rail control, the experimental task was semi-automated, so that it constituted a low workload environment that demanded sustained attention to identify only those trains that required an intervention. Drawing on Resource Theory (Helton & Warm, 2008; Helton et al., 2005), sustained attention to a task is presumed to impose a cognitive demand on information processing, leading to vigilance decrements that include an increase in errors and/or response latency across an extended exposure. Therefore, there was an implicit incentive for participants to adopt a strategy that would reduce cognitive load. In the present study, Experiment 1 examined the relationship between cue utilisation and performance on a simulated rail control task over a 20-min period of watch. Experiment 2 involved the imposition of a concurrent secondary task that was intended to, more explicitly, increase cognitive load.

Experiment 1

Experiment 1 was designed to examine the relationship between a composite measure of cue utilisation, and performance on a simulated rail-monitoring task that required participants to correctly reroute trains that were periodically misrouted. Trains travelled at a consistent and relatively slow rate, and only trains on incorrect routes required a response.

The simulated rail task was designed to incorporate specific elements of ecological validity, including the requirement to monitor multiple rail lines simultaneously, the requirement to intervene periodically, and the requirement to intervene within a specified period of time (Farrington-Darby, Wilson, Norris, & Clarke, 2006; Ho, Mao, Yuan, Liu, & Fung, 2002; Lenior, 1993; Neerincx & Greef, 1998). Aside from the adjustment of train routes, which is a fundamental task performed by real-world rail controllers (Neerincx & Greef, 1998), the movement of trains to and from different directions was also captured in the simulation interface. To account for the demands of experimental control, higher level features of real railway control systems such as the connection of track elements to a network (Berkenkötter & Hannemann, 2006) and the determination/ communication of critical incidents (Farrington-Darby et al., 2006) were not incorporated in the simulation task. Given the requirement for sustained attention, the rail-monitoring task continued over a 20-min period of watch. A 20-min period of watch was selected based on previous research which suggests that observable decrements in vigilance occur within this period of time (Helton et al., 2005; Small, Wiggins, & Loveday, 2014; Rose, Murphy, Byard, & Nikzad, 2002; Temple et al., 2000).

Based on the proposition that a propensity for cue acquisition enables the rapid identification of feature-event relationships, the performance of those participants with relatively higher levels of cue acquisition would, over a consistent period of exposure to a novel task, be impacted to a relatively lesser extent by the imposition of cognitive load. Since sustained attention is associated with increases in cognitive load (Helton & Warm, 2008; Helton et al., 2005), it was anticipated that, while all participants would experience a vigilance decrement during the latter part of the vigil, participants with higher levels of cue utilisation would experience the least increases in response latency coincident with the increase in cognitive load. Specifically, it was hypothesised that: (a) a main effect would be evident for response latency, in which all participants would experience an increase in response latency during the latter stages of the vigil, and (b) that an interaction would be evident, wherein participants with lower levels of cue utilisation would record a greater increase in mean response latency between the first and last 5-min blocks for accurate responses to misrouted trains, in comparison to participants with higher levels of cue utilisation.

Method

Participants

A total of 58 first and second year university students (41 females and 17 males) were recruited for the study, each of whom received course credit in return for their participation. Participants ranged in age from 18 to 22 years (*M* = 19.26, *SD* = 1.35). The inclusion criteria comprised existing motor vehicle drivers who had not been exposed to train control operations, and who were aged between 18 and 22 years. Utilising a cohort of 18 to 22 year old drivers enabled comparative assessments of cue utilisation, controlling to a limited extent, exposure to driving.

Instruments

Participants were asked to indicate their age, gender, months of driving experience, daily driving frequency, and their experience in rail control. Cue utilisation was assessed using the Expert Skills Evaluation (EXPERTise 1.0) (Wiggins, Harris, Loveday, & O'Hare, 2010) situation judgement test.

EXPERTise 1.0

EXPERTise 1.0 consists of experimental tasks that have been individually and collectively associated with differences in performance at an operational level (Loveday, Wiggins, Searle, Festa, & Schell, 2013; Loveday, Wiggins, Harris, O'Hare, & Smith, 2013; Loveday, Wiggins, Festa, Schell, & Twigg, 2013; Loveday, Wiggins, & Searle, 2014). Consistent with the notion that there are individual differences in populations for cue utilisation, the driving version of EXPERTise was selected, as it assesses the acquisition of cues in a specific cohort and at a specific point in time, and it is a context with which participants would be familiar (Wiggins, Brouwers, Davies, & Loveday, 2014). Tasks in the EXPERTise driving battery include a paired association task (also referred to as the Feature Association Task), a feature discrimination task, a feature identification task and an information acquisition task (also referred to as the Feature Prioritisation Task).

In the *Paired Association* task, participants are presented with two feature-event/object terms. Over a total of 30 trials, each two terms are displayed, adjacent to one another for 1500 milliseconds. After each pair is displayed, participants indicate the extent to which the two terms are related on a 6-point Likert scale (from 1 = "Extremely unrelated" to 6 = "Extremely related"). Examples include the related terms 'heavy traffic' (feature) and 'short-cut' (event) and relatively less related terms 'traffic-light' (feature) with 'free-way' (object). Higher levels of cue utilisation are associated with a greater variance in the perceived relatedness of terms (Ackerman & Rathburn, 1984; Morrison, Wiggins, Bond, & Tyler, 2013; Schvaneveldt, Beringer, & Lamonica, 2001).

In the *Feature Discrimination* task, participants are presented with a short, written description of a single scenario (i.e., "You are lost in an unfamiliar area. You find yourself in a quiet suburban area, and must find your way to a large shopping centre located on a main road. You can see heavier traffic on a main road ahead and high-rise buildings are in the distance..."). Participants are then asked to make a decision based on their typical response in this scenario (i.e., drive in the direction of heavier traffic, or drive toward high-rise housing, and so on). Following their decision, participants are presented with a list of fourteen features and, using a 10-point Likert scale (from 1 = "Not important at all" to 10 = "Extremely important"), are asked to rate these features based on their perceived relevance to his/her decision. Higher levels of cue utilisation are associated with greater variances within the feature-relevance ratings (Pauley, O'Hare, & Wiggins, 2009; Weiss & Shanteau, 2003).

The *Feature Identification* task involves the extraction of key information from an array or scene. Participants are presented with a familiar driving scene (i.e., an image of a road as viewed from the driver's seat of a car) and are directed to identify a road hazard as quickly as possible (i.e., a ball positioned in the road ahead). The position of the ball changes over trials. A lower mean reaction time is associated with greater levels of cue utilisation (Loveday, Wiggins, & Searle, 2014; Schriver, Morrow, Wickens, & Talleur, 2008; Schyns, 1998).

Finally, the *Information Acquisition* task presents participants with a way-finding scenario that requires a choice between three different driving routes. Accompanying the scenario instructions is a drop-down menu with 24 options (feature-cues), which are category-labelled (e.g., ‘distance’, ‘weather conditions’) and upon selection, provide participants with information pertaining to the distance, tolls, road works, weather conditions, traffic congestion, speed limit and the number of lanes for each route. Participants are given one minute to select information prior to making a response. This task assesses the capacity to acquire feature cues from the environment in a prioritised and non-linear pattern (Wiggins & O’Hare, 1995;

Wiggins, Stevens, Howard, & Henley, 2002). Individuals with lower levels of cue utilisation are more likely to select information in the sequence in which it is presented (e.g., from left to right as they appear on the display screen). Higher levels of cue utilisation are associated with a relatively lower ratio of pairs of information screens accessed in the sequence in which they are presented, against the total frequency of pairs of information screens selected.

The criterion validity of EXPERTise (1.0) has been established in a number of different domains in which typologies formed on the basis of EXPERTise performance differentiated workplace-related performance (Loveday, Wiggins, Searle, Festa, & Schell, 2013; Loveday, Wiggins, Harris, O'Hare, & Smith, 2013; Loveday, Wiggins, Festa, Schell, & Twigg, 2013). The test-retest reliability (Kappa = .59, $p < .05$) has been demonstrated with power control operators at six-monthly intervals (Loveday, Wiggins, Festa, Schell, & Twigg, 2013). In the present study, restricting the age of participants (18-22 years) controlled for exposure to driving experience. This ensured that any differences in cue utilisation would be unlikely to result from differences in driving experience. Overall, participants had accumulated a mean of 39 months of driving experience (*SD* = 15.82 months).

Rail control task

A simulated train control task was used as a novel, low workload context for the present study. In this task, a computer screen depicts a simulated, simplified train control display (see Figure 1).

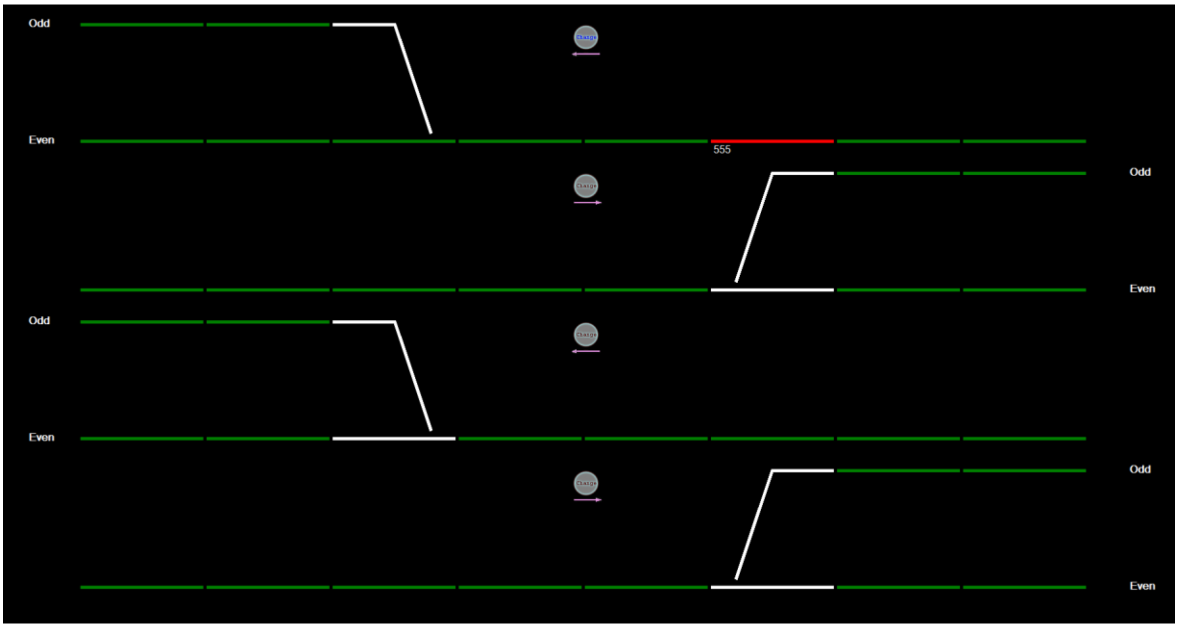

Figure 1. The simulated train-control display as viewed by participants. The four long, horizontal green lines represent railway tracks. The white portions on each track are the intersection lines, which are controlled by an interlocking switch labelled, 'Change'. This switch is depicted by a small circle icon, located above each track. If a participant selects the "Change" icon, any train travelling on the track beneath it, will be diverted onto the intersecting line.

Within the train task display, four long, horizontal green lines represent railway tracks (See Figure 1). Each track incorporates an intersection (depicted by white portions on the track), which is controlled by an interlocking switch labelled, 'Change'. This switch is depicted by a small circle icon, located above each track. If a user selects the 'Change' icon, (with a computer mouse), any train travelling on the connected track will be diverted onto the intersecting line.

A train is depicted by a red horizontal bar that appears at one end of a train line, and travels across the display. Each train has a three-digit number assigned as either odd or even (e.g., 888, 333). Each train line and its associated branch line also have an assigned label: Odd or Even. As the train appears onto the screen, a green line depicts the programmed route of the train. The participant's task is to ensure that trains run along the correct train lines (even-numbered trains run along even lines and odd-numbered trains along odd lines). Periodically, programmed routes will appear that are inconsistent with the train's number so that, for example, an even numbered train is programmed to take a route that is labelled 'odd'. To correct the programmed route of the train, participants must select the "Change" icon which will re-route the train.

Once a train appears on the computer screen, participants have seven seconds in which to decide whether or not to reroute a train. All trains travel at the same speed and trains appear within 5-30 seconds of each other. Therefore, the screen may display a static image of train lines (without any trains) for up to 30 seconds before another train appears. A total of sixty-seven trains appear on the four rail lines over the course of 20-minutes, half of which are not required to be re-routed. Data recorded from this task included response latency (in milliseconds, from the initial appearance of a train, to the selection of the "Change" icon) and the accuracy of responses (whether trains were diverted when required).

Cognitive Ability

The Raven's Standard Progressive Matrices cognitive test (SPM; Raven, Raven, & Court, 1998; Raven, Raven, & Court, 2000) was included as a measure of cognitive ability. The SPM broadly assesses general problem-solving ability or fluid intelligence by measuring the capacity to recognise and process patterns of spatial information (Kaplan & Saccuzzo, 2008; Raven, Raven, & Court, 2000). Cognitive ability encompasses constructs that include processing speed and working memory capacity (Conway, Cowan, Bunting, Therriault, & Minkoff , 2002) that can influence performance in attention-demanding tasks (Kane & Engle, 2003). In the present study, the SPM was included as a means of establishing whether cognitive ability was related to performance scores in the rail task. The SPM short version (10-min timed) was used (see Austin, 2005; Caffarra, Vezzadini, Zonato, Copelli, & Venneri, 2003; Jaeggi, Buschkuehl, Jonides, & Shah, 2011; Moutafi, Furnham, & Tsaousis, 2006). Cognitive ability scores reflected the total number of correct SPM responses.

The Group Embedded Figures Test

The Group Embedded Figures Test (GEFT: Oltman, Raskin, & Witkin, 2003; Witkin, Oltman, Raskin, & Karpe, 1971; 2002) is a perceptual test that assesses an individual's field dependence-independence. According to Witkin (1976), Field Independence -Dependence is a cognitive style that represents the extent to which an individual can overcome the influence of irrelevant background elements when attending to a task. Individuals who exhibit higher levels of field independence more easily overcome background elements in formulating judgements. The GEFT requires the test taker to identify and trace simple forms (i.e., shapes) that are embedded within more complex forms. The Embedded Figures Test has been linked to the capacity to perceive hazards, recognise faults and formulate mental representations of problems (Elander, West, & French, 1993; Leach & Morris, 1998; Vessey & Galletta, 1991). The GEFT was included in the present study to ascertain whether rail task responses were related to cognitive style. Test-retest reliability coefficients for the GEFT range from .79 to .92 over multiple time intervals of up to 3 years (Kepner & Neimark, 1984; Witkin, Oltman, Raskin, & Karpe, 2002).

Procedure

Participants were tested individually in 90-min sessions. After completing an on-line demographic questionnaire, a computer prompt directed the participants through the four EXPERTise tasks. Standardised instructions for the rail task were then provided verbally. This included the verbal instruction, “the aim of this task is to ensure that each train is on its correct track”. No information or direction was provided in relation to the speed or pace of the task (i.e., participants were not told that they had several seconds of decision-time available or that they could or should respond in either an immediate or delayed manner). After a 5-min trial to orient the participants to the task, the 20-minute experimental trial commenced. Participants then completed paper-and-pencil versions of the SPM and GEFT. Instructions for these tests were provided to participants verbally and through written directions, according to the test instruction manuals.

Results

Preliminary analysis

Rail task performance scores

Response latency for correct responses in the rail task comprised the primary dependent variable. Latencies were calculated from the initial appearance of a train to the selection of the 'change' icon where appropriate. Errors occurred when a train was re-routed from its correct path (a false alarm) or was not re-routed when required (a miss). The number of errors made by participants ranged from zero to five, with a median of one, and resulted in a floor effect, with 64% of the entire sample recording either zero or a single error during exposure to the sixty-seven trains. A Spearman's rank-ordered, non-parametric correlation between the number of errors committed in the rail task and mean response latencies was not statistically significant. The relationship between error frequency and interval, examined using a chi-square test of independence, failed to reveal any statistically significant variation in the distribution of errors across the four time intervals, χ^2 (3, 58) = 5.026, p = .17. Taken together, these results suggest that a speed-accuracy trade-off was not necessary to undertake the task successfully.

Since the task was 20-minute in duration, the mean response latencies (for correct responses) were calculated across four, 5-minute intervals, and these four variables comprised the dependent variables in subsequent analyses. Nineteen trains appeared within the first block, nine of which required re-routing. In the second block, 16 trains appeared, eight of which required re-routing. In the third block, 15 trains appeared, seven of which required re-routing, and in the final time block 17 trains appeared, of which nine required re-routing.

Cognitive ability and cognitive style

Scores on the Standard Progressive Matrices (SPM) were normally distributed and not significantly correlated with mean response latencies for any of the four blocks of trials ($-.04 \leq r \leq -.15$, $p > .05$). As GEFT (cognitive style) scores were negatively skewed, a square root transformation with reflection was applied to normalise the data. Subsequent Pearson's correlations failed to reveal any statistically significant associations between GEFT scores and mean response latencies across any of the four blocks of trials ($-.03 \leq r \leq -.22$, $p > .05$).

Cue utilisation typologies

Prior to analysis, it was necessary to identify the cue utilisation typologies that corresponded to relatively higher or lower levels of cue utilisation (Loveday, Wiggins, Harris, O'Hare, & Smith, 2013; Loveday, Wiggins, Festa, Schell, & Twigg, 2013; Wiggins, Brouwers, Davies & Loveday, 2014). Consistent with the standard approach to EXPERTise data, *z* scores were calculated for each task, with those corresponding to the Information Acquisition and Feature Identification tasks reversed so that for all four tasks, higher *z* scores represented higher levels of cue utilisation. A cluster analysis identified two groups with centroids corresponding to higher variance in the Paired Association and Feature Discrimination tasks, lower response latency in the Feature Identification task (reversed *z* score), and a lower ratio of sequential selections in the Information Acquisition task (reversed *z* score). The cluster analysis classified 34 participants in the lower cue utilisation typology and 24 participants in the higher cue utilisation typology (Table 1).

Table 1

Cluster Centroids for the EXPERTise Task Scores

	Cluster 1 (*n*=34)	Cluster 2 (*n*=24)
Paired Association	−.60	.86
Feature Discrimination	−.52	.74
Feature Identification	−.12	.17
Information Acquisition	−.40	.57

Driving experience and cue utilisation

To examine whether differences in cue utilisation resulted from differences in participants' length of driving experience, a one-way Analysis of Variance (ANOVA) was conducted using EXPERTise cluster as the independent variable, and months of driving experience as the dependent variable. The length of driving experience reported by participants in the lower cue utilisation cluster (M = 38.24, SD = 12.69) did not differ significantly from those participants with higher levels of cue utilisation (M = 39.50, SD = 19.70), $F(1, 57) = .088$, p = .77, suggesting that assessments of cue utilisation were not related to driving exposure.

Cue utilisation and rail task performance

The primary aim of the present study was to establish whether differences existed between levels of cue utilisation (cue typologies) and response latency across these four rail-control task blocks (a time block x cue typology interaction). A 2 x 4 mixed ANOVA, comprising two levels of cue utilisation (higher and lower) as a between-groups factor and four blocks of trials as a within-groups variable failed to reveal a statistically significant interaction between the variables, $F(2.62, 146.56) = 1.09$, $p = .349$, partial $\eta^2 = .019$. This suggests that the changes evident in the mean response latency over trials occurred at similar rates, irrespective of cue utilisation typology.

Despite the fact that an interaction was not evident between cue utilisation typology and blocks of trials, main effects were, nevertheless, evident for cue utilisation typology,

$F(1,56) = 20.36$, $p < .001$, $\eta^2 = .267$ and for blocks of trials, $F(2.60, 147.89) = 7.37$, $p = .001$, $\eta^2 = .114$. Inspection of the mean response latencies (Figure 2) indicated that participants with a higher level of cue utilisation recorded a *slower* mean response latency ($M = 2079.70$, $SD = 395.67$, $SE = 80.77$) across the four blocks of the rail-control task, in comparison to participants with a lower level of cue utilisation ($M = 1527.36$, $SD = 498.59$, $SE = 85.51$). Since there were no differences in the accuracy of the two groups, it suggests that participants with higher levels of cue utilisation either withdrew cognitive resources to reduce the demand on cognitive load, or alternatively, invested cognitive resources to maintain accuracy.

Post-hoc analysis of the mean response latencies for blocks of trials indicated that mean response latencies in the first block of trials ($M = 1595.51$, $SD = 558.33$, $SE = 73.31$) were significantly lower than the fourth block ($M = 1921.37$, $SD = 687.93$, $SE = 90.33$), $t(57) = -3.87$, $p < .001$. This increase in mean response latency over time, despite no changes in task requirements, is consistent with the vigilance decrement.

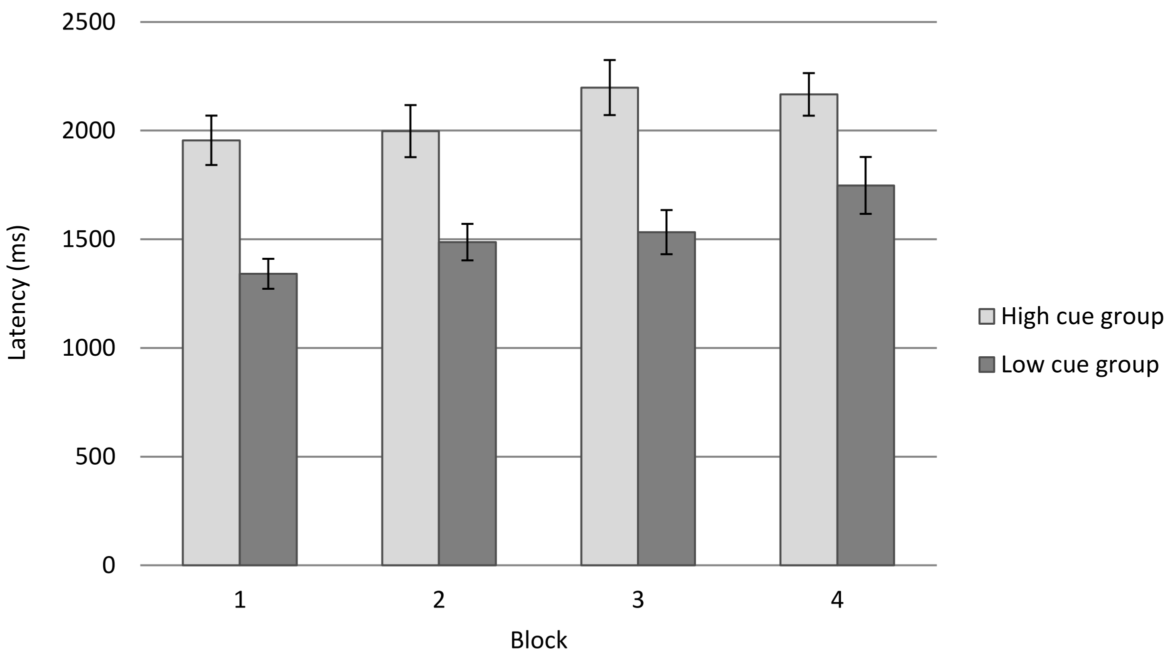

Figure 2. Rail task response latencies by cue utilisation typology and block number for Experiment 1. Error bars represent ±1 *SE*.

Discussion

This study was designed to examine whether, in response to a novel, short vigilance task, participants with a greater capacity for cue acquisition would adopt a strategy that would reduce the demands on cognitive resources. It was hypothesised that a strategy of least cognitive effort would be evident in an interaction that would emerge as the train control task progressed. On the basis of the Resource Theory explanation of the vigilance decrement, it was assumed that the increase in cognitive load that is associated with an extended period of watch would differentially affect those participants with lower levels of cue utilisation. Although a main effect was evident with progressive increases in response latency across blocks of trials, consistent with the hypothesised vigilance decrement, no statistically significant interaction occurred.

A main effect of cue utilisation was also evident in which participants with a higher level of cue utilisation showed increased response latencies in response to the diversion of trains. These mean response latencies were not associated with either cognitive ability (SPM scores) nor cognitive style (GEFT scores). However, it was unclear whether this response resulted in a reduction in cognitive load. Since there were no differences in the accuracy of responses amongst the two groups, the results suggest that participants with higher levels of cue utilisation recognised that time was available in which to initiate a response to reroute misrouted trains, and adopted a strategy of least cognitive effort.

Although higher levels of cue utilisation are normally associated with a reduction in response latency, this is not always the case. For example, in self-paced, targeting tasks such as rifle shooting and basketball (free throwing), superior shot accuracy is associated with longer quiet eye periods (the final fixation on the target prior to the initiation of movement) (Vickers, 1996; Vickers & Williams, 2007). As a result, skilled players tend to take more time to execute shots than lesser skilled players (Vickers, 2007; Williams, Singer, & Frehlich, 2002). This suggests that the advantage afforded by greater levels of cue utilisation lies in the capacity to recognise the need to adapt to different task demands. In the present study, there was no loss of performance associated with the increased response latency and it may have constituted a strategy of least cognitive effort which enabled the maintenance of performance despite the increase in cognitive demands.

There are at least two explanations for the lack of an interaction between levels of cue utilisation and blocks of trials, the first of which relates to the hypothesised reduction in cognitive load. In particular, the self-pacing of one's actions and responses within a task or job has been identified as a workload management strategy that effectively increases task control and reduces cognitive demands and anxiety (Johansson, 1981; Salvendy & Smith, 1981; Scerbo, Greenwald, & Sawin, 1993). However, it may be the case that the workload demands in the present study were insufficient to draw on the cognitive resources that would have been necessary to differentiate participants with higher or lower levels of cue utilisation.

An alternative explanation for the lack of an interaction relates to a potential investment of cognitive resources amongst participants with higher levels of cue utilisation. Specifically, it might be argued that greater attention to the task, although overcompensating for the resources necessary to maintain accuracy, resulted in the increase in response latency. Experiment 2 was designed to differentiate the two explanations through the imposition of a secondary task that explicitly increased the cognitive demands during the rail control simulation.

Experiment 2

Consistent with Experiment 1, participants in Experiment 2 completed the EXPERTise 1.0 situation judgement test and the 20-min simulated rail-control task. However, in addition to monitoring the rail display and re-routing trains as necessary, participants in Experiment 2 were asked to complete a secondary task during the final two blocks (10-min) of trials that comprised the monitoring task. This secondary task was designed to impose an explicit cognitive load, and required individuals to note the assigned number of each train (i.e., 888), together with the time at which it appeared (i.e., 2.07 PM).

Assuming that the advantage afforded by greater levels of cue utilisation during the performance of a novel task is a reduction in cognitive load, it was anticipated that the imposition of a secondary task would impact the performance of participants with higher or lower levels of cue utilisation differently and at different stages of the task. It was hypothesised that an interaction would be evident in which participants with lower levels of cue utilisation would record an increase in response latency, while no effect would be evident for participants with higher levels of cue utilisation.

Method

Participants

Fifty-nine university students (15 males and 44 females) aged between 18 and 22 years (*M* = 18.81, *SD* = 1.06) participated in the study and received course credit for their participation. As in Experiment 1, individuals were excluded if they were not existing drivers, had acquired experience in the context of rail control, or were outside of the 18-22 year-old inclusion range. Participants in Experiment 1 of the study were also excluded from participating in Experiment 2.

Instruments

EXPERTise

The same four driving EXPERTise tasks (Wiggins et al., 2010) utilised in Experiment 1, were included as a composite measure of driving-related cue utilisation across four cue-based problem solving and processing dimensions. An additional *Feature Identification* task was included, which exposed participants to a series of 18 different road images (photographs), each displayed for 500 msecs, and required participants to estimate the speed limit of each road from four multiple-choice options (50-60, 70-80, 90-100 or 110+ km/hr). Designed to assess the capacity to rapidly extract key information from a driving-related scene and form an accurate judgement, a greater number of accurate judgements in this task was expected to reflect higher levels of cue utilisation.

Rail control task

Participants in Experiment 2 completed the simulated train control task that was used in Experiment 1. However, in Experiment 2, participants completed the final two, 5-min blocks in conjunction with a secondary task.

Secondary task

A manipulation check was undertaken with five volunteers to ensure that the secondary task reduced the decision-time afforded to participants in the rail task, but did not induce an extremely low or an impossibly high level of workload such that the accuracy of responses would be impacted. The secondary task required participants to write down the train number and the time at which each train appeared on the screen. Following a 5-minute period of familiarisation, three volunteers completed the first half of the rail task (10-minute) with the inclusion of the secondary task, while two volunteers completed the second half of the rail task (10-minute) with the inclusion of the secondary task. Trials were counterbalanced to control for sequencing effects, such as fatigue, that were unrelated to the secondary task. The manipulation check revealed no errors in the secondary task (all trains were correctly logged), while response latency was greater for the dual task condition (*M* = 3063 msecs) compared to the vigil-only condition (*M* = 2691 msecs) suggesting that the secondary task increased the workload to an adequate but not extreme degree.

Subjective workload

Subjective workload was measured by the NASA Task Load Index (NASA-TLX: Hart & Staveland, 1988), a widely-used and validated multi-dimensional rating procedure that provides an overall workload score based on a weighted average of ratings on six subscales: Mental demands, physical demands, temporal demands, performance, effort, and frustration (Hart & Staveland, 1988; Xiao, Wang, Wang, & Lan, 2005) on a scale of 1-100. Participants completed the NASA-TLX following the single rail-task condition (Blocks 1 and 2) and again following the secondary task condition (Blocks 3 and 4).

Procedure

As in Experiment 1, participants were tested individually and completed the study in sessions of 90 minutes. Following the completion of a demographic questionnaire, participants undertook the EXPERTise 1.0 tasks and a 5-min practice trial to orient participants to the rail task. Prior to the rail control task, instructions were provided to participants in relation to the distractor task and they were given the paper-based secondary-task sheet. Once participants indicated that the instructions were understood, the simulated rail control task commenced. After 10 minutes, the rail task was paused by the researcher and participants completed the NASA-TLX. The rail task then recommenced, and for the remaining ten minutes of the task, participants diverted trains and completed the secondary-task sheet concurrently. Following the completion of the rail task, participants again completed the NASA-TLX.

Results

Cue Utilisation Typologies

Consistent with Experiment 1, a cluster analysis was undertaken using aggregated EXPERTise *z* scores for all five tasks to identify the cue utilisation typologies that corresponded with relatively higher and lower levels of cue utilisation. Two groups were identified with centroids corresponding to higher variance in the Paired Association and Feature Discrimination tasks, lower response latency in the Feature Identification tasks (reversed *z* scores), and lower ratio of sequential selections in the Information Acquisition task (reversed *z* score). In this case, the cluster analysis (Table 2) classified 22 participants in the lower cue utilisation typology (cluster 1) and 33 participants in the higher cue utilisation typology (cluster 2).

Table 2

Cluster Centroids for the EXPERTise Task Scores

	Cluster 1 (*n*=22)	Cluster 2 (*n*=33)
Paired Association	−.83	.56
Feature Discrimination	−.84	.53
Feature Identification	−.30	.21
Feature Identification II	−.45	.33
Information Acquisition	−.18	.18

Driving experience and cue utilisation

Consistent with Experiment 1, the duration of driving experience (months) reported by participants in the lower cue utilisation cluster (M = 29.73, SD = 13.06) did not differ significantly from those participants who were classified in the higher cue utilisation cluster

(M = 29.57, SD = 13.60), $F(1, 50) = .002$, $p = .97$. This suggests that differences in cue utilisation did not result from differences in participants' driving experience.

Rail task performance

As in Experiment 1, a floor effect was evident for the frequency of errors during the rail control task, ($Range$ = 0−4, Mdn = 1) with 68% of participants committing either zero or a single error during exposure to sixty-seven trains. A Chi-square test of independence indicated there were no significant differences in the distribution of errors across the four time intervals, χ^2 (3, 59) = 5.78, $p = .123$. The frequency of errors committed was unrelated to response latencies (Spearman's non-parametric, $.18 \leq r \leq .26$, $p > .05$).

Cue utilisation and rail task latencies

To investigate whether the imposition of the secondary task had a greater impact on participants with lower levels of cue utilisation compared to those participants with higher levels, a 2 x 4 mixed repeated ANOVA was undertaken, including the two levels of cue utilisation (higher, lower) as a between-groups variable and the four blocks of trials as a within groups variable. Consistent with the hypothesis, an interaction was evident between cue utilisation and block trials, $F(1.80, 90.21) = 10.81$, $p < .001$, partial $\eta^2 = .178$ (Greenhouse-Geisser correction), in which the mean response latency for participants increased with lower levels of cue utilisation, while the mean response latency for participants with higher levels of cue utilisation remained relatively consistent (Figure 3). This suggests that the imposition of the secondary task had a greater impact on participants with lower levels of cue utilisation in comparison to participants with higher levels of cue utilisation.

A main effect was evident for blocks of trials, $F(1.65, 95.72) = 12.11$, $p < .001$, partial $\eta^2 = .173$. Post hoc analysis of the mean response latencies for blocks of trials indicated that the mean response latencies in the first block of trials (M = 1608.56, SD = 594.66, SE = 77.42) were significantly lower than in the final block of trials (M = 2226.61, SD = 851.81, SE = 110.90), $t(58) = -4.51$, $p < .00$. The main effect of cue utilisation was not statistically significant, $F(1, 50) = 0.17$, $p = .90$.

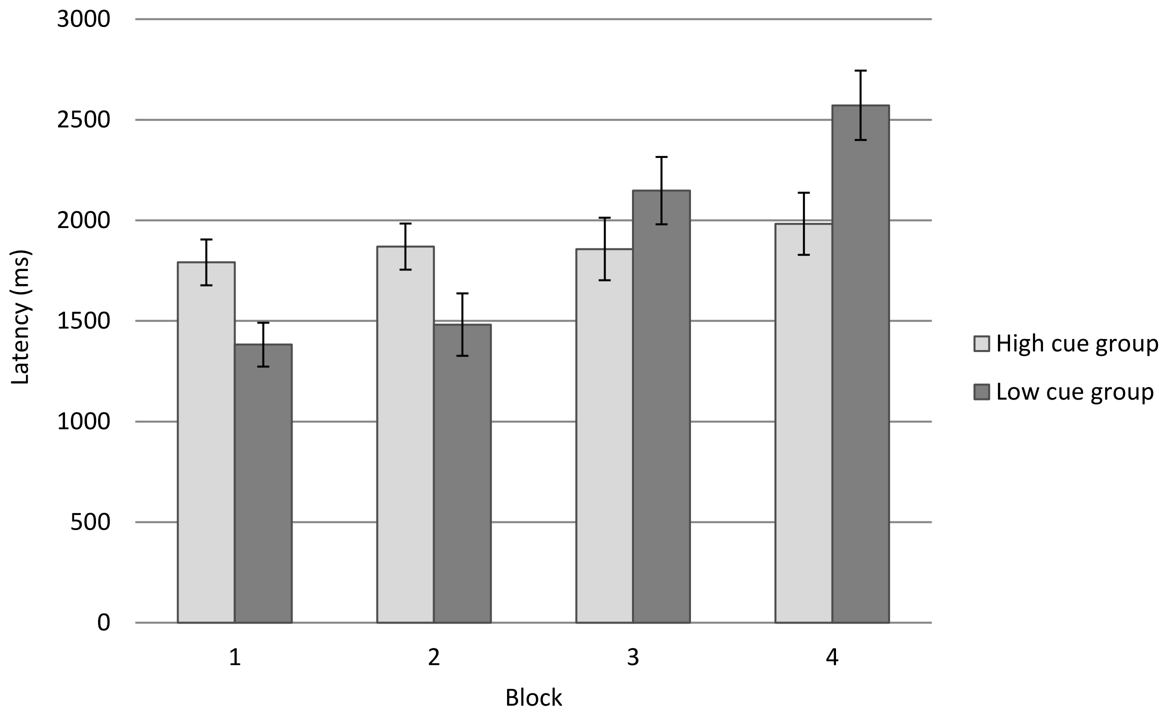

Figure 3. Rail task response latencies by cue utilisation typology and block number for Experiment 2. Error bars represent ±1 *SE*.

As is evident from Figure 3, the pattern of response latencies following the imposition of the secondary task differed on the basis of levels of cue utilisation. This suggests that the relative impact of the secondary task was greatest for participants with lower levels of cue utilisation than was the case for participants with higher levels of cue utilisation.

Cue utilisation and mental workload perceptions

To investigate whether the imposition of the secondary task impacted participants' perceptions of mental workload, a 2 x 2 mixed repeated ANOVA was undertaken, with cue utilisation level (higher and lower) as the between-groups factor and TLX scores (single-condition and dual-condition) as the within-groups variable. The results revealed a statistically significant main effect for perceptions of mental workload, $F(1, 50) = 85.33$, $p < .001$, partial $\eta^2 = .631$, in which participants perceived the task workload in the dual condition as significantly greater ($M = 26.83$, $SD = 1.90$), than during the single task condition ($M = 14.78$, $SD = 1.40$), $t\ (58) = -9.22$, $p < .001$. There was no main effect for cue utilisation, $F(1, 50) = 0.58$, $p = .449$.

Consistent with the results pertaining to response latency, a statistically significant interaction was evident between perceptions of mental workload and cue utilisation, $F(1,50) = 8.00$, $p = .007$, partial $\eta^2 = .138$. As is evident from Figure 4, the pattern of perceived mental workload (as measured by the NASA-TLX) following the imposition of the secondary task differed on the basis of levels of cue utilisation. Specifically, the perceived impact of the secondary task was greatest for participants with lower levels of cue utilisation.

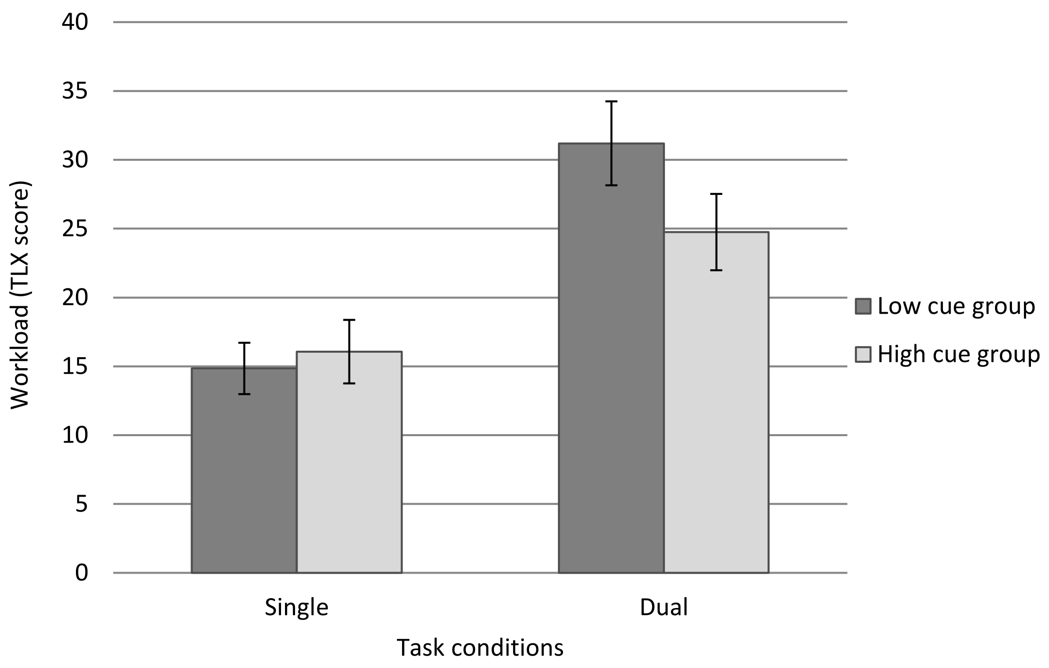

Figure 4. Mental workload across task conditions, by cue utilisation typology. Error bars represent ±1 *SE*.

Discussion

The introduction of the secondary task part-way during the 20-min period of rail control was designed to impose an explicit cognitive demand on the performance of participants. It was reasoned that if participants with greater levels of cue utilisation had adopted a strategy that effectively reduced the demands on cognitive resources, then an interaction should be evident following the introduction of the secondary task during the final two, 5-min blocks of the 20-min trial. Specifically, it was hypothesised that participants with lower levels of cue utilisation would record an increase in response latency, while only a minimal effect would be evident for participants with higher levels of cue utilisation. Consistent with the hypothesis, mean response latencies for participants with lower levels of cue utilisation increased following the introduction of the secondary task and continued to increase as the task progressed, while the mean response latencies for participants with higher levels of cue utilisation remained consistent with the vigilance decrement that was evident in Experiment 1. This effect occurred independent of driving experience but was reflected in perceptions of mental workload.

General discussion

In response to a novel task, the rapid development of associational cues in memory is one means by which the cognitive demands of a task can be minimised (Chung & Byrne, 2008; Evans, 2008; Norman & Shallice, 1986). The aim of the research presented in this paper was to examine whether differences in cue utilisation were associated with differences in performance during a novel, simulated rail control task, and whether these differences in performance reflected a reduction in cognitive load. On the assumption that cognitive load increases with sustained attention to a task (Helton & Warm, 2008; Helton et al., 2005), it was anticipated that individuals with relatively higher levels of cue utilisation would be relatively less impacted by the sustained attentional demands imposed by a simulated rail-control task in which participants were asked to identify and correct the path of trains that had periodically been misrouted.

Two experiments were conducted with motor vehicle drivers aged between 18 and 22 years who undertook an assessment of cue utilisation using the driving battery of EXPERTise 1.0. In Experiment 1, participants who were identified a priori with a relatively higher level of cue utilisation on the basis of their scores on EXPERTise 1.0, recorded a mean response latency greater than that recorded by participants with relatively lower levels of cue utilisation. The effect remained consistent across the four blocks of 5-min trials within the rail-control task. Importantly, there were no differences in accuracy and, in fact, a floor effect was evident in relation to errors.

A vigilance decrement was evident in the increases in response latency recorded across blocks of trials, irrespective of participants' level of cue utilisation. This suggests that, although an increase in cognitive load may have been associated with sustained attention to the task, the level was insufficient to differentiate the performance of participants on the basis of their cue utilisation. Consequently, Experiment 2 adopted a similar methodology but included a secondary task to invoke an explicit cognitive load part-way through the simulated rail control task.

The performance of participants in Experiment 2 during the initial two blocks of trials appeared consistent with the results from Experiment 1, whereby the response latency recorded was greater for participants with higher levels of cue utilisation. However, once the secondary task was initiated, the response latency of participants with lower levels of cue utilisation increased, while the response latency amongst participants with higher levels of cue utilisation remained relatively consistent. This suggests that the relative impact of the secondary task was greater for participants with lower levels of cue utilisation than it was for participants with higher levels of cue utilisation.

The relative consistency of response latencies recorded for participants with higher levels of cue utilisation across all blocks despite the imposition of a secondary task, suggests that they had adopted a strategy that reduced the demands on cognitive load. Until the introduction of a secondary task, the mean response latency for participants with higher levels of cue utilisation was consistently greater than the mean response latency recorded by participants with lower levels of cue utilisation. Therefore, it might be concluded that participants were adopting a strategy of self-pacing, which effectively increased task control and reduced cognitive demands (Johansson, 1981; Salvendy & Smith, 1981; Scerbo et al., 1993). As a decision to re-route trains in the rail simulation task could be initiated up to seven seconds from the appearance of a train, those participants with higher levels of cue utilisation appear to have recognised this opportunity and utilised the additional time, without sacrificing accuracy.

In contrast, the pattern of results for those participants with lower levels of cue utilisation, suggests that, until the imposition of the secondary task, these participants may have been responding rapidly and reactively, rather than in a manner consistent with the strategic conservation of resources to manage workload (Hollnagel, 2002; Hollnagel & Woods, 2005; Loft, Sanderson, Neal, & Mooij, 2007). Their rapid increase in mean response latencies subsequent to the imposition of the secondary task suggested that their reactive responses were unable to be sustained with the increasing level of workload.

It is noteworthy however, that those participants with lower levels of cue utilisation maintained consistent (and low) levels of error rates throughout the rail task, and this occurred despite the increased workload imposed by the secondary task. Therefore, it is also possible that those participants with lower levels of cue utilisation may have adopted a strategy that increasingly sacrificed speed for accuracy. Given that the workload of the task imposed demands that did not impact accuracy, it is likely that a further increase in cognitive demands would, despite efforts to minimise effort, exhaust the information processing resources of those participants with lower levels of cue utilisation and result in a deterioration in accuracy. To explore whether this is the case, future research may consider increasing the level of cognitive demand by either extending the duration of the vigil (e.g., Freeman, Mikulka, Scerbo, & Scott, 2004; Nelson, McKinley, Golob, Warm, & Parasuraman, 2014) or increasing the demands of the task (Matthews & Davies, 1998; Smit, Eling, & Coenen, 2004) to a point where accuracy is impeded (Smit et al., 2004).

Overall, the results of both experiments provide support for the assertion that a relatively greater capacity for cue utilisation is associated with an increased capacity to cope with the demands of a novel task. Throughout both experiments, several control measures were utilised to ensure that performance differences between individuals with lower and higher levels of cue utilisation were not due to cognitive ability nor cognitive style. These variables were not related to response latencies. Consistent with previous research (Moore & Muller, 2014; Muller & Abernethy, 2012; Smeeton, Ward & Williams, 2004; Wiggins et al., 2014), our results suggest that a propensity to identify critical cues and rapidly establish feature-event relationships may provide an opportunity to reduce cognitive demands, thereby enabling the acquisition of new features and/or the opportunity to revise or refine existing features.

In practice, implications that arise from the present study present tangible opportunities in the context of selection and training. The ability to identify the levels of cue utilisation may provide the basis to differentiate job applicants that are more or less likely to acquire skills in the absence of a dedicated training regime. The outcomes might also be applied to identify employees who are most in need of a training intervention, particularly in the context of the identification of key features that might enable a reduction in cognitive load and the subsequent acquisition and revision of feature-event relationships in the form of cues (Lagnado, Newell, Kahan, & Shanks, 2006; Wulf, McNevin, Fuchs, Ritter, & Toole, 2000).

What remains to be established is the extent to which the association between cue utilisation and performance evident in the present research, can be generalised. For example, driving and rail control both involve visual perception and spatial skills. The driving version of EXPERTise may be less capable of differentiating performance beyond this context. It is also noteworthy that while the results of this study suggest that participants with a greater capacity for cue utilisation adopted a strategy that minimised the impact of additional cognitive load on their performance, the precise nature of that strategy (which may pertain to the utilisation of available time to self-pace) has yet to be investigated and explicated.

In conclusion, the present study was designed to examine whether differences in cue utilisation were associated with differences in performance during a novel, simulated rail control task, and whether these differences in performance reflected a reduction in cognitive load. The results of two experiments suggested that levels of cue utilisation were associated with differences in response latencies throughout the simulated rail task, and that individuals with a higher level of cue utilisation were able to adopt a strategy that effectively reduced cognitive load without sacrificing accuracy.

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Bridging Section

Studies 1 and 2 were designed to examine whether differences in cue utilisation were associated with differences in performance during a novel, simulated rail control task, and whether these differences reflected a reduction in cognitive load. The relative consistency of response latencies recorded for participants with higher levels of cue utilisation across all blocks, despite the imposition of a secondary task, suggested that they had adopted a strategy that reduced the demands on cognitive load. It is possible, in effect, that the decision-time afforded in the task, represented a key feature, thereby enabling a 'strategy of least effort' for participants who identified and used this feature. However, it was unclear whether the performance of participants with higher levels of cue utilisation reflected a *deliberate* strategy of least cognitive effort insofar as those participants with higher levels of cue utilisation recognised and utilised the time available, or whether it was simply a response to the initial demands of the task.

Study 3 was designed to examine whether the performance of participants with relatively higher levels of cue utilisation during a novel, simulated rail control task, reflected strategies to reduce cognitive load, or whether a reduction in cognitive load was an outcome of cue utilisation. To achieve this, there were three key differences from Studies 1 and 2: Firstly, both speed and accuracy was emphasised in the rail task instructions provided to participants. The purpose of impressing a rapid response was to test whether participants with higher levels of cue utilisation prioritised a reduction in cognitive load over response latency. Secondly, trains were programmed to appear on the display in a specific sequence with only those trains on two specific lines requiring re-routing. This aspect of the task was designed to provide participants with the opportunity to recognise and response to key features or patterns of features within the rail-control and is consistent with the view that cue utilisation is an associational or pattern recognition process (Banning, 2008; Juslin, 2000; Williams, Ward &

Smeeton, 2004). Finally, in Studies 1 and 2, the overall performance accuracy of participants was maintained throughout both tasks, leaving some question as to whether the workload imposed by the rail task, was sufficiently high. There is also a question as to whether the signal rate of trains was low enough to be considered a vigilance task. Both of these factors were addressed in the third study by providing participants with relatively straightforward lower and higher workload tasks. To achieve this, a greater number of trains were programmed to appear in the rail task and, while the secondary task remained as a train log sheet, both tasks were calibrated to ensure that they imposed relatively lower and higher workloads.

STUDY 3

Publication history

The paper arising from Study 3 was entitled "The Role of Cue Utilisation in Reducing the Workload in a Train Control Task". This paper was published in *Ergonomics* on 30 May 2017. Ergonomics has an impact factor of 1.818. The author of the present dissertation wrote approximately 80% of this paper.

The Role of Cue Utilisation in Reducing the Workload in a Train Control Task

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Sue Brouwers*

Department of Psychology.

Macquarie University NSW 2109. Australia.

*Corresponding author

Mark W. Wiggins

Department of Psychology.

Macquarie University NSW 2109. Australia.

Barbara Griffin

Department of Psychology.

Macquarie University NSW 2109. Australia.

William S. Helton

The Psychology Department.

University of Canterbury, Christchurch, New Zealand

David O'Hare

Department of Psychology.

University of Otago, Dunedin, New Zealand

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Abstract

Skilled performance has been characterised, in part, by the capacity to accurately identify and respond to patterns as cues in the environment. The outcome is a reduction in cognitive load and a greater residual capacity to undertake concurrent tasks. The present study was designed to examine the relationship between cue utilisation and temporal pattern recognition in the context of a simulated, rail control task. Sixty-one university students undertook an assessment of cue utilisation and engaged in a rail control simulation. The appearance and movement of trains followed a consistent but implicit (undisclosed) pattern. Throughout the second half of the rail task, a secondary task was included. The results indicated that participants with relatively higher cue utilisation were more likely to identify the implicit pattern of rail movements, were more accurate, and responded more rapidly under increased workload conditions. The results suggest that a propensity to identify patterns as cues may provide an opportunity to reduce cognitive demands, thereby facilitating performance in a novel task. Implications for selection and system design are discussed.

Keywords: Cue Utilization, Rail control, Workload, Cognitive load, Learning

Practitioner Summary

This study was designed to explain differences in the way in which people learn, particularly when tasks involve recurring patterns. Using simulated rail control, the results indicated that participants who display behaviour that is indicative of the utilisation of cues, also recognise patterns in the movement of simulated trains. This enables them to manage trains more effectively, even while undertaking other tasks.

Introduction

Across a range of domains of practice, including fire-fighting (Klein, 1998; Perry & Wiggins, 2008)[5] aircraft piloting (Gopher, Weill, & Bareket, 1994; Sohn & Doane, 2004; Wiggins & O'Hare, 1995; Wiggins, Stevens, Howard, Henley & O'Hare, 2002), and sport (Fadde, 2009; Ward, Williams & Hancock, 2006; Williams, Ward, Knowles, & Smeeton, 2002), skilled performance is characterised by rapid and accurate responses, often in complex and dynamic settings (Beilock, Bertenthal, McCoy & Carr, 2004; Ericsson & Lehmann, 1996; Nakamoto & Mori, 2012; Salthouse, 1991; Young & Stanton, 2007). Various theories of skill acquisition (Anderson, 1993; Dreyfus & Dreyfus, 1986; Logan, 1988) would attribute this capability to specialised routines or associations that have been established through repeated application in the past (Klein, 2011). Associations between environmental features and events (or objects) are representative of situation-specific relationships, or cues (Brunswik, 1955; Klein, Calderwood & Clinton-Cirocco, 1986; Schriver, Morrow, Wickens, & Talleur, 2008; Wiggins, 2014) and their activation and retrieval from long-term memory is presumed to impose relatively few demands on working memory resources (Chung & Byrne, 2008; Evans, 2008; Norman & Shallice, 1986).

Evidence for the use of cues by skilled operators is drawn from investigations that contrast the performance of experts with novices or lesser skilled counterparts. Experts utilise a relatively limited number of specific features to interpret a situation and make earlier, anticipatory responses (e.g., Abernethy & Russell, 1987; Endsley, 2006; Fadde, 2006; Lesgold et al., 1988; Wiggins & O'Hare, 1995; Williams, Ward, Knowles, & Smeeton, 2002; Williams & Ward, 2003). This is particularly the case in time-pressed environments, such as fast-ball

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[5] References for this section can be found in the Reference List for Study 3

sport settings including soccer (e.g., Savelsbergh, Williams, Van der Kamp, & Ward, 2002), tennis (e.g., Jones & Miles, 1978; Shim, Carlton, Chow, & Chae, 2005), hockey (Salmela & Fiorito, 1979), and squash (e.g., Abernethy, 1990).

Expert operators also tend to pay more attention to *relevant* elements of visual stimuli, and interpret their observations with greater accuracy. This is evident for drawing artists (Antes & Kristjanson, 1991), chess players (Charness, Reingold, Pomplun, & Stampe, 2001), fish anatomists (Jarodzka, Scheiter, Gerjets, & Van Gog, 2010), meteorologists (Lowe, 1999) and drivers (Underwood, Chapman, Brocklehurst, Underwood, & Crundall, 2003). The tendency for experts to identify and focus on relevant visual features and produce more accurate interpretations has also been demonstrated in the medical domain, including diagnostic tasks relying on microscopic slides, patient photographs, X-rays, and mammograms (e.g., Brooks, LeBlanc & Norman, 2000; Krupinski et al., 2006; Kundel, Nodine, Krupinski, & Mello-Thoms, 2008; Lesgold et al., 1988).

On the basis that skilled performance involves the application of cues, the acquisition of skilled performance has been characterised by the capacity to rapidly and accurately extract and utilise meaningful information from features in the environment (Abernethy, 1987; 1990; Bellenkes, Wickens, & Kramer, 1997), thereby enabling the discrimination of relevant from less relevant cue-based associations (Weiss & Shanteau, 2003; Williams, Haslam & Weiss, 2008). Learners with a relatively greater capacity for generalised cue utilisation would normally be expected to quickly identify key features associated with the performance of a task which, in turn, reduces cognitive load, thereby providing an increased capacity for further skill acquisition (Wiggins, 2015).

Cognitive load refers to the total amount of mental activity imposed on working memory at an instance in time (Cooper, 1998). Wiggins, Brouwers, Davies, & Loveday (2014) demonstrated a relationship between a generalised capacity for cue utilisation and skill acquisition in experiments involving learning to land a simulated aircraft and learning to operate a simulated line-of-sight Unmanned Aerial Vehicle (UAV). Using the situation judgement test EXPERTise (2.0) (Wiggins, Loveday & Auton, 2015; Wiggins, Harris, Loveday, & O'Hare, 2010) to provide a composite assessment of cue-utilisation, higher cue utilisation was associated both with improved accuracy in landing an aircraft following four trials, and with a lesser frequency of trials to reach criterion in learning to take-off and land a simulated UAV.

To investigate whether the performance of learners with higher cue utilisation was due to a strategy that minimised cognitive load, a subsequent study (Brouwers, Wiggins, Helton, O'Hare & Griffin, 2016) exposed learners to a novel, simulated rail control task which presented participants with a relatively low workload task. A key aspect of the rail task was the provision of an extended period during which to formulate a decision so that, whether or not to re-route a train could be initiated up to seven seconds from the appearance of each train on the computer screen.

Two experiments were undertaken by Brouwers et al. (2016) using the simulated rail control task, the first of which required participants to re-route trains that periodically required a diversion. The results indicated that, in comparison to participants with lower cue utilisation, participants with higher cue utilisation recorded a consistently greater response latency with no difference in accuracy. In the second experiment, participants completed the rail task during which a concurrent, secondary task was introduced. The results revealed an interaction, whereby, under the increased workload imposed by the secondary task, participants with lower cue utilisation recorded an increase in response latency that exceeded the response latency for participants with higher cue utilisation. The relative consistency of the response latencies for participants with higher cue utilisation, across all Blocks and despite the imposition of a secondary task, suggested that they had adopted a strategy that was effectively minimising the impact of additional sources of cognitive load on their performance. Several control measures were also utilised in Brouwers et al. (2016) and the relationship between cognitive ability (as measured by scores on the Raven's Standard Progressive Matrices test) and performance scores in the rail task, revealed a non-significant correlation.

Of particular interest in Brouwers et al. was the observation that, during the low workload, single-task condition, participants with higher cue utilisation recorded a response latency greater than those participants with lower cue utilisation. It was unclear whether this performance reflected a deliberate strategy of least cognitive effort insofar as those participants with higher cue utilisation recognised and utilised the time available, or whether it was simply a response to the initial demands of the task. Consistent with previous research (Moore & Muller, 2014; Muller & Abernethy, 2012; Smeeton, Ward & Williams, 2004; Wiggins et al., 2014), a propensity to identify critical cues and rapidly establish feature-event relationships provides an opportunity to reduce cognitive demands, thereby enabling the acquisition of new features and/or the opportunity to revise or refine existing features. Therefore, the performance advantages of cue utilisation (such as increased accuracy and decreased response latency) are likely to arise as an 'outcome' rather than as a 'deliberate strategy' to reduce cognitive load.

Based on the assumption that cognitive load is implicitly reduced through cue utilisation, the present study was designed to establish whether the reduction in workload demands amongst participants with higher cue utilisation is a by-product of their relatively greater capacity to rapidly identify feature-event relationships in responding to a novel task. This was tested by examining whether differences in cue utilisation were associated with differences in performance during a novel, simulated rail control task that incorporated an implicit pattern of features that was directly associated with the passage of target trains (an event). A rail control task was adopted for the present study as it incorporated a temporal relationship between features and associated events and, in the present case, provides a context within which variations in response latency would not necessarily result in inaccurate performance. It is also an operating environment within which patterns of movements tend to occur in reality.

Unlike Brouwers et al., ‘trains’ in the present study were programmed to appear on the display in a specific sequence (spatial order), with only those trains on two specific lines requiring re-routing. Participants were asked to respond as rapidly and as accurately as possible where a train required a diversion. It was anticipated that incorporating an implicit pattern of features within the rail task would provide those participants with higher cue utilisation the opportunity to anticipate those trains that required a diversion, thereby providing an opportunity to reduce cognitive load while maintaining accuracy (Ashcraft & Kirk, 2001; Lamble, Kauranen, Laakso & Summala, 1999).

The first part of the task (Phase 1) required participants to divert trains as quickly as possible in the absence of any other tasks. In the second part of the rail task (Phase 2), a secondary task was included, constituting a dual-task condition. Based on the performance of the groups (higher and lower cue-utilisation groups) across these phases of the rail task, it was expected that the imposition of the secondary task would have a greater impact on participants with lower cue utilisation in comparison to participants with higher cue utilisation. More specifically, it was expected that there would be no difference in rail task performance between participants with higher and lower cue utilisation in Phase 1, while in Phase 2, (under increased workload conditions), participants with higher utilisation would respond faster and would make fewer errors (in the diversion of trains) than participants with lower cue utilisation. This would support the assumption that, rather than actively attempting to manage cognitive load (by, for example, using the available 7 seconds of time to divert trains), individuals with relatively higher cue utilisation acquire cue-based patterns, which results in a reduction of cognitive load, enabling rapid and accurate task performance. These expectations lead to two sets of hypotheses involving: (a) the mean response latency performance of participants, and (b) the performance accuracy of participants.

Hypotheses: Response latency performance

H1a. An interaction was hypothesised, wherein the mean response latencies of participants with higher and lower cue utilisation would not differ in Phase 1 of the rail task. However, in Phase 2, participants with lower cue utilisation would record a greater increase in mean response latencies, in comparison to participations with higher cue utilisation.

H1b. A main effect for trials was hypothesised, in which, irrespective of cue group, participants would record higher mean response latencies during Phase 2 (secondary task conditions), compared to Phase 1.

H1c. A main effect for cue utilisation was hypothesised, wherein participants with lower cue utilisation would record greater mean response latencies in Phase 2, compared to participations who recorded higher cue utilisation.

Hypotheses: Performance accuracy

H2a. An interaction between cue utilisation and trials was hypothesised, in which the frequency of errors for participants with lower cue utilisation would increase from Phase 1 to Phase 2, to a greater degree, compared to a change in error frequency for participants with higher cue utilisation.

H2b. A main effect for trials was hypothesised, in which, irrespective of cue group, participants would record a higher frequency of errors during Phase 2, compared to Phase 1.

H2c. A main effect for cue utilisation was hypothesised, wherein participants with lower cue utilisation would record a greater frequency of errors in Phase 2, compared to participations with higher cue utilisation.

Method

Participants

A total of 61 first and second year university students (41 females and 20 males) were recruited for the study, each of whom received course credit in return for their participation. The participants ranged in age from 18 to 22 years (*M* = 19.39, *SD* = 1.17). Since the present study was designed to assess the relationship between cue utilisation and the management of cognitive demands within a novel rail task, it was necessary to recruit participants who were naive to rail control. EXPERTise 2.0[6] is a cross-domain task that utilises driving-related tasks to assess cue utilisation. Therefore, the inclusion criteria comprised existing motor vehicle drivers who had not been exposed to rail control operations, and who were aged between 18 and 22 years. Utilising a cohort of 18 to 22 year old drivers enabled comparative assessments of cue utilisation, while controlling for exposure to driving.

Instruments

A summary of all measures included in the present study is provided in Table 1. The participants were asked to indicate their age, sex, months of driving experience, and daily driving frequency (See Table 2). Cue utilisation was assessed using the Expert Skills Evaluation (EXPERTise 2.0) (Wiggins, Loveday, & Auton, 2015) platform.

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[6] EXPERTise version 2.0 is comprised of essentially the same tasks as EXPERTise version 1.0, but with upgrades to some usability and scoring features. Some of the same tasks have different names.

An overview of all measures included in the present study

Measure	Description	Scoring/used as a variable
EXPERTise 2.0 Driving tasks (5 tasks)	A generalised measure of cue utilisation based on cue-based driving tasks (15-min)	Cluster analyses were used to identify high and low cue groups
Rail control task	A 20-min simulation rail control task. The first 10 min was a single-task condition, followed by a 10-min secondary task condition	Mean response latency for correct train diversions were calculated over 4 x 5-min time blocks. The number of errors (throughout the 20-min rail task)
Secondary task	A single-page form that required participants to write down the train number and time at which the train appeared, for each train in the task (10-min)	The number of errors (the number of missing or incorrectly logged pieces of data in the train log sheet)
Pattern identification	Participants provided verbal responses to the question: "Did you notice a pattern in the rail task"?	Based on their verbal responses, participants were classified as either successful (yes) or unsuccessful (no) in identifying the train pattern
The Perspective Taking/ Spatial Orientation Test (PTSO)	A 5-min timed test, used as a control variable for spatial and perspective taking ability	The number of correctly answered items within a 5-min period
Attentional Control Scale (ACS)	A twenty-item, self-report measure (ratings captured on a 4-point likert scale) which was used as a control for attentional control	The total sum of ratings
Subjective cognitive load (NASA-TLX)	The NASA-TLX was completed after Phase 1 of the rail task (the single task condition) and again after Phase 2 (the dual-task condition)	An overall score was obtained from a weighted average of ratings on six subscales

Table 2

Demographic data of participants

	Mean	*SD*	*SE*
Age (months)	19.39	1.17	0.15
Driving exposure (months)	40.30	14.50	1.86
Sex	Male: 32.8 % Female: 67.2 %		
Daily driving (hrs per day)	80.3% drove between 0.5 & 1 hour		

EXPERTise

EXPERTise 2.0 is an online platform that consists of experimental tasks that are designed examine different aspects of domain-related cue utilisation. The tasks have been individually and collectively associated with differences in performance at an operational level (Loveday, Wiggins, Searle, Festa, & Schell, 2013; Loveday, Wiggins, Harris, O'Hare, & Smith, 2013; Loveday, Wiggins, Festa, Schell, & Twigg, 2013). The 'driving' version of EXPERTise (Brouwers et al., 2016) was selected, as it assesses the acquisition of cues in a specific cohort and at a specific point in time, and it is a context with which participants would be familiar (Wiggins, Brouwers, Davies & Loveday, 2014). Tasks in the EXPERTise driving battery include a Feature Association task (previously referred to as the Paired Association Task), a Feature Discrimination task, a Feature Identification task, a Feature Recognition task and a Feature Prioritisation task (previously referred to as the Information Acquisition Task).

In the *Feature Association* task, participants are presented with two feature-event/object terms. Over a total of 30 trials, two terms are displayed, adjacent to one another for 1500 milliseconds. After each pair is displayed, participants indicate the extent to which the two terms are related on a six-point Likert scale (from 1 = "Extremely unrelated" to 6 =

"Extremely related"). Examples include the related terms 'heavy traffic' (feature) and 'short-cut' (event) and relatively less related terms 'traffic-light' (feature) with 'free-way' (object). Higher cue utilisation is associated with a greater variance in the perceived relatedness of terms (Ackerman & Rathburn, 1984; Morrison, Wiggins, Bond, & Tyler, 2013; Schvaneveldt, Beringer & Lamonica, 2001).

In the *Feature Discrimination* task, participants are presented with a short, written description of a single scenario (i.e., "You are lost in an unfamiliar area. You find yourself in a quiet suburban area, and must find your way to a large shopping centre located on a main road. You can see heavier traffic on a main road ahead and high-rise buildings are in the distance..."). The participants are then asked to make a decision based on their typical response in this scenario (i.e., drive in the direction of heavier traffic, or drive toward high-rise housing, and so on). Following their decision, participants are presented with a list of fourteen features and, using a 10-point Likert scale (from 1 = "Not important at all" to 10 = "Extremely important"), are asked to rate these features based on their perceived relevance to his/her decision. Higher cue utilisation is associated with greater variance within the feature-relevance ratings (Pauley, O'Hare, & Wiggins, 2009; Weiss & Shanteau, 2003).

The *Feature Identification* task involves the extraction of key features from an array or scene. Participants are presented with a familiar driving scene (i.e., an image of a road as viewed from the driver's seat of a car) and are directed to identify a road hazard as quickly as possible (i.e., a ball positioned in the road ahead). The position of the ball changes over trials. A lower mean response latency is associated with higher cue utilisation (Loveday, Wiggins, & Searle, 2014; Schriver, Morrow, Wickens, & Talleur, 2008; Schyns, 1998).

The *Feature Recognition task* exposes participants to a series of 18 different road images (photographs), each of which is displayed for 500 msecs, and requires participants to estimate the speed limit for each road from four multiple-choice options (50-60, 70-80, 90-100 or 110+ km/h). Designed to assess the capacity to rapidly extract key information from a driving-related scene and form an accurate judgement, a greater number of accurate judgements in this task reflects higher cue utilisation.

Finally, the *Feature Prioritisation* task involves a way-finding scenario where participants select one of three possible driving routes. Accompanying the scenario instructions is a drop-down menu with 24 options (feature-cues), which are category-labelled (e.g., 'distance', 'weather conditions') and upon selection, provide participants with information pertaining to the distance, tolls, road works, weather conditions, traffic congestion, speed limit and the number of lanes for each route. Participants are given one minute to select information prior to making a response. This task assesses the capacity to acquire feature cues from the environment in a prioritised and non-linear pattern (Wiggins & O'Hare, 1995; Wiggins, Stevens, Howard, Henley, & O'Hare, 2002). Individuals with lower cue utilisation are more likely to select information in the sequence in which it is presented (e.g., from left to right as they appear on the display screen). Higher cue utilisation is associated with a relatively lower ratio of pairs of information screens accessed in the sequence in which they are presented, against the total frequency of pairs of information screens selected.

The criterion validity of EXPERTise has been established in a number of different domains in which typologies formed on the basis of EXPERTise performance differentiated workplace-related performance (Loveday, Wiggins, Searle, Festa, & Schell, 2013; Loveday, Wiggins, Harris, O'Hare, & Smith, 2013; Loveday, Wiggins, Festa, Schell, & Twigg, 2013). The test-retest reliability (Kappa = .59, $p < .05$) has been demonstrated with power control operators at six-monthly intervals (Loveday, Wiggins, Festa, Schell, & Twigg, 2013). In the present study, restricting the age of participants (18-22 years) controlled for exposure to driving experience. This ensured that any differences in cue utilisation would be unlikely to result from differences in driving experience. Overall, participants had accumulated a mean of 40.30 months (or about 3 1/2 years) of driving experience (*SD* = 14.50 months).

Rail control task

A simulated rail control task (Howard, Chen & Wiggins, 2003) was used as a novel, low-workload context for the present study. In this task, a computer screen depicts a simulated, simplified rail control display (see Figure 1). The four long, horizontal green lines shown in the display represent railway tracks. Each track incorporates an intersection (depicted by white portions on the track), which is controlled by an interlocking switch labelled, 'Change'. This switch is depicted by a small circle icon, located above each track. If a user selects the 'Change' icon, (with a computer mouse), any train travelling on the connected track will be diverted onto the intersecting line.

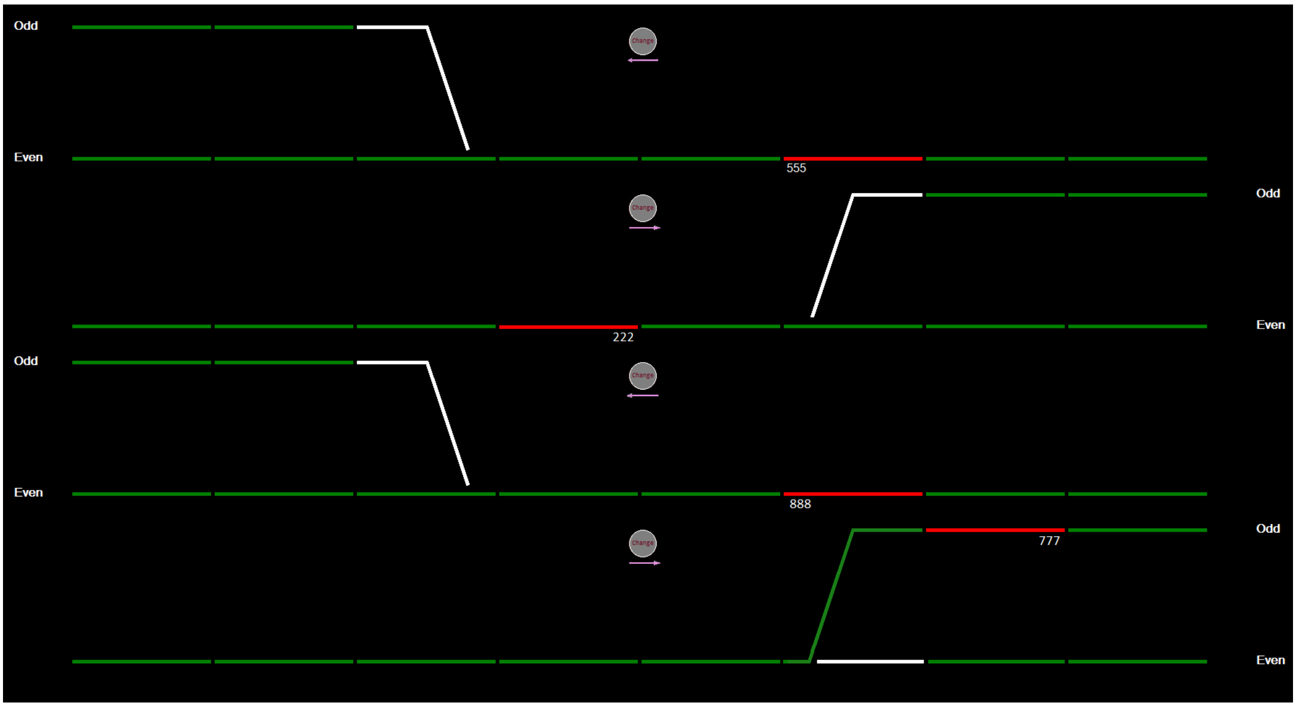

Figure 1. The simulated rail-control display as viewed by participants. The four long, horizontal green lines represent railway tracks. A train is depicted by a red horizontal bar that appears at one end of a train line, and travels across the display. The white portions on each track are the intersection lines, which are controlled by an interlocking switch labelled, "Change". This switch is depicted by a small circle icon, located above each track. If a participant selects the "Change" icon,

any train travelling on the track beneath it, will be diverted onto the intersecting line. The train on the lowermost track in this figure is labelled "777". This train is travelling from left to right, moving across the screen, and has been diverted (correctly) onto an odd labelled track.

A train is depicted by a red horizontal bar that appears at one end of a train line, and travels across the display. Each train has a three-digit number assigned as either odd or even (e.g., 888, 333). Each train line and its associated branch line also have an assigned label: Odd or Even. As the train appears onto the screen, a green line depicts the programmed route of the train. The participant's task was to ensure that trains run along the correct train lines (even-numbered trains run along even lines and odd-numbered trains along odd lines). Fifty percent of the programmed routes are inconsistent with the train’s number so that, for example, an even numbered train is programmed to take a route that is labelled ‘odd’. To correct the programmed route of the train, participants must select the ‘Change’ icon which will re-route the train.

All of the trains in the task progressed at the same speed and once a train emerges onto the computer screen, participants have seven seconds in which to decide whether or not to reroute the train. Trains however, appeared between 5 and 7 seconds of each other. Therefore, at any given time, the display depicted all four train lines occupied with a train. A total of one hundred and seventy trains appeared on the four rail lines over the course of twenty-minutes, eighty-four of which were not required to be re-routed. Designed as a low workload, process control task, the primary goal of the participant was to attend to the display, identify a match between each train and its planned route, and select the 'change' icon as appropriate so that a train's route corresponded with its number. Data recorded from this task included response latency (in milliseconds, from the initial appearance of a train, to the selection of the "Change" icon) and the accuracy of responses (whether trains are diverted when required).

A pattern within the rail task: Stimuli development and pilot study

The rail task was designed so that all trains that appeared on two (of the four) designated train lines would require a diversion, while trains that appeared on the remaining two lines did not require a diversion. To ensure that the pattern was sufficiently complex to remain unrecognised by all participants, yet likely to be recognised by a proportion of participants, three patterns were designed that incorporated an embedded pattern that varied in complexity. Version 1 incorporated a pattern whereby the upper two train lines (on the display screen) always required a diversion, while the lower two did not require a diversion. The pattern in Version 2 required users to divert trains on the uppermost and lowermost lines but never the middle two tracks. In the third version (most complex), alternate tracks were required to be diverted. In all versions, the order in which the trains appeared was sequential, beginning with the uppermost track, followed by the second, third, fourth (lowermost) and then the first once again and so on.

In a pilot study, nine volunteers were asked to complete three train tasks. While the volunteers were informed that the tasks embodied 'a pattern', which they needed to identify, they were not advised of the nature of the pattern (for example, whether it involved train numbers or the order and timing of train appearances). Each volunteer began by attempting the rail control task with the most complex version of the pattern and, unless the pattern was identified, s/he moved to the next, less complex version. This removed the likelihood that one version would provide a cue to the embedded pattern in another version. The pilot study revealed that none of the participants identified the most complex pattern (Version 3) and that all identified the simplest version (Version 1). As three of the six participants identified the pattern incorporated in Version 2 (medium-level complexity), this version was selected as most suitable for the study. As a result, the rail task utilised in the present study required participants to divert trains on the uppermost and lowermost train lines but never the middle two lines. To successfully identify the pattern within this task, participants were asked to correctly identify the correct diversion pattern and specify which tracks did or did not require a diversion.

Pattern identification: Coding responses

The participants were not advised of the pattern of train movements. After the completion of all tasks, participants were asked, "Did you notice a pattern in the rail task?" and their responses were recorded verbatim. The participants who replied that they did not notice a pattern were coded as unsuccessful in identifying the pattern. Of the participants who indicated that they did observe a pattern, their responses were examined to establish whether they provided a sufficiently accurate account of the pattern. Provided that the account described the pattern either partially or completely, they were considered to have successfully identified the pattern. For example, one participant noted, "Yes, I noticed that I didn't need to change the two tracks in the middle". Another replied "I had to move the trains on the top and lowest lines, but not the others". A third participant replied, "I think that the bottom track always needed to be diverted". In each case, participants were considered to have successfully recognised the pattern. In this way, each participant was classified as either successful (yes) or unsuccessful (no) in identifying the train pattern.

Secondary task and manipulation check

The secondary task utilised in the present study consisted of a single-page form that required participants to write the train number and time at which the train appeared, for each train in the task. This task has been used previously as a secondary task (Brouwers et al., 2016), where it was demonstrated to increase the workload associated with the primary rail control task, to an adequate, but not impossibly high degree.

Participants undertook the writing task during the second half of the train task. The number of missing or incorrectly logged pieces of data in the train log sheet constituted secondary task errors. For example, if the time of a train's appearance was logged incorrectly or was missing, or if a train number was logged incorrectly or was missing, each of these instances was coded as an error. A manipulation check was conducted to ascertain whether or not the frequency of secondary task errors was associated with response latencies and accuracy (frequency of errors) in the rail task. Examining the secondary task errors from all 61 participants indicated that the frequency of errors ranged from 0 - 6 (median = 1.0, total = 71) which generally produced a floor effect.

The distributions of errors in the secondary task were not normally distributed. Therefore, to examine the relationship between rail task response latencies and errors, a series of Spearman's rank-ordered, non-parametric correlations were conducted between secondary task error frequency, rail task error frequency (overall mean of errors committed in the rail task) and rail task response latencies. A positive relationship was evident between secondary task errors and rail task error frequency (Spearman's $r = .32$, $p = .011$) and between secondary task errors and response latencies in the third (Spearman's $r = .41$, $p =.001$) and final (Spearman's $r = .46$, $p = .001$) of the 4, five-minute blocks of the rail task. These correlations were statistically significant and indicated that an increase in the frequency of errors in the secondary task was associated with an increase in the frequency of errors in the rail task and slower response latencies in the final two rail task blocks. These results indicate that the secondary task was likely to have been effective in increasing the workload associated with the primary rail task.

Perspective taking and spatial orientation ability

It is possible that performance in the rail control task was associated with visual perspective taking (e.g., the ability to know where objects are located relative to another). Visual perspective taking has been shown to influence human performance in contexts such as navigation and spatial problem solving (Kozhevnikov, Motes, Rasch, & Blajenkova, 2006; Zacks, Mires, Tversky, & Hazeltine, 2000). To ensure that performance differences in the rail task, were not due to perspective taking and spatial orientation ability, the Perspective Taking/Spatial Orientation Test (PTSO: Kozhevnikov & Hegarty, 2001; Hegarty & Waller, 2004) was included as a control variable in the present study. The PTSO is a 12-item test that requires participants to imagine different perspectives or orientations in space. Each test item includes a visual array of seven objects (i.e., a cat, tree, house etc), a written question and a circular diagram to capture the participant's response. This task requires participants to imagine that s/he is standing at one object in the array (object A) while facing a second object (object B), and they are required to draw an arrow, indicating the direction that a third object would lie (C). The test is timed and scored as the number of correctly answered items within a 5-minute period. The PTSO has demonstrated divergent and convergent validity with other spatial ability and perspective taking measures (Kozhevnikov & Hegarty, 2001) and has shown for example, to be dissociable from measures of spatial visualisation that involve object manipulation rather than self-orientation. The Cronbach's alpha for the PTSO is reported as .79 (Hegarty & Waller, 2004).

Attentional control

The Attentional Control Scale (ACS: Derryberry & Reed, 2002) was employed in the present study as a measure of attentional control. To ensure that performance differences between individuals with lower and higher cue utilisation were not due to attentional control, the ACS was included as a control variable. Used previously in a range of studies as a measure of the executive ability of individuals to direct their attention (e.g., Lonigan & Vasey, 2009; Ólafsson et al., 2011; Wiersema & Roeyers, 2009), the ACS consists of twenty items that are rated on a four-point Likert scale from 1 (almost never) to 4 (always). Scores are calculated as the total sum of ratings, with higher attentional control indicated by higher test scores. The predictive and convergent validity of the ACS has shown adequate validity and factor structures (Judah, Grant, Mills, & Lechner, 2014) and test retest reliabilities range from .61 to .73 after one month (Fajkowska & Derryberry, 2010). In the present study, the internal consistency for the ACS was .83. (Cronbach's *alpha*).

Subjective workload

Subjective workload was measured with the NASA Task Load Index (NASA-TLX: Hart & Staveland, 1988), a widely-used and validated multi-dimensional rating procedure that provides an overall score from 1-100 based on a weighted average of ratings on six subscales: Mental demands, physical demands, temporal demands, performance, effort, and frustration (Hart & Staveland, 1988; Xiao, Wang, Wang, & Lan, 2005). Participants completed the NASA-TLX after Phase 1 of the rail task (the single task condition) and again after Phase 2 (the dual-task condition).

Procedure

The participants were tested individually in 60-min sessions. After completing an on-line demographic questionnaire, a computer prompt directed the participants through the five EXPERTise 2.0 tasks. Participants then completed the Perspective Taking/Spatial Orientation Test (PTSO) followed by the Attention Control scale (ACS) and then undertook a 5-min practice trial to orient them to the rail task. During this practice trial, standardised instructions for the rail task were provided verbally. This included the instruction, *"It is important that you respond as fast as possible in this task. It is also important that you are accurate: This means you need to ensure that all trains that are on correct tracks".* Prior to the rail control task, instructions were provided to participants in relation to the secondary task and they were given the paper-based, train-logging-task sheet. Once participants indicated that the instructions were understood, the simulated rail control task commenced. After 10 minutes, the researcher paused the rail task and participants completed the NASA-TLX. The rail task then recommenced, and for the remaining ten minutes, participants diverted trains and completed the secondary-task sheet concurrently. Following the completion of the dual-task period, participants completed the NASA-TLX for the second time. At the conclusion of all of the tasks, participants were asked, "Did you notice a pattern in the rail task?" If they indicated that they had observed a pattern, they were then asked to describe the pattern and their responses were recorded verbatim. Figure 2 shows a schematic outline of the rail task procedure.

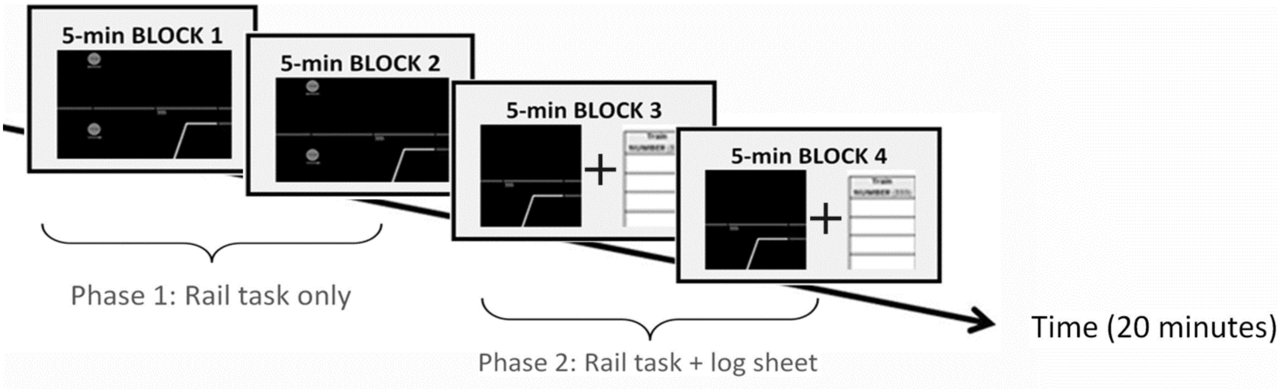

Figure 2. A schematic diagram of the rail task procedure. The rail task was twenty minutes in duration. In the first ten minutes (Phase 1), participants diverted trains in the absence of any other tasks. During the next ten minutes (Phase 2), a secondary task was included that required participants to write down the train number and time at which each train appeared. Blocks 1 to 4 represent 5-min intervals.

Results

Preliminary analysis

Rail task performance scores

Response latencies were calculated from the initial appearance of a train to the correct selection of the ‘Change’ icon. Since the task was 20-min in duration, the mean response latencies for correct responses were calculated across four, five-min blocks, and these four variables comprised the dependent variables in subsequent analyses. The distributions of response latencies within each of these five-min blocks were normally distributed. Approximately half of all trains that appeared required re-routing, and these are summarised, by block, in Table 3. A summary of the descriptive statistics and correlations between these response latencies, as well as all other continuous variables included in the present study, are shown in Table 4.

Table 3

Number of trains that appeared and required re-routing in the rail task

	Appeared	Required re-routing
Block 1	43	21
Block 2	42	22
Block 3	43	21
Block 4	42	22
	Total 170	86 (50.6%)

Table 4

Correlation Matrix and Descriptive Statistics

Variable	Mean	SD	1	2	3	4	5	6	7	8	9	10
1. Block 1 rail task	1894.47	456.58	1									
2. Block 2 rail task	1695.76	485.57	.536**	1								
3. Block 3 rail task	3283.84	1011.33	.403*	.254*	1							
4. Block 4 rail task	3084.02	1046.57	.308*	.275*	.672**	1						
5. Rail task errors	4.89	3.34	.075	.148	.300*	.362**	1					
6. Secondary task errors	Median=1		.228	.227	.406**	.458**	.323*	1				
7. Spatial orientation	7.61	2.64	-.093	-.027	-.241	-.174	.033	-.353**	1			
8 Attentional control	50.77	7.85	-.313*	-.035*	-.059	-.132	-.004	-.054	.020	1		
9. Driving experience	40.30	14.50	-.070	.116	.055	.051	.209	-.202	-.064	-.033	1	
10. TLX (single task)	29.19	13.64	.322*	.131	.190	.284*	-.011	.187	.083	-.232	-.094	1
11. TLX (dual task)	55.04	15.19	.208	-.023	.307*	.257*	.202	.166	.078	-.096	.002	.533**

* Correlation is significant at the 0.05 level (2-tailed), ** Correlation is significant at the 0.01 level (2-tailed),
The correlations for secondary task errors are Spearman rank-ordered.
The variables EXPERTise and pattern identification are not included in this table, as they are categorical.

The total counts of 'correct hits' (correct diversion of a train), 'misses' (where a train that required diversion was not diverted), 'false alarms' (where a train that did not require diversion, was diverted) and 'correct rejections' (correctly not diverting a train) were tallied across all four intervals. These responses were analysed for response bias to examine whether participants were more likely to indicate that a train required diversion (a 'yes' response bias) or more likely to respond that a train did not (a 'no' response bias). Based on signal detection theory calculations from Stanislav and Todorov (1999), the decision criterion (*C*) was calculated by averaging the z-score that corresponded to the hit rate of correct diversions, Z(HR) = 1.86 and the z-score that corresponded to the false alarm rate, Z(FAR) = -1.93. The analysis revealed a negligible response bias (*C* = 0.04), suggesting that respondents were only slightly more prone to a non-detection ('no') response. Subsequently, the frequency of errors committed (false alarms and misses) in Phase 1 (single task condition) and Phase 2 (dual-task condition) per participant, was included as an outcome measure. The distribution of error frequencies within each of these two phases, were normally distributed.

Spatial orientation ability

Scores on the perspective-taking/Spatial orientation (PTSO) were normally distributed and not significantly correlated with mean response latencies for any of the four blocks of train task trials (Pearson's r ranged from -.03 to -.24, $p > .05$). As PTSO scores were also unrelated to the frequency of errors committed in the rail task ($r = .03$, $p = .80$), they were not included in subsequent analyses.

Cue utilisation typologies

Prior to further analysis, it was necessary to identify the cue utilisation typologies that corresponded to relatively higher or lower cue utilisation (Loveday, Wiggins, Harris, O'Hare, & Smith, 2013; Loveday, Wiggins, Festa, Schell, & Twigg, 2013; Wiggins, Brouwers, Davies & Loveday, 2014). Consistent with the standard approach to EXPERTise data, z scores were calculated for each task, with those corresponding to the Information Acquisition and Feature Identification tasks reversed so that for all five tasks, higher z scores represented higher cue utilisation. A cluster analysis identified two groups with centroids corresponding to higher variance in the Feature Association and Feature Discrimination tasks, lower response latency in the Feature Identification tasks (reversed z scores), and a lower ratio of sequential selections in the Feature Prioritisation task (reversed z scores). The cluster analysis denoted 28 participants in the lower cue utilisation typology and 33 participants in the higher cue utilisation typology (Table 5).

Table 5

Cluster Centroids for the EXPERTise Task Scores

	Cluster 1 (*n*=33) High cue typology	Cluster 2 (*n*=28) Low cue typology
Feature Association	.62	-.76
Feature Discrimination	.42	-.50
Feature Identification	.09	-.10
Feature Recognition	.41	-.50
Feature Prioritisation	.44	-.52

Sex

As there were 41 females and 20 males in the present study, an analysis of sex was undertaken to ensure that participants' sex was not related to: (a) the mean response latencies in the rail task, (b) pattern identification, and (c) cue utilisation (EXPERTise cluster). A series of one-way Analyses of Variance (ANOVA) indicated that sex was not related to the mean response latencies in block 1: $F(1,59) = 1.36$, $p = .249$, block 2: $F(1,59) = 2.11$, $p = .151$, block 3: $F(1,59) = .083$, $p = .774$ or block 4: $F(1,59) = .089$, $p = .766$. The relationship between EXPERTise cluster (lower, higher) and sex (male, female) was examined using a 2 x 2 chi-square test of independence and the results indicated that the sex of participants was not related to cue utilisation group, $\chi^2(1, 61) = 2.38$, $p = .123$. Finally, a 2 x 2 chi-square test of pattern identification (yes, no) and sex, indicated that sex was not related to pattern identification, $\chi^2(1, 61) = 2.00$, $p = .655$.

Driving experience and cue utilisation

To examine whether differences in cue utilisation resulted from differences in participants' duration of driving experience, a one-way ANOVA was conducted using

EXPERTise cluster as the independent variable, and months of driving experience as the dependent variable. The duration of driving experience reported by participants in the lower cue utilisation cluster (M = 40.32 months, SD = 14.64), did not differ significantly from those participants with higher cue utilisation (M = 40.27, SD = 14.60), $F(1, 59) = .00$, $p = .99$, suggesting that assessments of cue utilisation were not necessarily related to driving exposure.

Cue utilisation and rail task performance (mean response latency)

To investigate whether the imposition of the secondary task had a greater impact on participants with lower cue utilisation compared to those participants with higher cue utilisation, a 2 x 4 mixed repeated ANOVA was undertaken, incorporating the two cue utilisation groups (higher, lower) as a between-groups variable, the four blocks of 5 minute trials as a within groups variable, and mean response latency as the dependent variable. A main effect was evident for blocks of trials, $F(2.28, 134.43) = 131.13$, $p < .001$, partial $\eta^2 = .69$ (Greenhouse-Geisser correction), and post hoc analyses indicated that the mean response latencies in the first block of trials (M = 1894.47 milliseconds, SD = 456.58, SE = 58.49) were significantly lower than in the final block of trials (M = 3084.02, SD = 1046.57, SE = 134.00), $t(60) = -9.25$, $p < .001$.

A main effect for cue utilisation was also evident, $F(1, 59) = 22.52$, $p < .001$, partial $\eta^2 = .28$, and post hoc analyses indicated that in Block 3, the mean response latency for participants with lower cue utilisation (M = 3793.18, SD = 959.66, SE = 181.36) was significantly greater than the mean response latency for participants with higher cue utilisation (M = 2851.68, SD = 849.17, SE = 147.82), $F(1,59) = 16.52$, $p < .001$. Similarly, in Block 4, the mean response latency for participants with lower cue utilisation (M = 3768.33, SD = 895.01, SE = 169.14) was significantly greater than the mean response latency for participants with higher cue utilisation (M = 2503.39, SD = 787.66, SE =137.11), F (1, 59) = 34.47, $p < .001$.

A statistically significant interaction was evident between cue utilisation and block trials, $F(2.28, 134.43) = 16.45$, $p < .001$, partial $\eta^2 = .22$, in which the mean response latency for participants with lower cue utilisation increased to a greater degree than the response latencies of participants with higher cue utilisation (Figure 3). As is evident in Figure 3, the pattern of response latencies following the imposition of the secondary task differed on the basis of cue utilisation. This suggests that, in comparison to participants with higher cue utilisation, the relative impact of the secondary task was greatest for participants with lower cue utilisation.

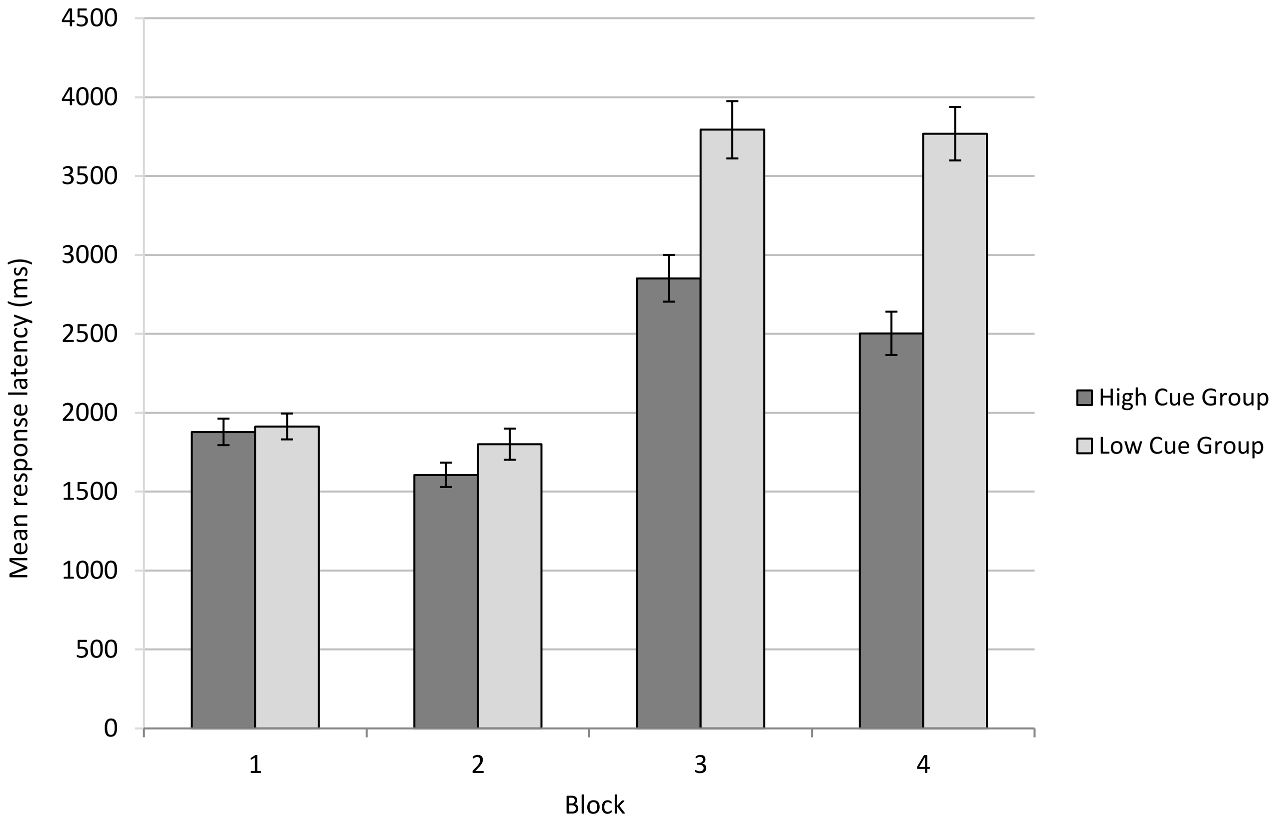

Figure 3. Mean rail task response latencies by cue utilisation typology and block number. Error bars represent ±1 *SE*.

Cue utilisation and rail task performance (accuracy)

Performance accuracy in the rail task was examined using a 2 x 2 mixed repeated ANOVA, incorporating the total number of rail task errors as the dependent variable, the two cue utilisation groups (higher, lower) as a between-groups variable and the two phases (single condition and dual condition) as a within-groups variable.

A main effect for cue utilisation was evident, $F(1, 59) = 27.84$, $p < .001$, partial $\eta^2 = .32$, and post hoc analyses indicated that, in the dual-task condition, the frequency of errors for participants with lower cue utilisation ($M = 4.25$, $SD = 2.52$, $SE = .48$) was statistically significantly greater than the error frequency of participants with higher cue utilisation ($M = 1.45$, $SD = 1.73$, $SE = .30$). A main effect for trials was not statistically significant, $F(1,59) = 4.67$, $p = .081$, suggesting that, irrespective of cue utilisation, the frequency of errors in the rail task did not increase significantly under the secondary task condition. A statistically significant interaction between cue utilisation and block trials was evident, $F(1, 59) = 10.20$, $p = .002$, partial $\eta^2 = .147$, in which the frequency of errors for participants with lower cue utilisation increased from 2.7 to 4.3, while the frequency of errors for participants with higher cue utilisation remained relatively consistent (changing from 1.8 to 1.5) (Figure 4).

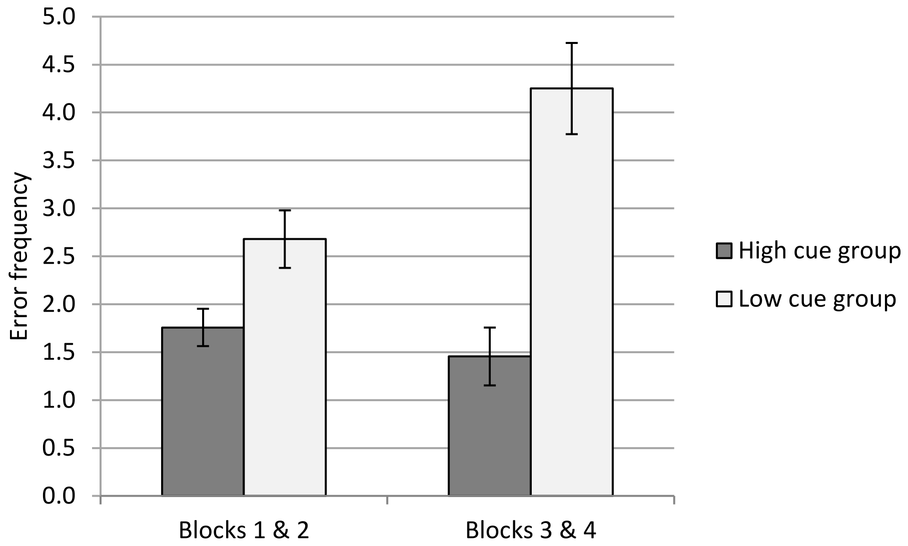

Figure 4. Mean frequency of errors committed in the rail task by cue utilisation typology across Blocks 1 and 2 (single task condition) and Blocks 3 and 4 (dual task condition). Error bars represent ±1 *SE*.

Cue utilisation and subjective workload

To investigate whether the imposition of the secondary task impacted participants' perceptions of workload, a 2 x 2 mixed repeated ANOVA was undertaken, with the mean TLX scores as the dependent variable, cue utilisation group (higher and lower) as the between-groups factor, and the two task phases (single condition and dual condition) as the within-groups variable. The results revealed a statistically significant main effect for perceptions of workload, $F(1, 59) = 204.27$, $p < .001$, partial $\eta^2 = .78$, in which participants perceived the task workload in Phase 2 as significantly greater ($M = 55.04$, $SD = 15.19$, $SE = 1.94$), than during Phase 1 ($M = 29.19$, $SD = 13.64$ $SE = 1.74$). No statistically significant main effect was evident for cue utilisation, $F(1, 59) = 2.57$, $p = .011$, nor was there an interaction, $F(1, 59) = .09$, $p = .761$, suggesting that participants' perceptions of workload across single and dual conditions, did not differ by cue utilisation (See Table 6).

Table 6

Subjective cognitive load across the single and dual task. While participants perceived the task workload in the Dual task as greater, perceptions of load did not differ by cue utilisation group

	Single Task			**Dual Task**		
	Mean	*SD*	*SE*	*Mean*	*SD*	*SE*
High cue group	27.09	14.52	2.53	52.43	16.23	2.82
Low cue group	31.67	12.31	2.32	58.12	13.49	2.55

Attentional control

There was a statistically significant, negative relationship between attentional control scores and overall response latencies in Block 1 (Pearson's $r = -.31$, $p = .014$) and Block 2 ($r = -.31$, $p = .017$) while attentional control was not related to response latencies in Blocks 3 ($r = -.060$, $p = .654$) and 4 ($r = -.132$, $p = .310$). As these first two blocks constituted the first two sets of trials in a novel rail task, it suggests that during the initial stages of learning, higher levels of attentional control were associated with improved response latency. However, to ascertain whether the relationship between cue utilisation and rail task performance was due to attentional control, attentional control scores were included as a covariate in a 2 x 4 mixed repeated ANOVA model, incorporating response latencies as the dependent variable, the two groups of cue utilisation (higher, lower) as a between-groups variable and the four blocks of trials as a within-groups variable. As the interaction between cue utilisation group and response latency (over four blocks), remained statistically significant, $F(3, 174) = 16.31$, $p < .001$, it suggests the relationship between cue utilisation and response latency is not explained by differences in levels of attentional control.

Reporting the pattern

A total of 36 percent of all participants (n = 22) accurately identified a pattern in the rail task. To investigate whether participants who reported a pattern, differed in their rail task performance, a series of One-way ANOVAs were conducted with response latency as the dependent variable and pattern identification (yes, no) as the grouping variable. A statistically significant difference in mean response latency was evident in Blocks 3 and 4. In Block 3, the mean response latency for those participants who did not report the pattern (M = 3,490.87 msecs, SD = 1034.41, SE = 165.64) was significantly greater than for those participants who did report the pattern (M = 2,916.85, SD = 874.84, SE = 186.52), F(1, 59) = 4.82, p = .032. In Block 4, the mean response latency for participants who did not report the pattern (M = 3,346.21, SD = 1106.71, SE = 159.42) was also statistically significantly higher compared to those participants who did report the pattern (M = 2,619.22, SD = 747.74, SE = 159.42), F(1, 59) = 7.53, p = .008.

Successful pattern identification and the frequency of errors in the rail task was investigated using a 2 x 2 mixed repeated ANOVA with the total number of rail task errors as the dependent variable, pattern identification (yes, no) as the between-groups factor and the two task phases (single condition and dual condition) as the within-groups variable. The results revealed a statistically significant interaction between pattern identification and error frequency, F(1, 59) = 8.48, p = .005, partial η^2= .126, in which the frequency of errors for participants who did not report the pattern increased from 2.4 to 3.6, while the frequency of errors for participants who did report the pattern remained relatively consistent (changing from 1.8 to 1.2). A main effect for pattern identification was evident, F(1, 59) = 15.05, p < .001, partial η^2= .203, and post hoc analyses indicated that in Phase 2 (the dual condition), the frequency of errors for participants who did not report the pattern (M = 3.62, SD = 2.64, SE =

.42) was significantly higher than the error frequency of participants who did report the pattern (*M* = 1.18, *SD* = 1.33, *SE* = .28).

The relationship between cue utilisation and pattern identification was examined using a 2 x 2 chi-square test of independence, incorporating the two cue utilisation groups (higher and lower) and two levels of pattern identification (yes, no). The results revealed a statistically significant relationship between pattern identification and the cue utilisation groups, $\chi^2(1, 61) = 14.43$, $p < 001$, phi = .486. While 57.6 percent of participants in higher cue utilisation group (n=19) verbally identified the pattern, 10.7 percent of the low cue utilisation group (n = 3) verbally identified the pattern. Therefore, participants with higher cue utilisation were 11 times more likely (odds ratio = 11.31, 95% CI = 2.84, 45.06, $p = .001$) to report the pattern compared to those participants with lower cue utilisation.

Pattern identification was also investigated in relation to mean levels of perceived workload. A 2 x 2 mixed repeated ANOVA was undertaken with mean, composite TLX scores as the dependent variable, pattern identification (yes, no) as a between-groups factor and the two task phases (single condition and dual condition) as a within-groups variable. The results revealed a statistically significant main effect for pattern identification, indicating that participants who did not report the pattern perceived their workload in the dual task as significantly greater (*M* = 59.16, *SD* = 13.60, *SE* = 2.18) than participants who reported the pattern (*M* = 47.74, *SD* = 15.40, *SE* = 3.28), $F(1, 59) = 11.89$, $p = .001$, $\eta^2 = .168$. The interaction (workload x pattern identification) was not statistically significant, $F(1, 59) = .15$, $p = .697$.

Discussion

In response to a novel task, the rapid development of associational cues in memory is a means by which the cognitive demands of a task can be minimised quickly, while maintaining accuracy (Chung & Byrne, 2008; Evans, 2008; Norman & Shallice, 1986). Based on the assumption that cognitive load is implicitly reduced through cue utilisation, the present study was designed to investigate whether a reduction in workload amongst participants with higher cue utilisation is a by-product of their relatively greater capacity to rapidly identify feature-event relationships in responding to a novel task.

The participants were motor vehicle drivers aged between 18 and 22 years who undertook an assessment of cue utilisation using the driving battery of EXPERTise 2.0 and completed the 20-minute train task that required them to monitor a display and re-route trains where the train numbers were inconsistent with their track label. During Phase 1, the participants were asked to manage trains as quickly as possible in the absence of any other tasks, while in Phase 2, a secondary task was included. Scores on EXPERTise clustered participants into two groups, reflecting relatively higher and lower cue utilisation and supporting prior research on this tool (Loveday, Wiggins, Searle, Festa, & Schell, 2013; Loveday, Wiggins, Harris, O'Hare, & Smith, 2013; Loveday, Wiggins, Festa, Schell, & Twigg, 2013). On the assumption that the performance of participants with higher cue utilisation is an outcome or product of their increased capacity for cue utilisation, it was expected that throughout the rail task, the imposition of a secondary task would have a greater impact on participants with lower cue utilisation in comparison to participants with higher cue utilisation.

Consistent with expectations, these groups were associated with differences in performance in the second phase of the rail task (dual-task condition), where, compared to participants with higher cue utilisation, those participants with lower cue utilisation demonstrated significantly greater mean response latencies together with a greater frequency of errors. Moreover, an interaction was evident between cue utilisation and block trials, in which the mean response latencies for participants with lower cue utilisation increased to a greater degree than the response latencies of participants with higher cue utilisation. As there were no statistically significant differences in the response latencies or frequency of errors between the groups in Phase 1, the results provide support for the proposition that performance amongst participants with higher cue utilisation may be a function or by-product of their ability to identify features in the rail task, rather than an active intention to reduce cognitive load.

To ensure that performance differences between individuals with lower or higher cue utilisation were not due to attentional control or perspective taking and spatial orientation ability, these variables were used as controls. Apart from attentional control, they were not related to performance. The moderate, negative association between attentional control scores and response latencies in Phase 1, appeared to reflect the link between increased attentional control and improved response latency during the initial stages of learning. The relationship between cue utilisation and response latency was not explained by differences in levels of attentional control.

Participants were asked if they were aware of a pattern in the rail task and the results revealed a significant relationship between the cue utilisation groups and pattern identification, with those participants in the higher cue group 11 times more likely, than those in the lower cue group, to report the pattern. Participants who successfully identified the pattern in the rail task also perceived the workload in the dual-task phase as significantly lower than those participants who failed to report the pattern. The successful identification of the pattern was also associated with fewer errors in the dual-task condition. Although it is not possible to determine whether the pattern went unnoticed by participants who did not report it, these outcomes, combined with the pattern of interaction results associated with errors and response latency, suggest that participants with higher cue utilisation may have an increased capacity to rapidly identify and acquire feature-event relationships which affords an opportunity to anticipate and make predictions (e.g., anticipate trains that require a diversion), and, in doing so, reduce the impact of cognitive load.

Based on their subjective ratings of task workload, all of the participants in the present study, regardless of their cue utilisation, perceived the demands in Phase 2 of the rail task (the secondary task) as significantly greater than the demands of Phase 1 (the single task condition). However, there was no main effect for cue utilisation, suggesting that subjective workload across Phases 1 and 2 did not differ across the cue utilisation groups. If participants with higher cue utilisation possess an increased capacity to rapidly identify and acquire feature-event relationships, then it might be expected that this group would experience and rate the workload (particularly in the secondary task) as less demanding, compared to perceptions of workload amongst participants with lower cue utilisation. It is possible that this outcome was due to a dissociation between perceived workload and performance in the dual-task condition (Horrey, Lesch, & Garabet, 2009; Vidulich & Wickens, 1986; Yeh & Wickens, 1998).

According to Yeh and Wickens (1998), dissociations between subjective measures of workload and performance can occur in dual-task conditions where the competition for resources results in distorted self-report estimates of workload. The secondary task conceivably increased the workload because both the rail task and the secondary task drew on related processing resources such as those that involved visual scanning and motor responses (Wickens, 2002; 2008). As there were differences in the performance between the groups, yet the perceived workload did not differ across conditions, it is likely that participants in the dual-task condition (which required participants to both write and monitor a display) experienced relatively less awareness of their own effort or levels of task performance. To address this issue, future studies may consider increasing the level of workload using the train task alone by increasing the number of trains, tracks and/or available decision time, rather than incorporating a secondary task.

It is also noteworthy that the present study included a specific set of hypotheses, wherein the response accuracy and response latency were designed to be tested separately, across time and by cue group. Future studies may consider investigating rail task performance in a combined error-latency format, as a function of time.

Theoretical and practical implications

Overall, the results of the present study provide support for the assertion that a relatively greater capacity for generalised cue utilisation is associated with a capacity to manage increasing workload demands when completing a novel task. Consistent with previous research (Moore & Muller, 2014; Muller & Abernethy, 2012; Smeeton, Ward & Williams, 2004; Wiggins et al., 2014), these results suggest that a propensity to identify critical cues and rapidly establish feature-event relationships may provide an opportunity to reduce cognitive demands, thereby enabling the acquisition of new features and/or the opportunity to revise or refine existing features. Particularly under time pressures and higher workload conditions, operators who are able to implicitly recognise and classify situations based on prior experience (relying on critical cues and patterns), will be able to respond quickly and adaptively to meet the needs of situations (Klein, 2008).

In practice, implications that arise from the findings of this study present opportunities for selection and training. The capacity to identify cue utilisation performance may aid in differentiating job applicants who are more or less likely to advance and acquire skills in the absence of resource-intensive training. The methodology might also be applied to identify employees who are most in need of a training intervention, particularly in the context of the identification of key features that might enable a reduction in cognitive load and the subsequent acquisition and revision of feature-event relationships in the form of cues (Lagnado, Newell, Kahan, & Shanks, 2006; Wulf, McNevin, Fuchs, Ritter, & Toole, 2000).

A limitation of the present research relates to domain specificity. Whether or not the association evident between cue utilisation and performance can be generalised to other contexts, is unclear. For example, driving and rail control both involve spatial and visual perception and skill, and the version of EXPERTise 2.0 may be less capable of differentiating performance beyond this context.

In conclusion, the present study was designed to examine whether the performance of participants with relatively higher cue utilisation during a novel, simulated rail control task, reflects a reduction in cognitive load as an outcome of cue utilisation. The results indicated that higher cue utilisation was associated with reduced response latencies and increased accuracy in the second phase of the simulated rail task (the increased workload phase), suggesting that a reduction in cognitive load amongst participants with higher cue utilisation may indeed be a by-product of their relatively greater capacity to rapidly identify feature-event relationships in responding to a novel task.

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Bridging section

Study 3 was designed to examine whether the performance of participants with relatively greater cue utilisation during a simulated rail control task, reflected strategies *to* reduce cognitive load, or whether a reduction in cognitive load represented an *outcome* of the process to achieve cue utilisation. A primary difference from Studies 1 and 2 was the inclusion of a pattern in the movement of trains. Trains were programmed to appear in a particular sequence, and trains on only two of the four tracks required a diversion. Importantly, this pattern was not disclosed to participants. It was anticipated that incorporating a pattern of features within the rail task would provide those participants with greater cue utilisation the opportunity to anticipate those trains that required a diversion, thereby providing an opportunity to reduce cognitive load.

The first stage of task (Phase 1) required participants to divert trains as quickly as possible in the absence of any other tasks. In Phase 2, a secondary task was included that imposed a cognitive load on participants. The results of Study 3 indicated that the performance of participants with lower and higher cue utilisation did not differ within the low workload phase. However, in the higher workload second phase which included a secondary task, participants with higher levels of cue utilisation were least affected by the imposition of the secondary task (they made fewer errors and were faster to respond in the rail task). Further, the participants in the higher cue group were eleven times more likely, than those in the lower cue group, to accurately report the rail pattern.

Overall, the results from Study 3 suggested that greater cue utilisation during a novel, simulated rail control task, reflected pattern-recognition mechanisms which *resulted* in a reduction of cognitive load (rather than the imposition of active strategies to reduce cognitive load). Extending these findings, Study 4 was designed to examine: (1) whether the relationship between cue utilisation and rail task performance depended upon pattern recognition (a moderating relationship) (2): whether individuals who have higher cue utilisation and who rapidly acquire task-related patterns, have an increased tendency toward miscueing, and (3): whether participants with higher cue utilisation would continue to be miscued by repeated changes to the rail task pattern.

The incorporation of an empirical assessment of miscueing with cue utilisation can be viewed as an important step toward bridging two, somewhat disparate notions of cue utilisation. On the one hand, there exists the view that cue-based reasoning is driven by associational, heuristic processes (Croskerry, 2009; Evans, 2008; Evans & Frankish, 2009; Gigerenzer & Goldstein, 1996) that can assist operators in making rapid and accurate judgements (Kahneman & Klein, 2009; Klein, 2008). However, there is also the view that these same processes are synonymous with bias and error (Kahneman, 2003; Tversky & Kahneman, 1974; Tversky & Kahneman, 1990). In the present study, it was reasoned that a sensitivity to cues and a proclivity to rapidly acquire patterns during routinised tasks, can have advantages in certain learning and operational contexts, as they enable operators to rapidly detect and respond to critical cues and patterns, but that this propensity may have the disadvantage of miscueing performance when patterns change. This reasoning is consistent with Kahneman and Klein (2009), who have argued that an overreliance on perceived regularities in the environment or invalid cues, can lead to poor judgments and decisions.

The design of the train control task used in Study 3 was extended in Study 4, and rather than enabling a single rail movement pattern to be acquired by participants, Study 4 included three different patterns of rail movement. Each of these patterns was programmed to change abruptly during the course of the twenty-four-minute rail task. It was reasoned that if participants who acquired the pattern were reliant on the pattern to formulate fast and accurate train diversions, the initial, abrupt change to this pattern would represent a miscue (Loveday,

2015) and result in a temporary reduction in performance evidenced by slower responses and reduced accuracy. Based on the assumption that pattern recognition is associated with cue utilisation, this *decrement* in performance was expected from participants with higher cue utilisation, specifically under increased workload conditions (during the secondary task), and following exposure to the rail task pattern. While this first pattern change was likely to result in a temporary decrement in performance (a performance 'dip'), it was also reasoned that the participants who detected and relied on the pattern would experience a lack of trust in the system and, as a result, further pattern changes were unlikely to impact performance.

STUDY 4

Publication History

The paper arising from Study 4 was entitled, "Operators Who Readily Acquire Patterns And Cues Risk Being Miscued In Routinized Settings". This paper was accepted for publication on 9 October, 2017 in the *Journal of Experimental Psychology: Applied* and is currently classified as *in-press.* The Journal of Experimental Psychology: Applied has an impact factor of 1.836. The author of the present dissertation wrote approximately 85% of this paper.

Operators Who Readily Acquire Patterns and Cues Risk Being Miscued in Routinized Settings.

Brouwers, S., Wiggins, M. W., & Griffin, B. (In-Press). Operators who readily acquire patterns and cues risk being miscued in routinized settings. *Journal of Experimental Psychology: Applied.*

Sue Brouwers

Macquarie University NSW 2109. Australia.

sue.brouwers@mq.edu.au Corresponding author

Mark Wiggins

Macquarie University NSW 2109. Australia.

mark.wiggins@mq.edu.au

Barbara Griffin

Macquarie University NSW 2109. Australia.

barbara.griffin@mq.edu.au

Abstract

The detection of critical cues is a hallmark of expert performance and in high-risk settings, can prevent serious incidents. A sensitivity to cues and a proclivity to rapidly acquire patterns during routinized tasks however, can miscue performance when these patterns change. In the present study, 75 university students undertook an assessment of cue utilisation and also engaged in a 24-minute rail control simulation. The rail control task involved monitoring with periodic interventions to re-route trains, according to a train-track matching rule. A hidden pattern in the sequencing of trains presented an opportunity to predict train movements and reduce the workload. This pattern was programmed to abruptly change 3 times during the rail task. Based on the response latency of participants and their detection of the rail task pattern (verbal descriptions), the results suggested that individuals who are sensitive to cues and who also detect patterns of dynamic stimuli (following limited exposure), experience a relatively greater risk of misapplying rules or misdiagnosing situations in routinized environments, when stimuli change. Following a temporary decline in performance however, if there are continued pattern changes, the performance of these individuals will remain unaffected. The implications are discussed for training and system design.

Public Significance Statement

The results of this study suggest that while a sensitivity to cues and a proclivity to rapidly acquire patterns during routinized tasks are generally associated with superior performance, these advantageous characteristics can also miscue performance, particularly in routinized environments when these patterns change.

Introduction

Highly skilled performance across a range of practice domains is characterised by accurate and rapid responses, often in complex and dynamic settings (Beilock, Bertenthal, McCoy, & Carr, 2004; Charness, Reingold, Pmplun & Steampe, 2001; Ericsson & Lehmann, 1996; Klein, 1993; MacKenzie, Nelson-Schultz, & Wills, 1983; Nodine, Kundel, Lauver, & Toto, 1996; Schriver, Morrow, Wickens & Talleur, 2008; Sherbino et al., 2012; Williams, 2000)[7]. This is attributed to associations or specialised routines that have been established through repeated application (Klein, 2011; Simon & Chase, 1973). These highly specialised associations, representative of situation-specific relationships between environmental features and events or objects, are referred to as cues (Brunswik, 1955; Klein, Calderwood & Clinton-Cirocco, 1986; Wiggins, 2014), and their activation and retrieval from long-term memory has the advantage of imposing relatively few demands on working memory resources (Chung & Byrne, 2008; Evans, 2008; Ericsson, & Kintsch, 1995; Norman & Shallice, 1986).

The rate at which individuals acquire skills has been attributed to a variety of factors including deliberate practice (Ericsson, Krampe, & Tesch-Roemer, 1993; Ericsson, 2007), motivation and self-regulation (Zimmerman, 2002; 2008), cognitive ability and intelligence (Ackerman, 1986; 2007; Ackerman & Beier, 2007), personality (Simonton, 2008; Singer & Janelle, 1999), working memory capacity (Meinz & Hambrick, 2010), and a range of general intrinsic abilities (Simonton, 2007; 2008; Thompson, Cowan, & Frieman, 1993). The acquisition of skilled performance is also characterised by the capacity to rapidly and accurately extract and utilise meaningful information from features in the environment (Abernethy, 1987; 1990; Bellenkes, Wickens, & Kramer, 1997; North et al., 2009; Reischman & Yarandi, 2002), thereby enabling the discrimination of relevant from less relevant cues

[7] References for this section can be found in the Reference List for Study 4

(Weiss & Shanteau, 2003). For example, in medical diagnostic tasks, learners gain expertise by acquiring knowledge about the specific features that are best able to differentiate diseases (Norman, Rosenthal, Brooks, Allen, & Muzzin, 1989; Norman, Brooks, Allen, Rosenthal, 1990).

The importance of cue utilisation in a high-stakes setting is illustrated by the 1989 Hillsborough stadium disaster in England (Nicholson & Roebuck, 1995; BBC, 2016). Ninety-six Liverpool football spectators were killed and hundreds injured when thousands of fans were allowed into two football standing 'pens', sealed off by crowd barriers and fences at the front of the stands. The event was live-telecast (BBC, 2016) and despite visible evidence of overcrowding amongst the Liverpool section of the stadium (Hillsborough Independent Panel, 2012), the danger went unnoticed until the crush caused barriers to break (Nicholson & Roebuck, 1995; Taylor, 1990) and injured spectators spilled onto the pitch. Crowd control officials and police later explained that they attributed the crowding, screams as well as other behaviours (such as attempts by some individuals to climb barriers), to fan revelry and rowdiness (Scraton, 1999; Taylor, 1990). By the time the first ambulance arrived, most of the fatalities had already occurred (Gibson, 1990; Scraton, 1999).

Miscueing refers to the activation of an inappropriate association in memory by a salient feature, thereby delaying or preventing the accurate recognition of an object or event (Rowe, Horswill, Kronvall-Parkinson, Poulter, & Mckenna, 2009; Wiggins & Loveday, 2015). Under certain circumstances, miscueing can result in an expert practitioner's speed and diagnostic accuracy decreasing to that approaching a novice (Shanteau, 1992). While miscueing is presumably reliant upon the existence of associations (mental models or scripts) in memory, there is also evidence that novice or learner-operators with limited experience can acquire cues (Abernethy, 1988; Brouwers, Wiggins, Helton, O’Hare, & Griffin, 2016; Brouwers, Wiggins, Griffin, Helton, & O'Hare, 2017; Fadde, 2006; 2009; Jarodzka et al., 2012; Wiggins & O'Hare, 1995; Wiggins, Brouwers, Davies, & Loveday, 2014; Williams, Ward, Smeeton, & Allen, 2004) which suggests that learners may also be subject to miscueing.

Wiggins et al. (2014) and Brouwers et al. (2016; 2017) suggested that some individuals who undertake novel tasks are capable, after relatively few trials, of acquiring patterns and effectively and efficiently responding to task-related features. Participants in Brouwers et al. (2017) were motor vehicle drivers with no previous experience in rail control, who first undertook a battery of situational judgement tasks (EXPERTise 2.0 driving battery) which provided a composite assessment of cue-utilisation in the context of motor vehicle hazard detection and way-finding. They subsequently engaged in a 20-min rail control simulation that required them to monitor and periodically re-route trains according to a train-number and track-label matching rule. Participants were not informed however, that trains on only two of the four tracks required re-routing. This pattern represented an opportunity to reduce the workload considerably, as it enabled participants to divert any train arriving on two particular tracks and disregard all other task features (e.g., the number-label matching rule and the trains on the two other train tracks). The rail task simulation included both a low workload and higher workload condition, and it was anticipated that under increased workload conditions, participants with higher cue utilisation would perform faster and with greater accuracy (compared to participants with lower cue utilisation), due to their capacity to detect and utilise the rail task pattern.

Consistent with this expectation, significant differences were evident between participants with lower and higher cue utilisation whereby, under increased workload conditions, participants with higher cue utilisation responded significantly faster and with greater levels of accuracy, compared to participants with lower cue utilisation. After completing the rail task, participants were asked if they noticed a pattern in the task, and if so, they were asked to describe it. Participants who recorded higher cue utilisation were 11 times more likely to report the pattern (and accurately describe it) compared to those participants with lower cue utilisation. Overall, the results of this study suggested that: (a) learners can acquire patterns and respond accurately to key features in a task, (b) there are differences in the rate at which learners acquire patterns and respond to key features, and (c), that pattern recognition may underpin cue utilisation.

With evidence that learners, exposed to patterns in a task, can acquire these patterns and detect and respond to cues, a key question is whether and to what extent, this capacity for cue utilisation may also induce a tendency toward miscueing. The human propensity for error in reasoning and judgement has been well documented and catalogued (Croskerry, 2003; Dekker, 2014; Hammond, 1996; Leape, 1994; Rasmussen, 1982; Reason, 1990; 2000; Shappell & Wiegmann, 2012; Shorrock, & Kirwan, 2002), and serious incidents such as industrial, aviation and nuclear power accidents are usually attributed to a culmination of failures at various operational and organisational levels (Le Bot, 2004; Shappell & Wiegmann, 2012; Shrivastava, Mitroff, Miller, & Miclani, 1988; Turner, 1978). It is prior to, and during this process of cascading failures (referred to as 'the critical period' by Stein, 2004), that the detection of critical cues or 'precursers', can be most useful in preventing or mitigating the scale of the disaster (Carroll, 2004; Marcus & Nichols, 1999; Szwedzicki, 2001). A sensitivity to cues, however, may come with an increased likelihood of being miscued. In real-world situations, features can be dynamic, patterns may change, and dangers may escalate quickly (Endsley, 1995; Klein, 1998; Klein et al., 1986; Muthard & Wickens, 2002; Orasanu & Connolly, 1993; Simon, 1972). As argued by Rerup (2009), in high-risk settings, what may appear to be a weak or non-significant feature can quickly become a highly relevant cue.

Given that the performance of learners in simulation tasks such as landing an aircraft (Wiggins et al., 2014) or monitoring railway traffic (Brouwers et al., 2016) has indicated that learners differ in the rate at which they acquire patterns, it may be the case that individuals who are faster to detect and acquire patterns, also have an increased proclivity to be miscued. If so, there are a number of potential training-related implications. For example, in high-stakes settings, it may be important to expose learner-operators to a wide range of real-world or simulation settings that vary in complexity, time-pressure and cue availability, thereby enabling them to acquire cues yet also detect and adapt to dynamic changes.

The aim of the present study was to examine the extent to which a propensity for pattern recognition is associated with a propensity for miscueing. Since miscueing occurs when an inappropriate association in memory is activated by salient features (also referred to a capture error) (Loveday, 2015), a miscue can be induced by abrupt changes to a previously acquired pattern (Huettel, Mack & McCarthy, 2002). The present study extended the design of the train control task in Brouwers et al. (2017) and rather than merely enabling a re-routing pattern to be acquired by participants, included three discrete changes to the re-routing pattern. It was reasoned that if participants who acquired the pattern were reliant on the pattern to formulate fast and accurate train diversions, an abrupt change to this pattern should represent a miscue (Loveday, 2015), and result in a temporary reduction in performance evident in slower responses and reduced accuracy.

To provide participants with the opportunity to acquire the pattern, the first six minutes of the rail task (Block 1) involved participants diverting trains in the absence of any other tasks. Throughout the remainder of the rail task (Blocks 2-5, lasting 18 minutes), participants completed a secondary task which was designed to increase the workload demands and necessitate the management of these demands, to maintain accuracy and speed (see Figure 2 for a timeline). Three changes in pattern occurred during Blocks 3-5. Consistent with the experimental design employed by Brouwers et al., participants were asked to respond as rapidly and as accurately as possible where a train required a diversion and they were not provided with any information concerning the pattern. Having completed the rail task, participants were asked if they noticed a pattern. Accurate responses were recorded as 'Yes' (for a correctly identified pattern) or 'No' (did not identify a pattern).

Based on the assumption that pattern recognition moderates the relationship between cue utilisation and rail task performance, it was anticipated that, following the extended period of exposure to the initial pattern of train diversions, for participants who identified the pattern, higher cue utilisation would be associated with a performance decrement (e.g., an increased mean response latency for accurate responses to misrouted trains) immediately following the initial miscue. For participants who failed to identify the pattern, no relationship would be evident between cue utilisation and their performance in the rail task.

It was reasoned that if a miscue effect was apparent, it would occur in response to the initial change in the pattern of train movements (the first miscue). For participants who detected and initially relied on the pattern, this first pattern change was likely to result in a temporary performance decrement (a 'dip' in performance) but also leave them with a lack of trust in the system and, as a result, further pattern changes were unlikely to impact performance. These expectations translate into three sets of hypotheses involving: (a) the relationship between cue utilisation and pattern identification, (b) the impact of the first miscue, and (c) performance across the series of miscue trials.

Cue utilisation and pattern identification

H1. It was hypothesised that a relationship would be evident between cue utilisation and pattern identification wherein a significantly greater proportion of participants who identified the pattern of trains would record higher cue utilisation scores on EXPERTise 2.0.

Impact of the first miscue:

H2. It was hypothesised that pattern recognition would moderate the relationship between cue utilisation and rail task performance. For participants who identified the pattern, as cue utilisation scores increased, so too would their mean response latency to the initial miscue. In the case of participants who failed identify the pattern, no relationship would be evident between cue utilisation and mean response latency.

Cue utilisation and performance across all three miscue trials

H3. It was hypothesised that an interaction would be evident between cue utilisation and miscue trials. During the initial miscue, there would be a positive relationship between cue utilisation and response latency, while in subsequent miscue trials (second and third pattern changes), no relationship would be evident between cue utilisation and response latency.

Method

Participants

A total of 75 first and second year university students (44 females and 31 males) were recruited for the study, each of whom received course credit in return for their participation. The participants ranged in age from 18 to 22 years (M = 19.16, SD = 1.13). The inclusion criteria comprised existing motor vehicle drivers who had not been exposed to rail control operations, who had corrected to normal vision, and who were aged between 18 and 22 years. Utilising a cohort of 18 to 22-year-old drivers enabled comparative assessments of cue utilisation, controlling to a limited extent, exposure to driving. Due to the use of visual stimuli during the study, prospective participants who were red-green colour blind were also excluded from participation.

Instruments

The participants were asked to indicate their age, sex, months of driving experience, daily driving frequency, and their experience in rail control. Cue utilisation was assessed using the Expert Skills Evaluation (EXPERTise 2.0) (Wiggins, Harris, Loveday, & O'Hare, 2010) situation judgement test.

EXPERTise

EXPERTise 2.0 consists of experimental tasks that have been individually and collectively associated with differences in performance at an operational level (Loveday, Wiggins, Searle, Festa, & Schell, 2013; Loveday, Wiggins, Harris, O'Hare, & Smith, 2013; Loveday, Wiggins, Festa, Schell, & Twigg, 2013). The driving version of EXPERTise 2.0 was selected, as driving is a context with which participants would be familiar and as it has previously demonstrated utility in predicting rail task performance (Brouwers et al., 2016; Brouwers et al., 2017; Wiggins et al., 2014).

The five tasks in the EXPERTise driving battery comprise a Feature Association Task, a Feature Identification Task, a Feature Recognition Task, a Feature Discrimination Task and a Feature Prioritisation Task. In the *Feature Association Task*, a series of 34 paired phrases, representative of feature-event/object terms were presented, and participants indicated the extent to which they believed each pair are related. For example, one phrase pair consisted of 'Residential road' and '50 Km/h'. The initial phrase 'Residential road' appeared on-screen for 1000 milliseconds (ms), followed by a blank screen with a red "X" indicating the fixation point, and then the second phrase '50 Km/hr' appeared for 1000 ms. Participants were then presented with a 6-point Likert scale (from 1 = "Extremely unrelated" to 6 = "Extremely related") accompanied with the instructions, "Please use the slider to indicate how related you believe the two phrases to be".

In the *Feature Identification Task I*, participants were presented with 21 different photograph images of a road scene as viewed from the perspective of a car driver. Each image was accompanied with the instructions, "Imagining you are the driver of this car, click on the area of concern to you". Contained within the images were potential hazards such as an area of roadwork, a reversing vehicle, or police horses. In many of these images, the potential hazards zones were to the far right or left of the driver's visual field, such that the potential hazard zone was not immediately obvious. On selecting a zone, participants were then presented with the next image. As higher cue utilisation and driving skill are associated with the fast and accurate detection of driving-related hazards (Lee et al., 2008; Scialfa et al., 2011; Underwood, Crundall, & Chapman, 2002), a lower mean reaction time and higher accuracy (based on the number of correctly identified hazard zones) across all 21 trials, was assumed indicative of higher performance on this task.

The *Feature Recognition Task* required participants to respond to a series of 17 different road photographs as viewed from the driver's seat of a car. Each of the images were displayed for 1000 msecs, and after exposure to an image, the participant was requested to estimate the speed limit of the road from four multiple-choice options (50-60, 70-80, 90-100 or 110+ km/hr). The images included photographs of highways, suburban and rural roads, and the roads appeared in varying daylight conditions (night time, dusk etc). Due to the association between increased levels of driving skill and the use of road-related cues to estimate speed limits, (Cantwell, Isler, & Starkey, 2012; Shinar, McDowell & Rockwell, 1974), higher accuracy scores in this task were indicative of higher cue utilisation.

In the *Feature Discrimination Task*, participants were presented with a half-page, written description of a single way-finding scenario in which they were required to make a decision based on their typical response. The participants were able to consider a map and the written scenario without any time limit and were then prompted to select one way-finding response of four available options: (a) Stay on Stevens St; (b) Take Maple Ave onto Ramsay Rd; (c) Take Rosemount Ave or (d) Take Yarra Rd. Following their decision, participants were presented with a list of 14 features and, using a 10-point Likert scale (from 1 = "Not important at all" to 10 = "Extremely important"), were asked to rate the importance of each of these aspects of the scenario in arriving at their decision. Amongst others, these features include 'Traffic congestion', 'Time of day', 'Meeting time', 'Slow moving traffic, 'Local radio reports', and 'Distance to destination'. As higher cue utilisation is associated with a greater variance in the perceived importance of features (Pauley, O'Hare, & Wiggins, 2009; Weiss & Shanteau, 2003), scoring in this task is calculated as the total variance over the 14 feature-importance ratings, and higher variance is indicative of higher cue utilisation.

Finally, in the *Feature Prioritisation Task*, participants were presented with a scenario that required a choice between five different travel methods to attend cinema event, arriving in time for the start of the movie (i.e., driving, car pooling, cycling, walking or using Uber). Accompanying the scenario was a drop-down menu with 17 options (feature-cues) which were category-labelled (e.g., ‘Current weather, ‘length of movie’, 'Parking availability') and upon selection, provided participants with information that might be useful in selecting a mode of transport. Above the 17 options, were the instructions: "You only have 120 seconds to access any information necessary (from the drop down tabs below)".

After two minutes, participants were asked to select a mode of transportation. This task assessed the capacity to acquire feature cues from the environment in a prioritized and non-linear pattern (Wiggins & O’Hare, 1995; Wiggins, Stevens, Howard, Henley, & O'Hare, 2002). Individuals with lower cue utilisation are more likely to select information in the sequence in which it is presented (e.g., from left to right as they appear on the display screen). Higher cue utilisation is associated with a relatively lower ratio of pairs of information screens accessed in the sequence in which they are presented, against the total frequency of pairs of information screens selected. A lower score in this task, was therefore indicative of higher cue utilisation.

The criterion validity of EXPERTise has been established in a number of different domains in which typologies formed on the basis of EXPERTise performance differentiated workplace-related performance (Loveday, Wiggins, Searle, Festa, & Schell, 2013; Loveday, Wiggins, Harris, O'Hare, & Smith, 2013; Loveday, Wiggins, Festa, Schell, & Twigg, 2013). The test-retest reliability (Kappa = .59, p < .05) has been demonstrated with power control operators at six-monthly intervals (Loveday, Wiggins, Festa, Schell, & Twigg, 2013). In the present study, restricting the age of participants (18-22 years) controlled for exposure to driving experience. This ensured that any differences in cue utilisation would be unlikely to result from differences in driving experience.

Rail control task

A simulated rail control task (used previously by Brouwers et al., 2016; Brouwers et al., 2017) was used as a novel, low-workload context for the present study. In this task, a computer screen depicted a simulated, simplified rail control display (see Figure 1). The four long, horizontal green lines shown in the display represented railway tracks. Each track incorporated an intersection (depicted by white portions on the track), which was controlled by an interlocking switch labelled, 'Change'. This switch was depicted by a small circle icon, located above each track. On selecting the "Change" icon, (with a computer mouse), any train travelling on the connected track was diverted onto the intersecting line. A train was depicted by a short, red horizontal bar that appeared at one end of a train line, and travelled across the display.

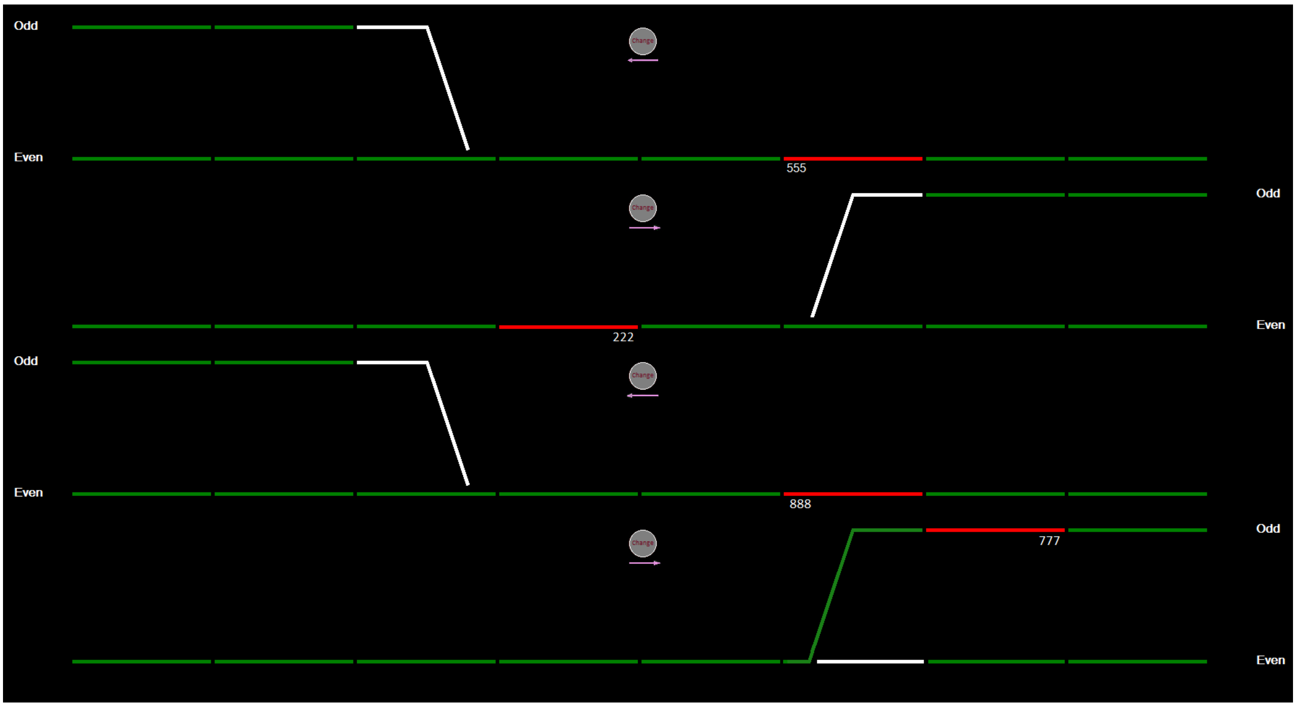

Figure 1. The simulated rail-control display as viewed by participants. Participants were given the following rule: "Even-numbered trains must run along even-labelled lines and odd-numbered trains must run along odd-labelled lines". The red lines represent trains and the four long, horizontal green lines represent railway tracks. The white portions on each track are the intersection lines, which are controlled by an interlocking switch labelled, "Change". This switch is depicted by a small circle icon, located above each track. If a participant selects the "Change" icon, any train travelling on the track beneath it, will be diverted onto the intersecting line. The train on the lowermost track in this figure is numbered "777". This train is travelling from left to right, moving across the screen, and has been diverted (correctly) onto an odd labelled track.

Each train had a three-digit number assigned as either odd or even (e.g., 333, 888) and each train line and its associated branch line also had an assigned label: Odd or Even. As the train appeared onto the screen, a green line depicted the programmed route of the train. Participants were given the following rule: Even-numbered trains must run along even-labelled lines and odd-numbered trains must run along odd-labelled lines. To ensure this rule was followed, participants were required to periodically select 'Change' to re-route trains whose number did not match its route.

All of the trains in the task progressed at the same speed and once a train emerged onto the computer screen, participants had up to seven seconds in which to decide whether or not to reroute the train. Different trains however, appeared between 6-8 seconds of each other. Therefore, at any given time, the display depicted all four train lines occupied with a train.

A total of 206 trains appeared on the four rail lines over the course of twenty-four minutes, half of which (103 trains) were not required to be re-routed. Designed as a low workload, sustained attention task, the primary goal of the participant was to attend to the display, identify a match between each train and its planned route, and select the 'change' icon as appropriate so that a train's route corresponds with its number. In the rail task display, if a train was unnecessarily diverted (a false alarm) or failed to be diverted when required (a miss), the word 'incorrect' appeared in red alongside that train's track. As participants in the study were not experienced in rail control, it was anticipated that this feedback would assist in the performance of the task accurately. Data recorded from this task included response latency (in milliseconds, from the initial appearance of a train, to the selection of the 'Change' icon), and the accuracy of responses (whether trains are diverted when required).

Miscues: Stimuli development and pilot study

The rail task utilised in Brouwers et al. (2016) was designed so that all trains that appeared tracks 1 and 4 would require a diversion, while trains that appeared on the remaining two tracks (tracks 2 and 3) did not require a diversion. Track 1 refers to the uppermost rail line in the display, track 2 is directly beneath this line, and track 4 is the lowermost line. As the aim of the present study was to investigate whether changes to this pattern resulted in differences in performance, a pilot study was conducted to investigate the utility of introducing pattern changes and to determine the required sample size for the study. It was important that the pattern change was not so obscure that no participants were able to identify it, nor that the change was so dramatic, that all participants immediately identified the change.

The program that was piloted was in the following format: (a) during the initial eleven minutes of the rail task, participants were given the opportunity to become accustomed to a pattern in the rail task , whereby only tracks 1 and 4 require diversions, (b) during the next 5 minutes, this pattern was completely reversed, and tracks 2 and 3 required diversions, (c) during the next 5 minutes, the original pattern reappeared, representing a second miscue, and (d) in the final 3 minutes of the task, a new and 'mixed version' of the previous patterns appeared wherein tracks 2 and 4 required diversions. This final change represented a third miscue. The total duration of the rail task was 24 minutes and throughout the final 18 minutes, participants diverted trains and completed a secondary task which required them to write down the number of every train, and the time at which it appeared. Figure 2 summarises the experimental timeline for the rail task that was piloted.

Fourteen volunteers participated in the pilot study (9 females and 5 males) with ages ranged from 18 to 21 years (*M* = 19.29, *SD* = 0.91). Prior to undertaking the rail task, basic orientation instructions were provided to the volunteers, and they were exposed to a brief, three-minute trial, in which trains appeared randomly on various tracks in the display (no pattern/s). The instructions for the secondary task were also provided and none of these instructions made reference to a pattern. On completion of the rail task, each volunteer was asked "did you notice a pattern?". Volunteers who indicated that they did, were probed further ("Can you describe the pattern?", "Do you recall if the pattern change?", "How?"), and their responses were recorded verbatim. The response latencies to accurately re-routed trains were recorded from the rail task program.

Four of the fourteen volunteers correctly identified at least one pattern. For example, one of these four volunteers stated,*" I noticed at the beginning I had to change the top and bottom trains but not the others. Then the pattern changed and I don't know after that*". An inspection of the mean response latencies between the volunteers who identified the pattern (n = 4) and those who did not (n =10), suggested a difference in the groups' responses to the first pattern change (the first miscue). For the volunteers who verbally identified the pattern, an increase in mean response latency was evident, whereby a mean response latency of 2855.35 milliseconds in the 4-minute period prior to the miscue, rose to 4371.77 immediately following the miscue. In contrast, the mean response latencies for volunteers who did not verbally identify the pattern, remained relatively stable throughout this same period (changing from 3626.92 msecs to 3371.49 msecs).

As the pilot study results suggested that at least one of the patterns was able to be verbally identified and that the pattern changes impacted the response latency performance of these volunteers, the rail task design used in the pilot study, (as presented in Figure 2), was considered suitable for the study. To determine the sample size required for the study, a power analysis (for a binary outcome trial) was conducted on the pilot study results. Following the results of the pilot study, 29% of the volunteers correctly identified a pattern. With an alpha significance level of .05, power of .8 and adjustment for an expected 5% cross over (participants in the non-success group who might guess correctly), the recommended sample size was 74. Therefore, 75 participants were recruited for the present study.

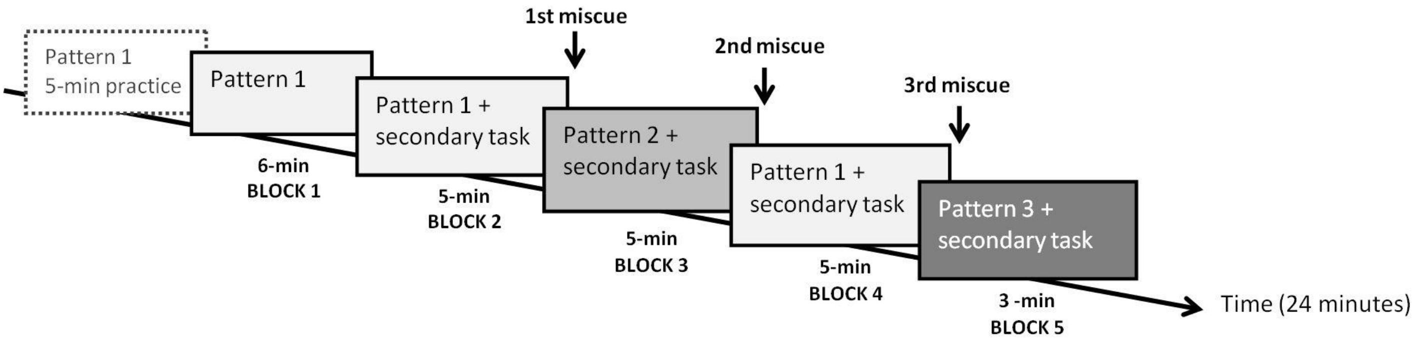

Figure 2. Experimental timeline for the rail task (not to scale). During Blocks 1 -2 participants were given the opportunity to become accustomed to a pattern in the rail task (only tracks 1 and 4 required diversions). In Block 3, a new pattern appeared in the task (only tracks 2 and 3 required diversions). In Block 4, the original pattern reappeared, representing a second miscue. In Block 5, another new pattern appeared in the task (tracks 2 and 4 required diversions), representing a third miscue.

Secondary task

The secondary task utilised in the present study consisted of a two-page form that required participants to write down the train number and time at which the train appeared, for each train in the task. This task has been utilised previously as a secondary task (Brouwers et al., 2016), which suggested the task has utility in increasing the workload associated with the primary rail control task, to an adequate, yet not impossibly high degree.

Subjective workload

Subjective workload was measured with the NASA Task Load Index (NASA-TLX: Hart & Staveland, 1988), a widely-used and validated multi-dimensional rating procedure that provides an overall workload score from 1-100 based on a weighted average of ratings on six subscales: Mental demands, physical demands, temporal demands, performance, effort, and frustration (Hart & Staveland, 1988; Xiao, Wang, Wang, & Lan, 2005). Participants completed the NASA-TLX after Block 1 of the rail task (the single task condition) and again after completing the secondary task condition.

Procedure

Participants were tested individually in 70-80 minute sessions. After providing demographic information via an on-line questionnaire, participants either commenced the rail task, which took twenty-four minutes to complete, or EXPERTise (on-line tasks), which took twenty minutes to complete. The completion of the rail and EXPERTise tasks was counterbalanced. During the completion of EXPERTise, participants were prompted by on-line instructions. The length of the break period was 5 minutes, and while asked to remain in the research room, participants were invited to spend this time however they chose (stretch/walk around/engage with their phone/listen to music and so on). The procedure and order of all tasks is shown in Figure 3.

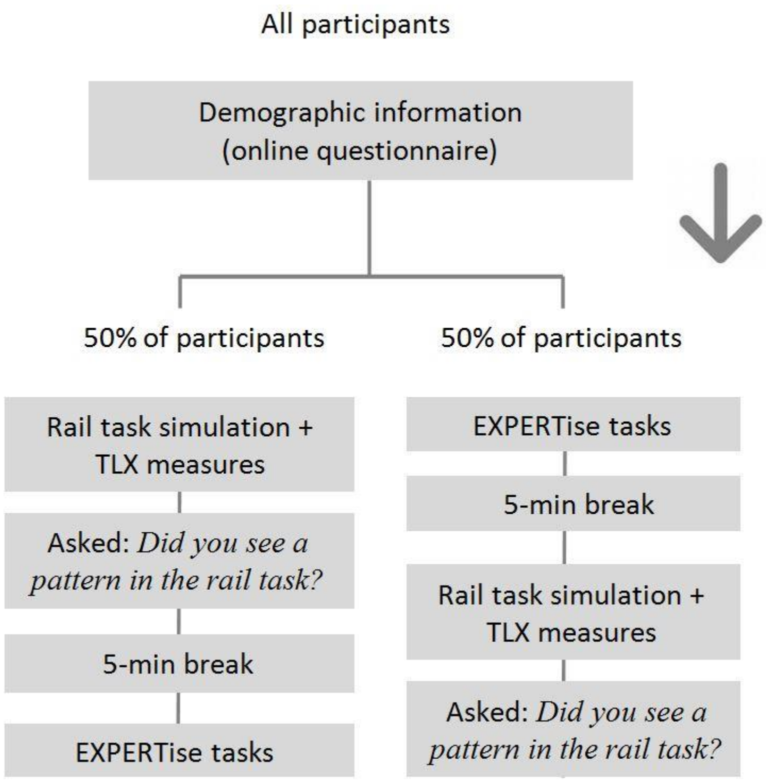

Figure 3. The task order utilised in the present study. While all participants completed the same measures, the completion of the rail and EXPERTise tasks were counterbalanced.

The rail task procedure consisted of an initial five-minute practice trial to orient participants to the rail task. During this trial, standardised instructions for the rail task were provided verbally. Instructions were also provided to participants in relation to the secondary task and they were given the paper-based, secondary-task sheet. To proceed in the rail task, participants were required to demonstrate the accurate diversion of trains immediately following the provision of verbal instructions. Participants then undertook the single-condition component of the simulated rail control task. After six minutes, the researcher paused the rail task and participants completed the NASA-TLX. The rail task then recommenced, and for the remaining eighteen minutes, participants diverted trains and completed the secondary-task sheet concurrently (logging the arrival of trains). The clock used by participants in logging the time of each trains' arrival, was a 22x7 cm-sized digital clock, positioned to the right of the computer monitor, so that no portion of the rail display was obscured. Following the completion of the secondary task, participants completed the NASA-TLX for the second time. At the conclusion of the rail task, participants were asked, "Did you notice a pattern in the rail task?" If they indicated that they had observed a pattern, they were then asked to describe the pattern and their responses were recorded verbatim.

Results

A primary aim of the present study was to investigate the impact of a miscue on performance in the one-minute period immediately succeeding the initial pattern change in the context of a process control task. A secondary aim was to determine the pattern of responses to miscue trials that occurred successively in a process control task.

Preliminary analysis

Rail task performance scores

Response latencies were calculated from the initial appearance of a train to the correct selection of the ‘Change’ icon. This meant that while the frequency of errors was recorded (false alarms or misses), if a participant did not divert a train when no response was necessary, no response time was recorded. The rail task was 24 minutes in duration and the mean response latencies for correct responses were calculated across eight time intervals which included five blocks (during which there were no pattern changes) and three post-miscue intervals, which captured the one-minute period following a pattern change.

To capture the immediate response of participants to the three miscues, a single response latency score was recorded (and named Miscue 1, Miscue 2 and Miscue 3) which constituted the participant's response latency to the single train diversion that immediately followed the pattern change. A total of 206 trains appeared on the four rail lines over the course of twenty-four minutes, half of which (103 trains) were not required to be re-routed (see Table 1). The response latencies captured over the five blocks, the three miscues and the three 'post-miscue' intervals, comprised the dependent variables in subsequent analyses.

The total counts of 'correct hits' (correct diversion of a train), 'misses' (where a train that required diversion was not diverted), 'false alarms' (where a train that did not require diversion, was diverted) and 'correct rejections' (correctly not diverting a train) were collated across all intervals. These responses were examined for response bias to examine whether participants were more or less likely to indicate that a train required diversion (a 'yes' response bias or a 'no' response bias). Based on the signal detection theory calculations from Stanislav and Todorov (1999), the decision criterion (*C*) was calculated by averaging the z-score that corresponded to the hit rate of correct diversions, Z(HR) = 1.89 and the z-score that corresponded to the false alarm rate, Z(FAR) = -2.07. The analysis revealed a negligible response bias (c = 0.09), suggesting that respondents were only slightly more prone to a non-detection ('no') response. While the total number of errors committed throughout the rail task ranged from 0-16, over 60% of participants made fewer than four errors. As a result, the frequency of errors committed (both false alarms and misses) across the 24-minute duration of the rail task, was included as an outcome measure (M = 4.97, SD = 3.60).

Cue utilisation scores

Prior to the analysis, the participants' z-scores across the six EXPERTise tasks were converted into factor scores using the SPSS Confirmatory Factor Analysis (CFA) procedure. Using principle components extraction with varimax rotation, a single factor was extracted (Eigenvalue = 2.14) which accounted for 35.8% of the total variance in the EXPERTise task scores (observed variables). This provided a composite and normally-distributed set of scores reflecting the extent to which each participant's score loaded onto a single, common, cue utilisation factor.

Driving experience and cue utilisation

Overall, participants had accumulated a mean of 37.56 months (or about 3 years) of driving experience (SD = 12.70 months). These mean scores were normally distributed and were not related to cue utilisation (Pearson's r = -.047, p = .691), suggesting that cue utilisation was not related to driving exposure.

Pattern identification

In the rail control task, participants were initially required to divert trains on the uppermost and lowermost lines but never for the middle two tracks. Throughout the 24-min task, this pattern changed three times, presenting participants with three different opportunities to be miscued. Participants were neither informed that the trains would progress in a pattern nor that there were miscues and when they would occur. After the completion of all tasks, each participant was asked, "Did you notice a pattern in the rail task?" and their responses were recorded. The participants who replied that they did not notice a pattern, were coded as unsuccessful in identifying the pattern.

Of the participants who indicated that they did observe a pattern, their responses were examined to establish whether they provided a sufficiently accurate account of the pattern. Provided that the account described at least one accurate pattern (e.g., one or more of the three patterns), they were considered to have successfully identified the pattern. For example, one participant noted, "I noticed the lowest and highest tracks didn’t need to be changed as often as the others". Another replied, "The top and bottom trains had to be changed. Then the middle two. Then every second line". A third participant replied, "The two middle routes didn’t seem to need to be changed". In each case, participants were considered to have successfully recognised the pattern. The successful identification of a rail task pattern (yes, no) comprised an independent, grouping variable in subsequent analysis. Based on their verbal responses, a total of 42.7 percent of all participants (n = 32) successfully identified a pattern in the rail task, while 57.3 failed to identify a pattern (n = 43). The response latencies for the two pattern identification groups (those who did not verbally report a pattern and those who did) is summarised in Table 1.

Table 1

The number of trains that appeared and required re-routing in the rail task and the descriptive statistics for the re-routing of trains by participants who either identified the rail task pattern or did not. Latencies are reported in milliseconds.

			Response latency means (SD)	
	Appeared	Required re-routing	Did not report pattern	Reported pattern
Block 1 (6-min)	52	26	1927.49 (613.6)	1862.32 (554.2)
Block 2 (5-min)	43	21	3078.67 (855.8)	2804.31 (843.2)
Miscue1	1	1	3121.92 (1048.9)	3765.01 (2136.9)
Post miscue 1 (1-min)	8	4	2975.25 (1069.7)	3725.28 (1243.9)
Block 3 (4-min)	34	17	3093.64 (1020.7)	2847.25 (1009.0)
Miscue2	1	1	2921.80 (1982.9)	2674.22 (1319.3)
Post miscue 2 (1-min)	8	3	2815.18 (1126.7)	3013.49 (1304.7)
Block 4 (4-min)	34	17	2773.88 (1044.8)	2646.78 (947.7)
Miscue3	1	1	3103.56 (1638.8)	2730.75 (1514.0)
Post miscue 3 (1-min)	8	4	2697.50 (1002.9)	2333.79 (1015.8)
Block 5 (2-min)	16	8	2774.13 (957.4)	2343.45 (1007.7)
24-min	206	103 (50%)	2843.91 (340.2)	2795.15 (564.3)

Pattern identification and cue utilisation

To investigate whether a relationship exists between cue utilisation and the likelihood of identifying the pattern of train movements, the relationship between cue utilisation and pattern identification was examined using an Independent Samples t-test and Logistic Regression model. The Independent Samples t-test between pattern identification (yes, no) and cue scores indicated that participants who identified the pattern recorded significantly higher cue utilisation scores (M = .500, SD = .978) compared to participants who did not identify the pattern (M = -.370, SD = .853), t(73) = 4.08, p <.001. Participants with higher cue utilisation were 2.87 times more likely (Odds Ratio = 2.87, 95% CI = 1.57, 5.27, p = .001) to report the pattern compared to participants with lower cue utilisation**.**

Impact of the first miscue

Hayes′ (2013) SPSS macro PROCESS (version 2.03) was used to investigate whether pattern identification moderated the relationship between cue utilisation and rail task performance. The moderation model included cue utilisation factor scores as the independent variable, pattern identification (yes, no) as a binary, moderator variable, and mean response latency to the first miscue (milliseconds) as the dependent variable. To ensure that the dependent variable in this analysis captured the *change* in participant's response latency to the first miscue, the response latency to the first miscue was calculated as the difference between the one-minute period following the initial pattern change (post-miscue 1) and the five minutes preceding this pattern change (Block 2). See Table 1.

The overall moderation model was statistically significant, $R\text{-}square$ = .28, F(3,71) =9.19, p < .001 and a significant main effect was evident for pattern identification, t(3,71) = 2.61, p = .011. The mean response latencies of participants who successfully identified the pattern increased by almost one second (a mean difference of 920.97 milliseconds, SD = 1188.87) in response to the first pattern change, while the mean response latencies of participants who failed to identify that pattern changed only slightly, decreasing by 103 msecs, (*SD* = 1068.48).

While a main effect for cue utilisation scores was not statistically significant, $t(1,71) = -.115$, $p = .909$, a significant interaction between cue utilisation scores and pattern identification was evident, $t(1,71) = 5.69$, $p = .020$. This interaction (see Figure 4) provides support for the hypothesised moderating role of pattern identification and indicated that, for participants who identified the rail task pattern, higher cue utilisation scores were associated with an increase in mean response latency when the pattern changed initially (*Pearson's* $r = .52$, $p = .002$), while for participants who did not report the pattern, there was no relationship between cue utilisation scores and changes in response latency when the pattern changed ($r = -.02$, $p = .911$).

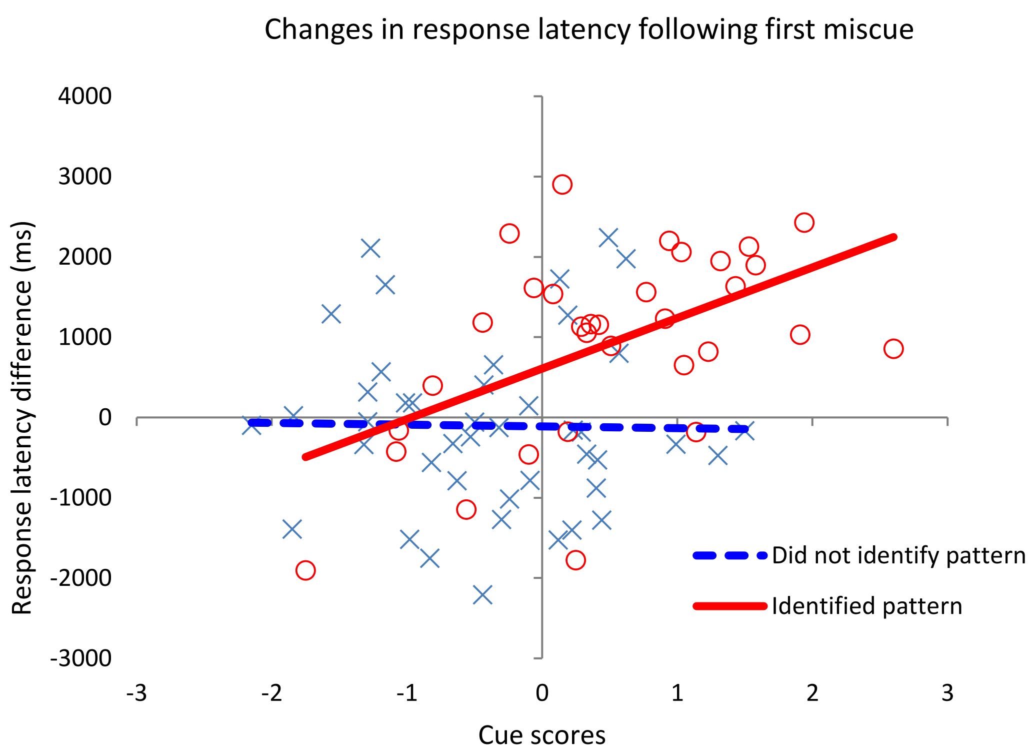

Figure 4. Mean response latency differences to the first pattern change, plotted against cue utilisation scores, and grouped by pattern identification. Linear regression lines are shown.

Pattern of response latencies to miscues

To investigate whether participants differed in their mean response latency across the three changes in pattern, and whether this difference depended upon their cue utilisation, a mixed repeated ANOVA was employed with the three miscue trials as a within-groups variable (Miscue 1, Miscue 2, Miscue 3) and cue utilisation scores as a covariate. The mean of Miscue 1, Miscue 2 and Miscue 3 (the mean time taken by all participants to divert a train immediately following the first pattern change, the second pattern change and the third pattern change) comprised the three dependent variables. A statistically significant interaction effect was evident between miscue trials and cue utilisation scores, $F(2, 146) = 8.80$, $p < .001$, partial $\eta^2 = .108$, (See Figure 5), suggesting that the relationship between cue utilisation scores and response latency changed across the three miscue trials. An inspection of the slopes indicated that, in response to the initial pattern change (Miscue 1), higher cue utilisation scores were associated with greater response latency ($r = .404$, $p < .001$). However, in response to subsequent pattern changes, no relationship was evident between cue utilisation scores and response latency (Miscue 2: $r = -.011$, $p = .926$; Miscue 3: $r = -.024$, $p = .835$).

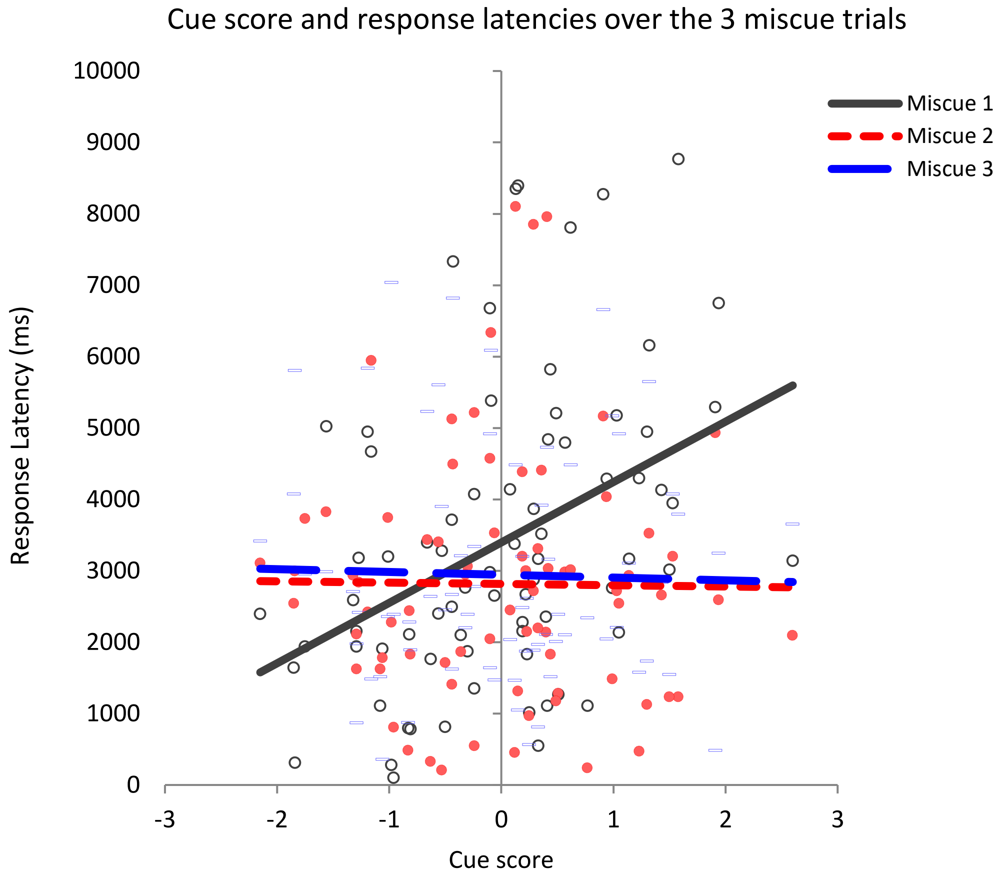

Figure 5. Mean response latency to the three pattern changes (Miscue trials 1-3), plotted against cue utilisation scores. Linear regression lines are shown.

While pattern identification was not expected to be a significant predictor after the first pattern change, the same model (mixed repeated ANOVA) was run with pattern identification as a between-groups variable and as predicted, the interaction between pattern identification and miscue trials was non-significant, $F(2,142) = .190$, $p = .827$.

Subjective workload

Perceptions of workload were examined using a 2 x 2 mixed-repeated ANCOVA, incorporating two categories of pattern recognition (yes, no) as a between-groups variable, two levels of task condition (single, dual) as a within-groups variable, and cue utilisation scores as a covariate. Scores on the NASA TLX scores constituted the dependent variable. As anticipated, the results indicated that overall, a greater level of subjective workload was associated with the dual task condition (M = 52.97, SD = 18.02) in comparison to the single task condition (M = 29.41, SD = 13.86), $F(1, 72) = 302.14$, $p < .001$, partial $\eta^2 = .808$.

No interaction was evident between cue utilisation and task condition, $F(1,72) = .758$, $p = .387$. However, the interaction between pattern identification and task condition was statistically significant, $F(1,72) = 4.39$, $p = .040$, partial $\eta^2 = .057$. Post-hoc tests revealed that the differences in the assessment of subjective workload occurred during the dual-task condition, rather than the single task condition. Participants who failed to identify the pattern of trains recorded significantly greater subjective workload (M = 57.38, SD = 17.29), compared to participants who identified the pattern (M = 47.06, SD = 17.53), $F(1,74) = 6.45$, $p = .013$. This suggests that the capacity to identify patterns of train movement offers advantages in the perception of workload, particularly under subsequent conditions that embody greater demands.

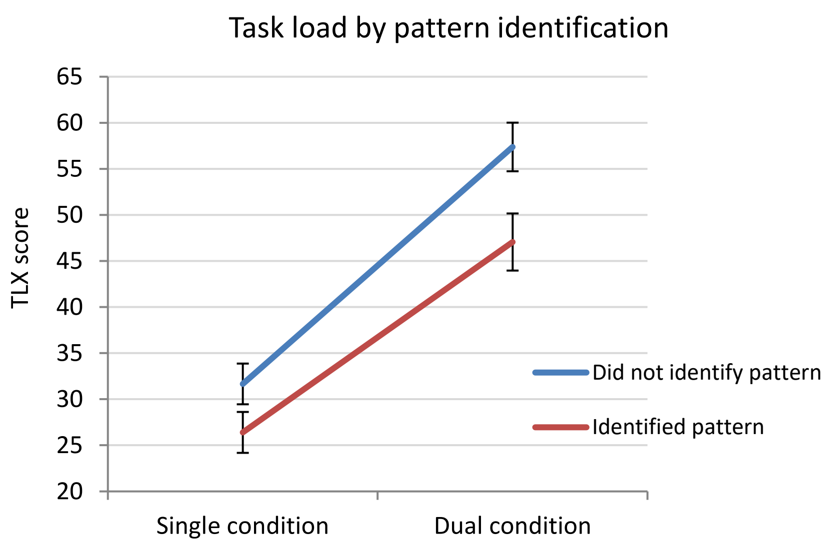

Figure 6. Subjective workload ratings (TLX scores) across single and dual task conditions from participants who identified and pattern and did not identify the pattern. Error bars represent ±1 *SE*.

Discussion

The superior performance of skilled operators across a range of occupational domains, has been attributed to a reliance on cues and patterns, which allow operators, often tacitly, to recognise previous solutions (Klein, 1998; Klein et al., 1986; Orasanu & Connolly, 1993). However, due to the dynamic nature of real-world settings, which are often marked by uncertainty and changing patterns, a sensitivity to cues or patterns, may have the disadvantage of increasing the likelihood of being miscued when unexpected or non-routine events occur following extended exposure to a pattern. The aim of the present study was to examine whether the relationship between cue utilisation and the propensity for miscueing during a simulated rail control task is moderated by pattern recognition.

To control for previously acquired cues and patterns in the domain of rail control, naive participants were recruited, who were inexperienced in rail control operations. The participants completed EXPERTise v. 2.0 which is designed to assess cross-task cue utilisation (Wiggins et al., 2014) and participants also engaged in a 24-minute rail control simulation that required them to monitor and periodically re-route trains according to a train-number and track-label matching rule. Participants were not informed however, that trains on only two of the four tracks required re-routing. If detected and utilised, this pattern represented an opportunity to reduce the workload considerably.

After 11 minutes of exposure, this initial pattern of train movements abruptly reversed (Miscue 1), requiring participants to re-route trains that previously did not require an operator response. After a further five minutes, the pattern changed once again (Miscue 2) and after 3 minutes, a final pattern change occurred (Miscue 3). To provide participants with the opportunity to initially acquire the pattern, in the first six minutes of the rail task participants diverted trains in the absence of any other tasks (single task condition) and throughout the remainder of the rail task, participants completed a secondary task (dual task condition), which was designed to increase the workload and thereby create an implicit incentive for the management of these demands.

It was hypothesised that a greater proportion of participants with higher cue utilisation scores would verbally identify the rail task pattern (H1) and that pattern recognition would moderate the relationship between cue utilisation and rail task performance in response to the initial miscue (H2). It was also hypothesised that during the initial miscue, there would be a positive relationship between cue utilisation and response latency, while in subsequent miscue trials, no relationship would be evident between cue utilisation and response latency (H3). All three hypotheses were supported.

Consistent with H1, participants with higher cue utilisation were 2.9 times more likely to identify the train pattern, compared to participants with lower cue utilisation. The results of the moderation model (H2) indicated that, for participants who verbally identified the rail pattern, higher cue utilisation was associated with an increase in mean response latency to the initial miscue, while for participants who did not identify the pattern, no relationship was evident. Consistent with H3, during the initial miscue, higher cue utilisation scores were associated with a greater response latency, and during subsequent pattern changes (miscues 2 and 3), no relationship was evident between cue utilisation scores and response latency. These findings provide support for the relationship between cue utilisation and pattern recognition, and are generally consistent with descriptions of cue utilisation as being an associative or pattern recognition process (e.g., Banning, 2008; Juslin, 2000; Williams, Ward & Smeeton, 2004), rather than differences in cognitive ability (Brouwers et al., 2016) or personality (e.g., risk taking propensity or conscientiousness).

In real-world settings, as illustrated by the 1989 Hillsborough stadium disaster (BBC, 2016; Nicholson & Roebuck, 1995), seemingly innocuous and routine associations such as attributing crowd noise to crowd revelry, can have significant consequences. Major disasters often stem from proportionately 'minor' or 'normal' causes, such as interruptions to activities or plans (Perrow, 1984; Reason, 1997) or to routine actions and decisions in the workplace (Vaughan, 1997; Weick, 1993). Importantly, increased workloads can exacerbate the tendency to regress toward learned behavioural responses (Allnutt, 1982; Barthol & Ku, 1959) and, as noted by Rudolph and Repenning (2002), unexpected events can often produce "cues that are either invisible or defy existing categories" (p. 1).

Differences in the ‘visibility’ of cues is associated with capture errors (Reason, 1990) where the presence of one or more key features triggers or ‘captures’ more familiar action sequences in memory. Pocketing a borrowed pen, or unintentionally driving to the office instead of the supermarket, are examples of capture errors. However, they are also evident in clinical diagnostic errors (Graber, Franklin, & Gordon, 2005; Norman & Eva, 2010). For example, during winter periods, general practitioners become very familiar with young children presenting with symptoms of influenza. The presentation of these symptoms is very similar to the early stages of the much less common viral meningitis (Chadwick, 2005; Peltola, Ziegler, & Ruuskanen, 2003). Therefore, it has the tendency to miscue medical practitioners to a disease with a rapid onset and fatal outcomes that tends to affect young children (Peltola et al., 2003).

The results of the present study are consistent with the view that cue-based reasoning, driven by associational, heuristic processes (Croskerry, 2009; Evans, 2008; Evans & Frankish, 2009; Gigerenzer & Goldstein, 1996), can assist operators in making rapid and accurate judgements (Kahneman & Klein, 2009; Klein, 2008), yet may also be subject to error (Kahneman, 2003; Tversky & Kahneman, 1974; Tversky & Kahneman, 1990). Importantly however, the results of the present study suggest that there are individual differences in the propensity to acquire patterns and to be miscued by changes in routine.

In the present study, participants who rapidly acquired task-related patterns and formed associational cues, demonstrated an increased tendency toward miscueing. While participants with higher cue utilisation demonstrated an increased vulnerability to miscueing, this occurred only after the *initial* pattern changed. When faced with continued changes in patterns, the performance of these individuals returned to, and remain relatively stable at, pre-disturbance levels, demonstrating an adaptation to changing conditions. This provides support for the notion that operators' trust in the system can be compromised when automated systems fail or do not perform as expected (Parasuraman & Riley, 1997; Sheridan & Farrell, 1974; Wickens & Hollands, 2000). It may also reflect the fact that feedback was immediately available (e.g., a continued reliance on the initial pattern would have resulted in misrouted trains), which allowed participants to discard unreliable or invalid cues and patterns and quickly identify a new pattern to the effect.

Implications

The present research has demonstrated that there are individual differences in cue utilisation which has an impact on the susceptibility to changes in patterns and routines. These results suggest that there may be opportunities to optimise the relationship between operators and the work environment through initiatives relating to selection, training and/or design (technology). For example, depending on the job role, there is the potential to select those individuals who have a higher or lower propensity to be miscued following an extended period of routine operations. Similarly, in training contexts, support might be provided for employees to identify key features and patterns, while remaining sensitive to changes in routines. In high-consequence environments, it is important to enable learners, and particularly those operators with high cue utilisation, to test the boundaries and thereby elucidate the underlying patterns of behaviour of stimuli. This can be achieved by exposing trainees to a range of real-world or simulation settings that vary in complexity, time-pressure and cue availability, thereby enabling them to acquire cues, yet also detect and adapt to dynamic settings.

Finally, technologies such as alarm systems may assist operators by warning that a pattern of movements is non-normal or that a routine has changed. There are existing technologies such as diagnostic alarm systems designed for use in medical fields (Baig, GholamHosseini, Lee, & Harrison, 2011; Curtis et al., 2008), that alert staff to critical events and pattern changes in a patient's state.

Future research

In the present research, a specific set of train movement sequences was embedded within a train control task to examine whether individuals who are faster to detect and acquire patterns, also have an increased proclivity to be miscued during an initial change in the sequence of movements. As it was necessary to control for prior exposure to train control, non-rail controllers were recruited. To examine whether the same individual differences in performance outcomes apply to rail controllers, future research should be directed towards explorations of the extent to which adherence to patterns and routines results in miscueing amongst experienced operators. A longitudinal approach will be particularly useful in examining the extent to which cue utilisation and pattern recognition in trainee rail controllers predicts performance over the longer term.

Conclusion

The aim of the present study was to examine whether the relationship between cue utilisation and the propensity for miscueing during a simulated rail control task, is moderated by pattern recognition. The results supported a moderating role of pattern recognition and suggested that, while a sensitivity to cues and a proclivity to rapidly acquire patterns during routinized tasks are generally associated with superior performance, these advantageous characteristics can also miscue performance, particularly in routinized environments when these patterns change.

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General Discussion

Over the last several decades, research across a number of practice domains has suggested that the advanced perceptual-cognitive skills or cue utilisation of experts (Abernethy, 1987; Aglioti, Cesari, Romani & Urgesi, 2008; de Groot, 1978; Chase & Simon, 1973; Jackson, Warren & Abernethy, 2006; Mann et al., 2007; Smeeton, Ward & Williams, 2004; Williams et al., 1999; Williams, 2000) enable these operators to excel in tasks that rely upon anticipatory decisions and the formation of rapid responses (Klein, Calder-wood, & Clinton-Cirocco, 1986; 2010; Klein, 1998). Indeed, skilled performance itself has been characterised by rapid and accurate responses, often in complex and dynamic situations (Beilock, Bertenthal, McCoy, & Carr, 2004; Ericsson & Lehmann, 1996; Salthouse, 1991). These specialised associations, which represent situation-specific relationships between environmental features (i.e., visual features) and outcomes or objects, are referred to as cues (Brunswik, 1955; Klein, Calderwood & Clinton-Cirocco, 1986; Wiggins, 2014). The retrieval and activation of cues from long-term memory has the advantage of imposing relatively few demands on working memory resources (Chung & Byrne, 2008; Evans, 2008; Norman & Shallice, 1986).

Cue utilisation has been described as a pattern recognition or associational process (Banning, 2008; Williams, Ward & Smeeton, 2004). However, the cognitive mechanisms that underlie cue utilisation remain unclear. Given that cue utilisation encompasses the capacity to identify key features relevant to a task or objective, create causal relationships between these key features and events, retain this information in long-term memory, and then apply this to different environments and contexts (Oaksford, 2000; Wiggins & Bollwerk, 2006), it has been argued that pattern recognition presents a likely mechanism that underpins cue utilisation (Smeeton et al., 2004).

The achievement of expertise relies upon focussed, practice-related activities (Ericsson, 2007; Ericsson, Krampe, & Tesch-Roemer, 1993) undertaken for a minimum period of ten years (Simon & Chase, 1973; Bloom, 1985). However, individuals with the same number of years within a field, or having undertaken the same training, will often not achieve the same level of performance and expertise (Ackerman & Beier, 2007; Hambrick et al., 2014; Scardamalia & Bereiter, 1991). This has led to the view that practice is a necessary but not sufficient condition for the attainment of expertise (Campitelli & Gobet, 2011).

Given that cue acquisition appears integral to the progression of skill, and that individuals differ in their rates of learning and progression toward expertise, a key question is whether there are individual differences in the propensity to acquire cues and form feature-event associations. A further two questions pertain to the nature of cue utilisation itself: (a) *Is a greater propensity for cue utilisation associated with a reduction in cognitive load in task-related contexts*?. and (b) *is cue utilisation associated with pattern recognition processes*? The four studies conducted within the present thesis were designed to address these questions.

Studies 1 and 2 were designed to examine whether differences in cue utilisation were associated with differences in performance during a novel, simulated rail control task, and whether these differences reflected a reduction in cognitive load. Both studies were conducted with motor vehicle drivers aged between 18 and 22 years who undertook an assessment of cue utilisation using the driving battery of The Expert Skills Evaluation (EXPERTise 1.0). In Study 1, based on the proposition that a propensity for cue acquisition enables the rapid identification of feature-event relationships, it was hypothesised that the performance of participants with higher cue utilisation would, over a consistent period of exposure to a novel task, be impacted to a relatively lesser extent by the imposition of cognitive load. As the task was designed as a sustained attention task, it was presumed to draw on cognitive resources, consistent with Resource Theory. On this basis, it was expected that while all participants would show an increase in response latency (for accurate responses in the rail task) over time, participants with lower cue utilisation would record a greater increase in mean response latency in comparison to participants with higher cue utilisation.

The results however, indicated that participants who were identified a priori with relatively higher cue utilisation on the basis of their scores on EXPERTise 1.0, recorded a mean response latency *greater* than that recorded by participants with lower cue utilisation. The effect remained consistent across the four blocks of five-minute trials throughout the rail-control task. Importantly, there were no differences in accuracy and, in fact, a floor effect was evident in relation to errors. A vigilance decrement was evident in the increases in response latency recorded across blocks of trials, irrespective of participants' level of cue utilisation. This suggested that, although an increase in cognitive load may have been associated with sustained attention to the task, the level was insufficient to differentiate the performance of participants on the basis of their cue utilisation.

One explanation for these results is that it was possible to re-route trains during the rail simulation task up to seven seconds from the first appearance of a train. Participants with greater cue utilisation may have recognised this opportunity and utilised the additional time. Since there were no differences in the accuracy of responses amongst the two groups, participants with greater cue utilisation might have recognised that time was available in which to initiate a response to reroute misrouted trains, and adopted a strategy of self-pacing, which can increase task control and reduce cognitive demands (Johansson, 1981; Salvendy & Smith, 1981; Scerbo, Greenwald, & Sawin, 1993).

Study 2 was designed to test this explanation and consequently, adopted a methodology similar to Study 1 but included a secondary task to invoke an explicit cognitive load part-way through the simulated rail control task. The performance of participants in Study 2 during the initial two blocks of trials (which replicated Study 1) appeared consistent with the results from Study 1, whereby the response latency recorded was higher for participants with higher cue utilisation. However, once the secondary task was initiated, the response latencies of participants with lower cue utilisation increased, while the response latency amongst participants with higher cue utilisation remained relatively consistent. Consistent with the hypothesis, this suggested that the relative impact of the secondary task was greater for participants with lower cue utilisation than it was for participants with higher cue utilisation.

Overall, the results of the experiments in Studies 1 and 2 provide support for the assertion that a relatively greater capacity for cue utilisation is associated with an increased capacity to cope with the demands of a novel task. In response to a novel task, the rapid development of associational cues in memory is one means by which the cognitive demands of a task can be minimised (Chung & Byrne, 2008; Evans, 2008; Norman & Shallice, 1986). The relative consistency of response latencies recorded for participants with higher cue utilisation across all blocks, despite the imposition of a secondary task, suggested that they had adopted a strategy that reduced the demands on cognitive load.

Throughout both experiments, several control measures were utilised to ensure that performance differences between individuals with lower and higher cue utilisation were not due to cognitive ability, cognitive style, attentional control, or spatial ability. These variables were not related to performance during the rail control task. Consistent with previous research (Moore & Muller, 2014; Muller & Abernethy, 2012; Smeeton, Ward & Williams, 2004; Wiggins et al., 2014), the results of Studies 1 and 2 suggest that a propensity to identify critical cues and rapidly establish feature-event relationships may provide an opportunity to reduce cognitive demands, thereby enabling the acquisition of new features and/or the opportunity to revise or refine existing features.

Based on the results of Study 2, it was unclear whether the performance of participants with higher cue utilisation reflected a *deliberate* strategy of least cognitive effort insofar as those participants with greater levels of cue utilisation recognised and utilised the time available, or whether it was simply a response to the initial demands of the task. There also remains an overarching question as to whether cue utilisation is related to pattern recognition. Study 3 was designed to examine whether the performance of participants with greater cue utilisation during a novel, simulated rail control task, reflected strategies to reduce cognitive load, or whether a reduction in cognitive load was an outcome of cue utilisation.

Consistent with methodologies in Studies 1 and 2, the participants in Study 3 were motor vehicle drivers aged between 18 and 22 years who undertook an assessment of cue utilisation using the driving battery of EXPERTise 2.0 and completed a 20-minute train task that required them to monitor a display and re-route trains the numbers for which were inconsistent with their track label. During Phase 1 (the initial 10 minutes), the participants were asked to manage trains as quickly as possible in the absence of any other tasks, while in Phase 2 (the remaining 10 minutes), a secondary task was included.

To provide participants with the opportunity to recognise and respond to key features or patterns of features within the rail-control task, trains in Study 3 were programmed to appear on the display in a specific sequence, and only those trains on two specific lines requiring re-routing. The inclusion of this pattern was not disclosed to participants and it was reasoned that the pattern would enable participants to anticipate trains that required a diversion, thereby providing an opportunity to reduce cognitive load. Further, to ensure that the workload imposed by the rail task was sufficiently high (incentivising efforts to reduce workload), a greater number of trains was programmed to appear in the rail task. While the train logging sheet was retained as the secondary task, both tasks were calibrated to ensure that they imposed relatively lower and higher workloads.

On the assumption that the performance of participants with higher cue utilisation is an outcome or product of their increased capacity for cue utilisation, it was expected that there would be no difference in rail task performance between participants with higher and lower cue utilisation in Phase 1, while in Phase 2, (under increased workload conditions), participants with higher utilisation would respond faster and would make fewer errors (in the diversion of trains) than participants with lower cue utilisation. This outcome would provide support for the assumption that, rather than actively attempting to manage cognitive load (by, for example, using the available time to divert trains), individuals with relatively higher cue utilisation acquire cue-based patterns, which results in a reduction of cognitive load, thereby enabling rapid and accurate task performance.

Consistent with expectations, the higher and lower cue utilisation groups were associated with differences in performance in the second phase of the rail task (dual-task condition), where, compared to participants with higher cue utilisation, those participants with lower cue utilisation demonstrated significantly greater mean response latencies together with a greater frequency of errors. Moreover, an interaction was evident between cue utilisation and block trials, in which the mean response latencies for participants with lower cue utilisation increased to a greater degree than the response latencies of participants with higher cue utilisation. As there were no statistically significant differences in the response latencies nor the frequency of errors between the groups in Phase 1, the results provide support for the proposition that performance amongst participants with higher cue utilisation may be a function or by-product of their ability to identify features in the rail task, rather than an active intention to reduce cognitive load.

During Study 3, participants were asked if they were aware of a pattern in the rail task and the results revealed a statistically significant relationship between cue utilisation and pattern identification, with those participants in the high cue utilisation group 11 times more likely than those in the low cue utilisation group, to report the pattern accurately. Participants who successfully identified the pattern in the rail task also perceived the workload in the dual-task phase as significantly lower than those participants who failed to report the pattern. Several control variables were included in Study 3 to ensure that performance differences between individuals with lower or higher cue utilisation were not due to attentional control or perspective taking and spatial orientation ability. The results suggested that the relationship between cue utilisation and response latency was not explained by differences in attentional control, perspective taking nor spatial orientation ability.

These outcomes, combined with the pattern of interaction results associated with errors and response latency, suggest that participants with higher cue utilisation may have an increased capacity to rapidly identify and acquire feature-event relationships which affords them the opportunity to anticipate and make predictions (e.g., anticipate trains that require diversions), and, in doing so, reduces the impact of cognitive load. Therefore, the results of Study 3 suggested that the performance of participants with greater cue utilisation during the simulated rail control task did not reflect strategies *to* reduce cognitive load, but rather, reflected a reduction in cognitive load as an *outcome of* cue utilisation. A relatively greater capacity for generalised cue utilisation appears to be associated with a capacity to manage increasing workload demands when completing a novel task. This is consistent with previous research (Moore & Muller, 2014; Muller & Abernethy, 2012; Smeeton, Ward & Williams, 2004; Wiggins et al., 2014), which suggests that a propensity to identify critical cues and rapidly establish feature-event relationships may provide an opportunity to reduce cognitive demands, thereby enabling the acquisition of new features and/or the opportunity to revise or refine existing features.

While there was no specific hypothesis in relation to pattern recognition in Study 3, it was noted that higher cue utilisation was significantly associated with the recognition of the train movement sequence (the pattern). This is consistent with the notion that cue utilisation is an associational or pattern recognition process (Banning, 2008; Juslin, 2000; Williams, Ward & Smeeton, 2004). It may be the case that higher cue utilisation during a novel task reflects pattern-recognition, which results in a reduction of cognitive load and improved performance. While this has not yet been subject to empirical investigation, a related and perhaps more profound question, is whether there are disadvantages to an 'increased sensitivity' to patterns and cues. It might be argued for example, that a propensity to rapidly acquire and rely on patterns and routines will also increase an operator's tendency toward being miscued (activating/relying on inappropriate associations in memory), particularly in situations where patterns or routines change unexpectedly. The empirical assessment of miscueing with cue utilisation can be viewed as an important step towards bridging two, seemingly incongruent notions of cue utilisation. According to a naturalistic approach, cue-based reasoning is driven by associational, heuristic processes (Croskerry, 2009; Evans, 2008; Evans & Frankish, 2009; Gigerenzer & Goldstein, 1996) that can assist operators in making rapid and accurate judgements (Kahneman & Klein, 2009; Klein, 2008). However, according to the rational account, these same processes are synonymous with bias and error (Kahneman, 2003; Tversky & Kahneman, 1974; 1990).

Following similar methodologies to those used in Study 3, Study 4 was designed to examine: (1) whether the relationship between cue utilisation and rail task performance depended upon pattern recognition (a moderating relationship) (2): whether individuals who demonstrate higher cue utilisation and who rapidly acquire task-related patterns, have an increased tendency toward miscueing, and (3): whether participants with higher cue utilisation would continue to be miscued by repeated changes to the rail task pattern.

A key difference in Study 4 was the inclusion of multiple rail movement patterns in the rail task. While the rail task in Study 3 contained a single and consistent pattern of rail movement, the rail task in Study 4 included three different patterns of rail movement. Each of these patterns were programmed to change abruptly during the course of the twenty-four-minute rail task. It was reasoned that if participants who acquired the pattern were reliant on the pattern to formulate rapid and accurate train diversions, the initial, abrupt change to this pattern would represent a miscue, and result in a temporary reduction in performance.

Reduced performance, it was reasoned, would be evident in *slower* responses to accurate train-diversion responses, coincident with the initial pattern change. Based on the assumption that pattern recognition is associated with cue utilisation, this decrement in performance was expected from participants with higher cue utilisation, specifically under increased workload conditions (during the secondary task), and following exposure to the rail task pattern. While the first pattern change was likely to result in a temporary decrement in performance, it was assumed that the participants who had detected and relied on the pattern would thereafter experience a lack of trust in the system and, as a result, further pattern changes were unlikely to impact performance.

In Study 4, it was hypothesised that: (1) a greater proportion of participants with higher cue utilisation scores would verbally identify the rail task pattern; (2) pattern recognition would moderate the relationship between cue utilisation and rail task performance in response to the initial miscue; and (3) during the initial miscue, there would be a positive relationship between cue utilisation and response latency, while in subsequent miscue trials, no relationship would be evident between cue utilisation and response latency. The results of Study 4 provided support for these hypotheses. Participants with higher cue utilisation were 2.9 times more likely to verbally identify the train pattern, compared to participants with lower cue utilisation. Moderation was evident insofar as higher cue utilisation was associated with an increase in mean response latency to the initial miscue, but only for participants who verbally identified the rail pattern. For participants who did not identify the pattern, no relationship was evident.

Finally, during the initial miscue, higher cue utilisation scores were associated with a greater response latency, while during subsequent pattern changes (miscues 2 and 3), no relationship was evident between cue utilisation scores and response latency.

Consistent with the results of Studies 1-3, these findings support the view that cue utilisation is an associational or pattern recognition process (e.g., Banning, 2008; Juslin, 2000; Williams, Ward & Smeeton, 2004). These findings also suggest that learners who can rapidly acquire task-related patterns and form associational cues, may have an increased tendency toward miscueing. This is consistent with the view that cue-based reasoning, driven by associational, heuristic processes (Croskerry, 2009; Evans, 2008; Evans & Frankish, 2009; Gigerenzer & Goldstein, 1996) can assist operators in making rapid and accurate judgements (Kahneman & Klein, 2009; Klein, 2008), yet may also be subject to bias and error (Kahneman, 2003; Tversky & Kahneman, 1974; 1990).

Operators with higher cue utilisation may experience a relatively greater risk of initially misapplying rules or misdiagnosing situations in routinized environments when there is a change in stimuli. According to Kahneman and Klein (2009), an environment of sufficient regularity (which provides valid cues to situations) is necessary for the development of expertise. However, an overreliance on perceived regularities in the environment or invalid cues can contribute to overconfidence and lead to poor intuitive judgments and decisions in some cases.

Taken together, the results of Studies 1-4 suggest that: (a) a relatively greater capacity for cue utilisation appears to be associated with a capacity to manage increasing workload demands when completing a novel task, (b) a reduction in cognitive load appears to reflect an outcome of cue utilisation, rather than conscious strategies to reduce cognitive load, (c) cue utilisation is an associational or pattern recognition process that affords learner-operators a performance advantage in managing the increasing workload demands within learning tasks, and (d) learners who can rapidly acquire task-related patterns and form associational cues may also have an increased tendency toward miscueing.

Cue utilisation and pattern recognition

A key and overarching aim of the present body of research was to investigate the underlying mechanisms of cue utilisation and explain how cue utilisation impacts performance. The observation that cue utilisation can aid an individual's progress toward expert performance (Fadde, 2006; Jarodza et al., 2012; Müller & Abernethy, 2012; Paull & Glencross, 1997; Wiggins, Brouwers, Davies, & Loveday, 2014), has not explained *how* cue utilisation drives performance. The ability of experts to rapidly respond to a situation has been referred to as 'intuitive pattern matching' (Kahneman & Klein, 2009; Klein, 1993; 1998), 'fast and frugal reasoning' (Goldstein & Gigerenzer, 1996), 'proceduralised responses' (Anderson, 1982; 1993) or triggered 'case-based matching' (Dreyfus & Dreyfus, 1986; Logan, 1988). Thus, while cue utilisation has been described as an associative or pattern recognition process (Banning, 2008; Juslin, 2000; Williams, Ward & Smeeton, 2004), this has not previously been subject to empirical investigation. In the present set of studies, we examined the impact of cue utilisation on performance and the underlying mechanisms of cue utilisation from a number of different perspectives and through the use of various manipulations.

In the present programme of research, the initial study was conducted with the aim of investigating the impact of cue utilisation on performance in a simplified and novel rail control task. The results indicated that there were significant differences in the performance of participants with higher and lower cue utilisation. Throughout the 20-minute rail task, the mean response latency of participants with higher cue utilisation remained significantly greater, compared to participants with lower cue utilisation. While this appeared somewhat counterintuitive to the notion that cue utilisation is associated with superior performance, it was noteworthy that accuracy and not speed, was emphasised in the rail task instructions and that there were no differences in the accuracy of responses between the two groups.

As a simplified and monotonous task, the rail task placed relatively low work demands on participants. Further, the decision to re-route trains in the rail simulation task could be initiated up to seven seconds from the appearance of a train, and therefore, those participants with greater cue utilisation may have recognised this opportunity and utilised the additional time, without sacrificing accuracy. As a consequence, it was unclear from this initial study whether participants with higher cue utilisation identified and relied on task cues (such as decision-time features), and recognised that they had to time to respond, or whether their performance was, indeed, poorer than participants with lower cue utilisation.

In Study 2, a manipulation of the workload demands was used to clarify whether the identification and use of cues was impacting the performance of participants in the rail task. In designing Study 2, it was reasoned that if the differences evident on the basis of cue utilisation were due to the utilisation of cues, then an increase in the task workload should impact differently the performance of participants. On the assumption that increased cue utilisation is associated with reduced cognitive load, an increase in work demands should increase the mean response latency and reduce the accuracy of participants with lower levels of cue utilisation. However, the same demands should have a minimal impact on those participants who are engaging cues.

In Study 2, a secondary task was introduced part-way through the rail control simulation to impose an explicit cognitive demand on the performance of participants. It was expected that during the initial portion of the task, the performance of participants would replicate the outcomes in Study 1, since there was no additional load imposed. However, in response to the increased workload (with the introduction of the secondary task), participants with lower cue utilisation were expected to record an increase in response latency, while no effect would be evident for participants with higher cue utilisation. The outcomes of Study 2 were consistent with this interaction wherein the mean response latencies for participants with lower cue utilisation increased following the introduction of the secondary task and continued to increase as the task progressed, while the mean response latencies for participants with higher cue utilisation remained consistent, suggesting that they had adopted a strategy that reduced the impact of the additional load that was imposed.

The outcomes of Study 2 suggested that participants with higher cue utilisation had identified cues in the environment (e.g., decision-time availability) that allowed them some advantage, reducing the demands on cognitive load, and thereby enabling their performance to be less impacted by an increase in cognitive demands. This is consistent with the view that the rapid development of associative cues in memory is a means by which the cognitive demands of a task can be minimised (Chung & Byrne, 2008; Evans, 2008; Norman & Shallice, 1986). However, it was not clear from Study 2 whether the performance of participants with higher cue utilisation, which seemed to be impervious to higher workload conditions during the rail task, reflected an *intention* to reduce cognitive load (that is, the use of cues may be viewed as having the purpose of reducing cognitive load) or whether a reduction in cognitive load was an *outcome* of the cue utilisation process.

Based on the results of Study 2, it was also unclear whether the 'time available' during the rail task was the specific key feature or a repeating feature-pattern, that allowed participants with high cue utilisation to effectively reduce the demands on cognitive resources. Since cue utilisation has the distinguishing feature of focusing on the *way* that humans acquire and respond to information (the pattern of human *responses* to features), rather than on the specific cues or features themselves, it can be more useful to consider whether any feature-event associations (or patterns) were relied upon by participants during the train task. That is, there may be a range of implicit and explicit features available during a task that allow participants to make reliable predictions and to respond adaptively. Therefore, a key challenge in the attempt to investigate cue utilisation, (and its impacts on performance and mechanisms of such) is the possibility that even obscure, instructional aspects of a task, such as the emphasis on accuracy rather than speed, or the availability of decision-making time, can be utilised as cue-features that enable a reduction in a cognitive load.

In designing Study 3, it was reasoned that a somewhat 'salient' cue-based pattern was necessary, which could be programmed within the rail task, but one that would not be disclosed explicitly to participants. Following a pilot study, ‘trains’ in the rail task were programmed to appear on the display in a specific sequence and with only those trains on two specific lines requiring re-routing. This aspect of the task was designed to provide participants with the opportunity to identify and response to key features or patterns of features within the rail-control, and afford them the opportunity to reduce the cognitive demands of the task. With the purpose of motivating participants with high cue utilisation to respond as quickly as possible and to seek out strategies to achieve as much (i.e., by using the rail task pattern), all of the participants in Study 3 were also instructed to respond as fast and as accurately as possible. The pattern utilised in Study 3 constituted visual features (trains on train tracks) that were temporally spaced and situated, and which reliably signified the need for an operator's intervention (a train's diversion). Consequently, the pattern contained meaningful information or ‘critical features’, which presented participants with a means of rapidly and accurately responding to train movements. While the pattern itself instantiated feature-event relationships (cues), the cue utilisation of participants (who had similar years of experience in driving) was also independently assessed through a driving task. All of the participants were initially exposed to the rail task pattern under low workload (single task) conditions,

If cue utilisation represented an *intention* to reduce cognitive load, then participants with high cue utilisation would be expected to immediately (even in the Phase 1 low-workload condition) exhibit differences in performance in comparison to participants with lower cue utilisation. However, if a reduction in cognitive load was an outcome of cue utilisation (that is, if cue utilisation involves the acquisition of cue-based patterns, which results in a reduction of cognitive load, enabling rapid and accurate task performance), then no differences would be expected in the rail task performance between participants with higher and lower cue utilisation (where the pattern was being acquired under low workload conditions).

In Phase 2 however, under increased workload conditions, participants with higher utilisation would be expected to respond faster and would make fewer errors in the diversion of trains, in comparison to participants with lower cue utilisation. The results of Study 3 were consistent with the latter explanation. Performance differences between the group were apparent in Phase 2 of the rail task (the increased workload condition), where, in comparison to participants with higher cue utilisation, participants with lower cue utilisation demonstrated significantly greater mean response latencies, together with a greater frequency of errors.

The results of Study 3 confirmed that the propensity to identify critical cues and rapidly establish feature-event relationships provides an opportunity to reduce the cognitive demands of the task-at-hand. Most notably, under increased workload conditions, the performance of participants with lower cue utilisation was slower and more error-prone, while the performance of participants with higher cue utilisation remained consistent, suggesting an imperviousness to the increased workload. These results supported the proposition that the rapid development and acquisition of feature-outcome/object associations releases or 'frees-up' cognitive resources, thereby enabling learner-operators, to cope with increases in workload. As the rail task performance appeared to be impacted by cue utilisation indirectly, and only after the associative pattern was acquired, the results provided some support for a potential mechanism for cue utilisation. That is, it may be the case that pattern recognition operates as a mechanism, underpinning cue utilisation processes.

Aside from the interaction effect, other results of Study 3 also supported the view that pattern recognition may operate as an underlying mechanism of cue utilisation. For example, in Study 3, participants were asked if they were aware of a pattern in the rail task (and if yes, were asked to describe it) and participants in the higher cue group were significantly more likely than those in the lower cue group, to successfully report and describe the pattern. Participants who successfully identified the pattern in the rail task also perceived the workload in the dual-task phase of the rail task as significantly lower than those participants who failed to report the pattern. Finally, the successful identification of the pattern was associated with fewer errors in the dual-task condition.

With the aim of specifically testing whether pattern recognition operates as a mechanism for cue utilisation, 'miscueing' was utilised as a manipulation in Study 4. In designing the study, it was expected that, if pattern recognition was a mechanism for cue utilisation, then a disruption to an acquired pattern in the train task (e.g., an unexpected change in the train-movement sequence) should coincide with a deterioration in task performance. This decrement in performance would presumably only be demonstrated by participants who had acquired the pattern and were relying on those pattern-specific, associational cues during the completion of the task (participants with high cue utilisation). As a means of examining whether subsequent pattern changes would continue to influence performance, Study 4 also included three pattern interruptions. If a miscue effect was apparent, this would likely occur in response to the initial change in the pattern of train movements (the first miscue, after a period of exposure to the pattern), while subsequent changes would be less impacted because new associations would be acquired (learned) or due to a mistrust in the system.

Using the same train control task from Studies 1-3, the same secondary task manipulation used in Studies 2 and 3, and the same pattern from Study 3 (as the initial pattern), Study 4 provided an experimentally controlled set of conditions which tested a moderation model the aim of which was to establish whether the impact of cue utilisation on performance is dependent upon pattern recognition. The results from Study 4 indicated that, for participants who verbally identified the rail pattern, higher cue utilisation was associated with an increase in mean response latency to the initial miscue, where there was no relationship evident for participants who failed to identify the pattern. These results demonstrated that the impact of cue utilisation on task performance was dependent upon pattern recognition. In isolation, the relationship between pattern recognition and performance was statistically significant (successful 'pattern recognition' was associated with slower responses when the pattern changed), and participants with higher cue utilisation were 2.9 times more likely to identify the train pattern, compared to participants with lower cue utilisation. Together, these results supported a moderation model, suggesting that the relationship between cue utilisation and task performance is reliant upon pattern recognition.

Theoretical contributions

The present programme of research has made four key theoretical contributions. The first of these relates to an explanation for the motivations or impetus for cue utilisation and conceptualises cue utilisation as a generalisable ability (rather than as a skill-based attribute tied to experience). The activation and retrieval from long-term memory, of highly specialised associations or cues, which are representative of situation-specific relationships between environmental features and events or objects (Brunswik, 1955; Klein, Calderwood & Clinton-Cirocco, 1986; Wiggins, 2014), has the advantage of imposing relatively fewer demands on working memory resources (Chung & Byrne, 2008; Evans, 2008; Norman & Shallice, 1986). However, it has hitherto remained unclear whether the performance improvements of individuals with higher cue utilisation, are a *consequence* of participants' ability to quickly establish feature-event relationships in the form of cues and the associated reduction in the demands on cognitive load, or whether performance improvements reflect *active strategies to* reduce cognitive load.

The results from Study 3 in particular, suggested that the reduction in cognitive load evident amongst participants with higher cue utilisation, was a by-product or outcome of their relatively greater capacity to rapidly identify feature-event relationships in an initial task phase (a lower workload condition that exposed them to pattern). Arguably, if a reduction in cognitive load was an active and intentional strategy, enabled by higher cue utilisation, then it would be expected that immediate differences in rail task performance would have been apparent between the lower and higher cue utilisation groups. Instead, the results indicated that a reduction in cognitive load is an outcome of cue utilisation. Importantly, this suggests that cue utilisation may be an ability, rather than a skill-based attribute that is necessarily tied to expertise.

Traditionally, cue utilisation has been conceptualised as arising from experience and as being associated with the performance of experts (Chase and Simon, 1973a; Ericsson & Charness, 1994; Klein, 1989; Klein et al., 2010). However, experience alone does not adequately account for expert performance (Campitelli & Gobet, 2011) and the conceptualisation of cue utilisation as an ability, is consistent with research (Moore & Muller, 2014; Muller & Abernethy, 2012; Smeeton, Ward & Williams, 2004; Wiggins et al., 2014), that suggests that a propensity to identify critical cues and rapidly establish feature-event relationships provides an opportunity to reduce cognitive demands and facilitate performance. Thus, rather than merely being fostered or developed alongside expertise, cue utilisation may provide a foundational element for progression to expertise.

Higher cue utilisation may be a prerequisite for the development of expertise and the rapid acquisition of cues may facilitate performance within any domain of practice or task that relies upon anticipatory decisions and the formation of rapid responses. Further, and as suggested by the outcomes of all four of the Studies in the present programme of research, one's level of cue utilisation can potentially be assessed at a relatively early stage of skill acquisition. The ability to identify levels of cue utilisation may provide the basis to differentiate job applicants that are more or less likely to acquire skills in various conditions (i.e., in the absence of a dedicated training regime) or identify employees who are most in need of a training intervention .

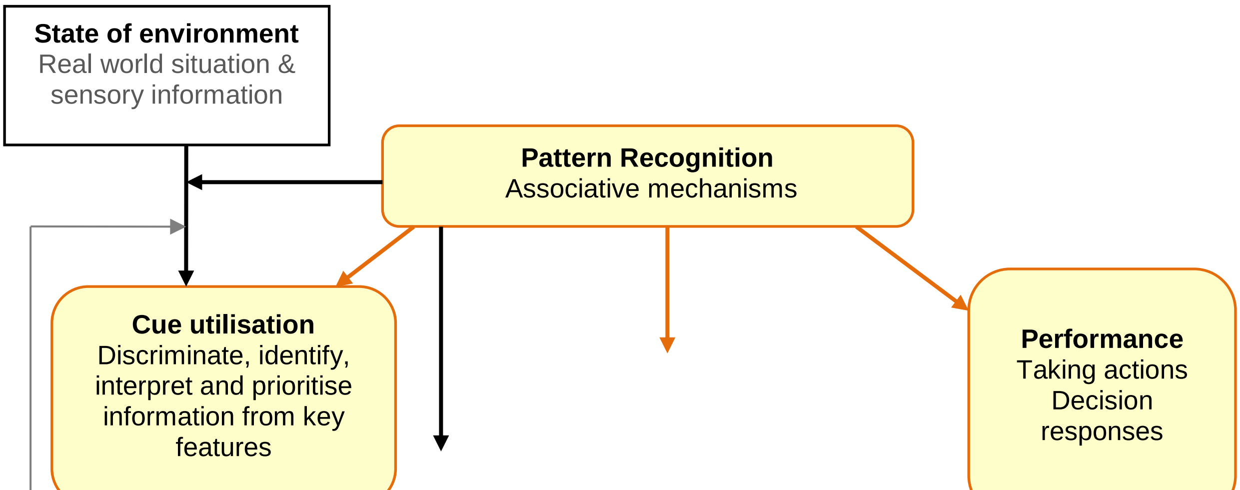
The second theoretical contribution builds on the conceptualisation of cue utilisation as a generalisable ability, and relates to cross-task cue utilisation. If cue utilisation is an ability, then the cue utilisation of learners, assessed in a particular domain (such as driving), should be associated with task performance in different domains, such as those involving rail control or flying. The results of all four Studies supported cross-task cue utilisation, demonstrating a relationship between participants' cue utilisation scores in a set of driving tasks (using EXPERTise 1.0 and 2.0) and subsequent performance in simulated rail control tasks. Similarly, Wiggins, Brouwers, Davies and Loveday (2014) observed that the driving-based cue utilisation scores of learners predicted superior performance in a simulated flight landing task and an unmanned aerial vehicle task. While these results provide support for the view that cue utilisation may be an ability that represents a foundational element of skill acquisition and expert performance, the precise mechanisms that underlie cue utilisation were unclear and formed the foundation for Studies 3 and 4.

Emerging from the outcomes of Studies 3 and 4, the third theoretical contribution is that pattern recognition may act as a potential mechanism for cue utilisation. The results of Study 3 indicated that, throughout increases in workload during the rail task, participants with higher cue utilisation were more accurate and responded more rapidly, and were also more likely than participants with lower cue utilisation, to identify an implicit pattern of rail movements. While this indicated a relationship between pattern recognition and the impact of cue utilisation on performance, it was unclear whether pattern recognition operated as a moderating variable in the relationship between cue utilisation and task performance. Therefore, Study 4 was specifically designed to test a moderation model by incorporating programmed changes to the pattern (miscues). The results confirmed a moderating role for pattern recognition, indicating that, for participants who identified the rail pattern, higher cue utilisation was associated with an increase in mean response latency when the pattern initially changed while, for participants who did not identify the pattern, no relationship was evident between cue utilisation and response latency to the initial pattern change. These results suggested that the capacity to detect and respond to task-related patterns, may act as an underlying mechanism for the impact of cue utilisation on task performance.

The fourth and final contribution made by the present programme of research, is in the provision evidence to indicate that the same cognitive processes that allow individuals to be successful in forming rapid and accurate solutions, are the processes that can also, through errors of judgement, lead to miscues. The results of Study 4 represented one of the first empirical efforts to show experimentally, that a capacity for higher cue utilisation and an ability to rapidly detect patterns of dynamic stimuli, can also give rise to miscueing in environments marked by regularity and routine. The underlying cognitive processes are cue-based or production-based, associative heuristics (Anderson, 1982; 1993; Croskerry, 2009; Evans, 2008; Evans & Frankish, 2009; Gigerenzer & Goldstein, 1996) and while cognitive heuristics, for the most part, operate as successful rules and techniques, (Gigerenzer & Goldstein, 1996; Kahneman & Klein, 2009; Klein, 2008), there are situations where the nature of heuristics is such that the operator can be miscued. For example, during winter periods, general practitioners become very familiar with young children presenting with symptoms of influenza. As the presentation of influenza symptoms is very similar to the early stages of viral meningitis, there are cases where medical practitioners have misdiagnosed children who were in the early stages of viral meningitis (Chadwick, 2005; Peltola, Ziegler, & Ruuskanen, 2003).

Medical practitioners, like others, are prone to miscues because of an underlying tendency to make an assessment or judgement based on the degree to which a feature or event appears to belong, or is similar to, a larger category prototype in memory (Gilovich & Savitsky, 2002; Tversky & Kahneman, 1974). As noted by Rudolph and Repenning (2002), unexpected events can often produce "cues that are either invisible or defy existing categories" (p. 1). In this way, the tendency to group or categorise items according to similar characteristics (Freeman, 1992; Gilovich & Savitsky, 2002; Wagemans et al., 2012) can both assist operators in formulating rapid and accurate judgements (Gigerenzer, Todd & ABC Research Group, 1999; Kahneman & Klein, 2009; Klein, 2008) and be disadvantageous and, on occasion, result in miscues.

In sum, a number of components of cue utilisation have been identified that were hitherto unclear. These contributions form the basis of a re-conceptualisation of the processes that drive and derive from cue utilisation, and are summarised and visually depicted in Figure 4. Within this theoretical model, cue utilisation and pattern recognition are situated as a broader set of cognitive processes that enable situation assessment in high-reliability, dynamic, process-control environments. Several elements of the model, together with their relationships are yet to be empirically explored. Therefore, these components represent potential avenues and platforms for future research.



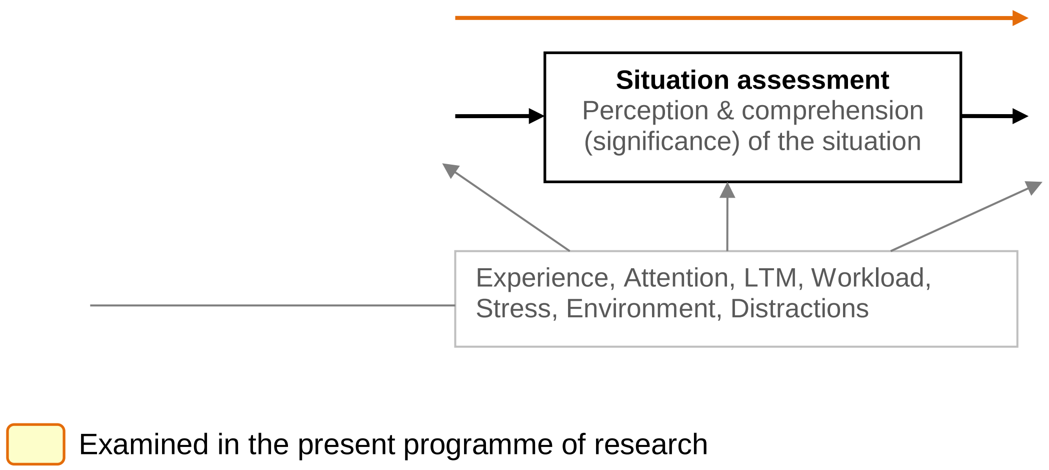


Figure 4. A theoretical model: Cue utilisation as a precursor to situation assessment and its impact on performance moderated by pattern recognition

Implications for applied environments

The present programme of research has demonstrated that there are individual differences in cue utilisation which are associated with: (a) differences in performance in process control tasks such as rail control; and (b) differences in susceptibility to changes in patterns and routines. These differences in performance suggest that there may be opportunities to optimise the relationship between operators and the work environment through initiatives relating to selection, training and/or design (technology). For example, depending on the job role, there is the potential to select those individuals who have a higher or lower propensity to be miscued following an extended period of routine operations. Similarly, awareness training may help improve trainees' awareness of bias (e.g., reminders of the propensity for bias and miscueing) and training content can target strategies to manage miscues. In high-consequence environments, it is important to enable learners, and particularly those operators with higher cue utilisation, to test the boundaries and thereby elucidate the underlying patterns of behaviour of stimuli. This can be achieved by exposing trainees to a range of real-world or simulation settings that vary in complexity, time-pressure and cue availability, thereby enabling them to acquire cues, yet also detect and adapt to dynamic settings.

Finally, technologies such as alarm systems may assist operators by warning that a pattern of movements is non-normal or that a routine has changed. For example, there are existing technologies such as diagnostic alarm systems designed for use in medical fields (Baig, GholamHosseini, Lee, & Harrison, 2011; Curtis et al., 2008) that alert staff to critical events and pattern changes in a patient's state.

The results of the present research also suggested that operators with higher cue utilisation learned to recognise pattern changes relatively rapidly. Importantly, they were not miscued by repeated changes to a pattern within a computer system. In effect, they were not 'fooled twice'. This raises the intriguing possibility that cue utilisation may be a means of identifying, at least in some process control domains such as rail control, 'tomorrow's experts'. Under time pressures and higher workload conditions, operators who are able to implicitly recognise and classify situations based on prior experience (relying on critical cues and patterns), may be the same individuals who are able to respond quickly and adaptively to meet the needs of changing situations (Klein, 2008).

Future directions and limitations

While the present programme of research makes a theoretical contribution and provides implications for applied environments, there are inevitably a number of limitations associated with the outcomes. These limitations and future research recommendations can be summarised under three themes, which include: (a) domain specificity and cross-task cue utilisation, (b) generalisability and experienced operators, and (c) miscues.

Domain specificity and cross-task cue utilisation

Throughout the programme of research, the performance of naive rail controllers in a simulated rail control task was associated with cue utilisation, which was assessed in a driving context. The importance of cross-task cue utilisation is evident in that it can be used to predict the performance of operators in different contexts. However, where cue utilisation has typically been assessed using domain and context-specific assessments, the present study used cue utilisation in the context of driving, to infer performance on rail control, which potentially lacks explicit predication and should be addressed. The impact of cue utilisation on the performance of an early-driver cohort in *driving tasks* (rather than rail control) should be examined. This is important as it would enable an assessment of performance that relates to the context in which the information was acquired.

While the results of the present research suggested that there may be a capacity for cue acquisition that generalises across different tasks, it is not clear whether the association between cue utilisation and rail task performance generalises to other, related contexts. For example, driving and rail control both involve spatial and visual perception and skill, and the version of EXPERTise 2.0 (which was used to assess cue utilisation) may be less capable of differentiating performance beyond this context. To investigate whether one's capacity for cue acquisition can facilitate performance in skill acquisition tasks more generally, there is a need to investigate the impact of cue utilisation across different process control tasks. The impact of cue utilisation on learner-performance in air traffic control, piloting or power control tasks could be a feasible next step. Specifically, piloting allows an hour-by-hour count of exposure, which, from an experimental design, would enable a high degree of control over the operator's exposure. This would help to establish the opportunity for cue acquisition.

From a methodological design perspective, there may also be the potential to construct an edition of EXPERTise that is context-independent. This could be achieved by designing a neutral or more generalised context for assessing dimensions of cue utilisation. The use of facial expression stimuli and human communication scenarios and cues or stimuli derived from nature (animals and landscapes) would be appropriate for this purpose. These types of stimuli would allow a comparison between situations where individuals have a strong degree of familiarity in contrast to situations where individuals have a lack of familiarity (e.g., a novel task).

Generalisability and experienced operators

In the present programme of research, participants comprised a specific cohort (car drivers aged from 18-22 with no rail control experience) and their performance was examined in a specific train-control task over a short period of time. While these strategies were necessary to control for exposure and reduce confounding factors, these constraints also present opportunities for future research. For example, the same set of tasks can be undertaken with (and adapted for) experienced rail controllers, to investigate whether the results are similar for more experienced operators. It is possible that higher cue utilisation may facilitate skill acquisition in the early stages of learning, while exposure/experience, deliberate practice, (as well as quality of training and a variety of other variables) would begin to play a significant role in subsequent learning trajectories. To investigate whether these outcomes extend to a wider population of participants, these experiments should be replicated with non-university students and with participants of varying age ranges. A longitudinal approach will help to make clear how cue utilisation and pattern recognition in learners, both in rail control and within other operational domains, is associated with performance over the longer term. For example, a longitudinal design may involve testing pilots or rail controllers throughout their careers, to understand the impact of cue utilisation on both early and more progressed stages of skill acquisition in real-world, operational contexts.

Miscues

The results of the final study suggested that participants who rapidly acquired task-related patterns and formed associational cues, demonstrated an increased tendency toward miscueing, at least to an initial pattern change. This was a key finding within the present research programme and was important because it suggested that there may be individual differences in cue utilisation which has an impact on the susceptibility to changes in patterns and routines. Replication of the present study is necessary and this can be undertaken using a similar train control task and by the design and use of air traffic control or other process-control tasks, in which miscues (changing sequences and patterns) can be embedded. Future research should be directed towards explorations of the extent to which adherence to patterns and routines results in miscueing amongst experienced operators.

Another area of focus for future research is the investigation of the potential factors that might explain an apparent resilience to miscueing following an initial miscue experience. In the present study, a miscue response was evident from participants who identified the rail task pattern, but it was only the initial pattern change that resulted in a miscue response (e.g., marked by increased response latencies). This initial pattern change occurred after 11 minutes of participants' exposure to a consistent rail movement pattern, while the second and third pattern changes each occurred after only 5 minutes of exposure to new patterns. A key question therefore, is whether the time available for acquiring the pattern (e.g., the learning opportunity) influenced the occurrence of miscues. To test this, a study design with a similar methodology to Study 4, could compare the performance of different groups which have temporally manipulated changes in the programmed pattern. The outcomes of such a design could help disentangle whether exposure duration explains the occurrence of miscues, or whether a decreased vulnerability to miscueing represents an adaptation to changing conditions.

A related issue that should be investigated pertains to the nature of the pattern itself. In the present study (Study 4), the patterns were contrived and required participants to divert the trains on two specific tracks, but not divert other trains. Future studies should explore whether sequences that more closely resemble patterns found in actual operating environments, have the same outcomes. A rail task pattern that could be considered is one where designated trains travel at a slower speed than others. After a period of time, a miscue could be induced by programming these trains to abruptly increase their speed, simulating what might be evident after an upgraded infrastructure service or a release from a delay.

Conclusions

An understanding of the cognitive processes that underlie human mastery and skill acquisition provides a valuable guide for training and development, and enhances current theoretical perspectives concerning human performance and ability. The superior cue utilisation of experts, in extracting visual information and making anticipatory judgements, has been evident across a wide range of operational domains, and cue utilisation has been implicated in models of skill acquisition and appears integral to the progression towards expertise. The present programme of research was designed to investigate the nature of cue utilisation and examine its impact on performance in the early stages of learning a new task/skill. In Study 1, the impact of cue utilisation on the performance of participants was explored using a simplified rail control task. The results indicated that the mean response latency of participants with higher cue utilisation remained significantly higher, compared to participants with lower cue utilisation. One explanation for these results was that the decision to re-route trains in the rail task could be initiated up to seven seconds from the appearance of a train, and therefore, participants with greater cue utilisation may have recognised this opportunity and utilised the additional time.

Study 2 was designed to test this explanation and used a methodology similar to Study 1, but included a secondary task to invoke an explicit cognitive demand part-way through the simulated rail control task. During the low-workload condition, the performance of participants was consistent with the results from Study 1, whereby the response latency recorded was higher for participants with higher cue utilisation. However, once the secondary task was initiated, the response latencies of participants with lower cue utilisation increased, while the response latency amongst participants with higher cue utilisation remained relatively consistent.

These results provided support for the view that participants with higher cue utilisation identified cues in the environment (e.g., decision-time availability) that allowed them some advantage, reducing the demands on cognitive load, and thereby enabling their performance to be less impacted by an increase in cognitive demands. More generally, this suggested that, in the case where participants with high cue utilisation are confronted with a low-workload, novel task with no incentive to respond rapidly (i.e., participants are only given instructions to be accurate), and ample decision-time, the response latencies of participants with higher cue utilisation, compared to those with lower cue utilisation, will remain relatively high, and will reflect a strategy that reduces the demands on cognitive load.

Based on the results of Study 2 however, it was unclear whether the performance of participants with higher cue utilisation reflected a deliberate strategy of least cognitive effort insofar as they recognised and utilised the time available, or whether it was simply a response to the initial demands of the task. In Study 3, a deliberately embedded 'cue-based pattern' was used as a manipulation in the rail task. The results suggested that the reduction in cognitive load evident amongst participants with higher cue utilisation, was a by-product or outcome of their relatively greater capacity to rapidly identify feature event relationships. Furthermore, the results of Study 3 suggested that pattern recognition may operate as an underlying mechanism of cue utilisation. Participants with higher cue utilisation were more accurate and responded more rapidly in the rail task, and were also more likely than participants with lower cue utilisation, to identify an implicit pattern of rail movements.

As pattern recognition was implicated as an underlying mechanism for cue utilisation, the aim of Study 4 was to better understand the mechanisms of cue utilisation and investigate whether the relationship between cue utilisation and performance is moderated by pattern recognition. A further aim was to investigate whether there are disadvantages to an 'increased sensitivity' to patterns and cues. While Study 4 used a similar methodology to Study 3, the use of *miscues* (changes in the programmed pattern of trains) was incorporated as a manipulation in Study 4. The results provided support for a moderation model, indicating that for participants who verbally identified the rail task pattern, higher cue utilisation was associated with an increase in mean response latency to the initial miscue, while there was no relationship evident for participants who failed to identify the pattern. This suggested that the capacity to detect and respond to task-related patterns may act as an underlying mechanism for the impact of cue utilisation on task performance. The results of Study 4 also suggested that a capacity for higher cue utilisation and an ability to rapidly detect patterns of dynamic stimuli, can give rise to miscueing in environments that are typically marked by regularity and routine.

Overall, the present programme of research resulted in four key theoretical contributions which re-conceptualise the processes that underpin and derive from cue utilisation. These include: (1) support for the conceptualisation of cue utilisation as a generalisable ability; (2) evidence to support cross-task cue utilisation; (3) evidence that the capacity to detect and respond to task-related patterns may act as an underlying mechanism for the impact of cue utilisation on task performance, and (4) evidence to suggest that participants who rapidly acquire task-related patterns and form associational cues may also demonstrate an increased tendency to commit miscues in response to initial and sudden changes in routine.

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Appendix A: Secondary Task Sheet

To be completed in conjunction with the rail control simulation

Participant: ______________________________ **Date:** ______________

Train NUMBER (i.e., 333)	**TIME that train appeared** (2.51)

Train NUMBER (i.e., 333)	**TIME that train appeared** (2.51)

Appendix B: Ethics Approval Letters

from: **Fhs Ethics** <fhs.ethics@mq.edu.au>

to: Professor Mark Wiggins <mark.wiggins@mq.edu.au>

cc: Dr Thomas Loveday <thomas.loveday@mq.edu.au>, Ms Sue Brouwers <sue.brouwers@students.mq.edu.au>

date: Wed, Apr 23, 2014 at 5:27 PM

subject: RE: HS Ethics Application - Approved (5201400351)(Con/Met)

Dear Associate Professor Wiggins,

Re: "The Mechanisms of Cue Utilisation in skill Acquisition"(5201400351)

Thank you for your recent correspondence. Your response has addressed the issues raised by the Faculty of Human Sciences Human Research Ethics Sub-Committee and approval has been granted, effective 11th April 2014. This email constitutes ethical approval only.

This research meets the requirements of the National Statement on Ethical Conduct in Human Research (2007). The National Statement is available at the following web site:
http://www.nhmrc.gov.au/_files_nhmrc/publications/attachments/e72.pdf.

The following personnel are authorised to conduct this research:
Associate Professor Mark Wiggins
Dr Thomas Loveday
Ms Sue Brouwers

Please note the following standard requirements of approval:

1. The approval of this project is conditional upon your continuing compliance with the National Statement on Ethical Conduct in Human Research (2007).

2. Approval will be for a period of five (5) years subject to the provision of annual reports.

Progress Report 1 Due: 11th April 2015
Progress Report 2 Due: 11th April 2016
Progress Report 3 Due: 11th April 2017
Progress Report 4 Due: 11th April 2018
Final Report Due: 11th April 2019

NB. If you complete the work earlier than you had planned you must submit a

Final Report as soon as the work is completed. If the project has been discontinued or not commenced for any reason, you are also required to submit a Final Report for the project.

Progress reports and Final Reports are available at the following website:

http://www.research.mq.edu.au/for/researchers/how_to_obtain_ethics_approval/human_research_ethics/forms

3. If the project has run for more than five (5) years you cannot renew approval for the project. You will need to complete and submit a Final Report and submit a new application for the project. (The five year limit on renewal of approvals allows the Sub-Committee to fully re-review research in an environment where legislation, guidelines and requirements are continually changing, for example, new child protection and privacy laws).

4. All amendments to the project must be reviewed and approved by the Sub-Committee before implementation. Please complete and submit a Request for Amendment Form available at the following website:

http://www.research.mq.edu.au/for/researchers/how_to_obtain_ethics_approval/human_research_ethics/forms

5. Please notify the Sub-Committee immediately in the event of any adverse effects on participants or of any unforeseen events that affect the continued ethical acceptability of the project.

6. At all times you are responsible for the ethical conduct of your research in accordance with the guidelines established by the University. This information is available at the following websites:

http://www.mq.edu.au/policy

http://www.research.mq.edu.au/for/researchers/how_to_obtain_ethics_approval/human_research_ethics/policy

If you will be applying for or have applied for internal or external funding for the above project it is your responsibility to provide the Macquarie University's Research Grants Management Assistant with a copy of this email as soon as possible. Internal and External funding agencies will not be informed that you have approval for your project and funds will not be released until the Research Grants Management Assistant has received a copy of this email.

If you need to provide a hard copy letter of approval to an external organisation as evidence that you have approval, please do not hesitate to contact the Ethics Secretariat at the address below.

Please retain a copy of this email as this is your official notification of ethics approval.

Yours sincerely,

Dr Simon Boag
Acting Chair
Faculty of Human Sciences
Human Research Ethics Sub-Committee

Faculty of Human Sciences - Ethics
Research Office
Level 3, Research HUB, Building C5C
Macquarie University
NSW 2109

Ph: +61 2 9850 4197
Fax: +61 2 9850 4465

Email: fhs.ethics@mq.edu.au

http://www.research.mq.edu.au/

Fhs Ethics <fhs.ethics@mq.edu.au> 15 September 2015 at 16:40
To: Professor Mark Wiggins <mark.wiggins@mq.edu.au>
Cc: Ms Sue Brouwers <sue.brouwers@students.mq.edu.au>

Dear Professor Wiggins,

Re: "The Role of Cue utilisation in Skill Acquisition"(5201500725)

Thank you very much for your response. Your response has addressed the issues raised by the Faculty of Human Sciences Human Research Ethics Sub-Committee and approval has been granted, effective 15th September 2015. This email constitutes ethical approval only.

This research meets the requirements of the National Statement on Ethical Conduct in Human Research (2007). The National Statement is available at the following web site:
http://www.nhmrc.gov.au/_files_nhmrc/publications/attachments/e72.pdf.

The following personnel are authorised to conduct this research:
Ms Sue Brouwers
Professor Mark Wiggins

Please note the following standard requirements of approval:

1. The approval of this project is conditional upon your continuing compliance with the National Statement on Ethical Conduct in Human Research (2007).
2. Approval will be for a period of five (5) years subject to the provision of annual reports.

Progress Report 1 Due: 15th September 2016
Progress Report 2 Due: 15th September 2017
Progress Report 3 Due: 15th September 2018
Progress Report 4 Due: 15th September 2019
Final Report Due: 15th September 2020

NB. If you complete the work earlier than you had planned you must submit a Final Report as soon as the work is completed. If the project has been discontinued or not commenced for any reason, you are also required to submit a Final Report for the project.

Progress reports and Final Reports are available at the following website:
http://www.research.mq.edu.au/current_research_staff/human_research_ethics/application_resources

3. If the project has run for more than five (5) years you cannot renew approval for the project. You will need to complete and submit a Final Report and submit a new application for the project. (The five year limit on renewal of approvals allows the Sub-Committee to fully re-review research in an environment where legislation, guidelines and requirements are continually changing, for example, new child protection and privacy laws).

4. All amendments to the project must be reviewed and approved by the Sub-Committee before implementation. Please complete and submit a Request for Amendment Form available at the following website:
http://www.research.mq.edu.au/current_research_staff/human_research_ethics/managing_approved_research_projects

5. Please notify the Sub-Committee immediately in the event of any adverse effects on participants or of any unforeseen events that affect the continued ethical acceptability of the project.

6. At all times you are responsible for the ethical conduct of your research in accordance with the guidelines established by the University.

This information is available at the following websites:
http://www.mq.edu.au/policy
http://www.research.mq.edu.au/for/researchers/how_to_obtain_ethics_approval/human_research_ethics/policy

If you will be applying for or have applied for internal or external funding for the above project it is your responsibility to provide the Macquarie University's Research Grants Management Assistant with a copy of this email as soon as possible. Internal and External funding agencies will not be informed that you have approval for your project and funds will not be released until the Research Grants Management Assistant has received a copy of this email.

If you need to provide a hard copy letter of approval to an external organisation as evidence that you have approval, please do not hesitate to contact the Ethics Secretariat at the address below.
Please retain a copy of this email as this is your official notification of ethics approval.

Yours sincerely,
Dr Anthony Miller
Chair
Faculty of Human Sciences
Human Research Ethics Sub-Committee

Faculty of Human Sciences - Ethics
Research Office
Level 3, Research HUB, Building C5C
Macquarie University
NSW 2109
Ph: +61 2 9850 4197
Email: fhs.ethics@mq.edu.au
http://www.research.mq.edu.au/