Planning, Evaluation, and Cognition: Exploring the Structure and Mechanisms of Expert Performance in a Representative Dynamic Task

Kevin R. Harris (harris@psy.fsu.edu)
Human Performance Laboratory, Learning Systems Institute
Florida State University, 2010 Levy Ave., Suite 254
Tallahassee, FL 32309 USA

Lauren Tashman (lst03@fsu.edu)
Human Performance Laboratory, Learning Systems Institute
Florida State University, 2010 Levy Ave., Suite 254
Tallahassee, FL 32309 USA

Paul Ward (pward@lsi.fsu.edu)
Human Performance Laboratory, Learning Systems Institute
Florida State University, 2010 Levy Ave., Suite 254
Tallahassee, FL 32309 USA

K. Anders Ericsson (ericsson@psy.fsu.edu)
Human Performance Laboratory, Learning Systems Institute
Florida State University, 2010 Levy Ave., Suite 254
Tallahassee, FL 32309 USA

David W. Eccles (deccles@lsi.fsu.edu)
Human Performance Laboratory, Learning Systems Institute
Florida State University, 2010 Levy Ave., Suite 254
Tallahassee, FL 32309 USA

A. Mark Williams (m.williams@livjm.ac.uk)
Liverpool John Moores University, Henry Cotton, Campus, 15-21 Webster St.
Liverpool, L3 2ET, United Kingdom, UK

Jason Ramrattan (jcr03c@fsu.edu)
Human Performance Laboratory, Learning Systems Institute
Florida State University, 2010 Levy Ave., Suite 254
Tallahassee, FL 32309 USA

Laura Hassler Lang (lhassler@lsi.fsu.edu)
Learning Systems Institute, Florida State University, C4600 University Center
Tallahassee, FL 32306 USA

Abstract

A novel approach to protocol analysis designed for dynamic tasks is introduced and applied to the domain of law enforcement. This Task Analysis Period (TAP) methodology is designed to allow exploration of the structural mechanisms of expert performance in a task not traditionally investigated via protocol analysis methods. Preliminary evidence supports the view that Long Term Working Memory enables construction of an on-line dynamic situation model and supplementary memory support that skilled performers use for planning, evaluation, and monitoring during task performance.

Introduction

The study of experts and expert performance has become a prominent research topic in cognitive psychology and other fields. In their original expertise approach, Chase and Simon (1973) focused upon skill-based differences in the ability to encode and recall briefly presented chess positions. A host of studies on expertise followed that were designed to examine the superior memory and recall of experts in a given domain (e.g., Allard & Starkes, 1980; Allard, Graham, & Parsaalu, 1980). Rather than assume that expert performance was based upon superior memory recall, Ericsson and Smith (1991) proposed an approach that identified activities on which experts could consistently demonstrate superior performance. Once identified, Ericsson and Smith (1991) recommended that representative tasks be created in the laboratory such that performance could be examined under controlled conditions, and the mechanisms for superior performance could be investigated using process tracing methods and experimental manipulations.

Ericsson and Kintsch (1995) extended earlier work on skilled memory (Chase & Ericsson, 1982) by proposing that experts acquired the skills to index information at encoding in such a way that allowed information stored in long term memory (LTM) to remain accessible via the use of retrieval cues in short term memory. These skills, and the underlying representation, were termed Long-term Working Memory (LTWM). In their original paper, Ericsson and Kintsch (1995) suggested that LTWM has a dual function. These representations not only provide memory support for performance, in the form of planning, monitoring and evaluations, but also permit retrieval structures to be built on-the-fly (i.e., situation models, see Kintsch, 1988). These retrieval structures allow experts to predict the occurrence and the consequence of future events and anticipate future retrieval demands. In many real-world, dynamic, and complex domains, the challenges and time pressures posed by the task require that individuals are able to process relevant, often partial, information in an efficient and meaningful way, whilst still retaining the ability to engage in necessary reasoning processes. We contend that the dual function of LTWM supports such activity and, in particular, construction of, and updates to the situation model permit direct access to information needed to make the predictive inferences that result in a response that constrains the situation in an appropriate and effective manner (Ward, Eccles, et al., 2006; Ward, Ericsson, & Williams, 2006; see also Ward, 2002). Long-term working memory has been successfully demonstrated in domains such as typing and text comprehension (see Ericsson & Kintsch, 1995). In the present experiment, LTWM is explored in domains characterized by dynamic tasks for which performance is often undertaken under time pressure and stressful circumstances.

Existing literature discussing performance under these types of situations often proposes performance as either a recognition (e.g., Recognition Primed Decision-making; see Klein, Calderwood, & MacGregor, 1989; Gobet & Simon, 1996), intuitive (Dreyfus & Dreyfus, 1986) or automatic process (see Schneider & Chen, 2003). Moreover, many of these views are based upon stimulus activation-type models in which an expert would primarily rely upon transient storage in working memory (WM) as opposed to LTM, as proposed by LTWM theory. Research involving text comprehension and chess suggests that when skilled individuals are interrupted during task performance using an interpolation task (e.g., reading an unrelated sentence, or memorizing a 2nd chess board configuration), there is no effect on comprehension or performance other than a delay in processing time (e.g., 400 ms) to reinstate appropriate access to LTM via retrieval cues in short term working memory (Charness 1976; Glanzer et al., 1981, 1984). Consequently, LTWM theory advocates an alternative and more eloquent, explanation of expert performance (Ericsson & Kintsch, 1995). In our view, individual performance on challenging, stressful tasks, and time-sensitive, critical tasks within a particular domain of expertise should be viewed within a comprehension framework (see Ericsson & Kintsch, 1995; Kintsch, 1998), In other words, rather than a cue triggering an automatic response, direct access to information required to anticipate future events and their consequences is provided by LTWM representations through the on-line, dynamic situation model construction process and supplementary memory support for performance that allows planning, evaluation, and monitoring to take place when time permits. Thus, the expert performer may appear to be acting automatically due to the rapidity of their actions, but selective access is provided to highly indexed and organized information stored in memory which facilitates and constrains action planning and selection (see also Ward, et al., 2006). The domain of law enforcement was chosen for the present experiment. Representative tasks in this domain are extremely dynamic and typically involve responding to a critical event, often under time pressure. An officer may be required to write a speeding ticket at one moment and be engaged in an exchange of gunfire the next. Furthermore, the tasks involved in law enforcement can be a matter of life and death. The potential for life or death situations inherent in law enforcement make it fruitful domain for investigating dynamic, time-constrained, and stressful situations.

In order to assess the processes and mechanisms responsible for superior expert performance in the domain of law enforcement, a new methodology for analysis was developed (for a more detailed explanation, see Ward, Eccles, et al., 2006). We predict that the retrospective verbal reports (see Ericsson & Simon, 1980; 1993) will provide evidence that skilled officers engage in more active planning (i.e., predictions and intentions), evaluation, and cognitions compared to novice police officers. Furthermore, evidence will be provided that experts make predictive inferences and anticipate future events beyond information available in the scenario by building an on-line situation model. We also predict that this process will constrain expert performers (i.e., skilled officers) to engage in more target-directed actions and verbalizations than novice police officers.

Prior to analyzing the data, trials were categorized on the basis of their outcome being either consistent or inconsistent with the rest of the scenario. In other words, consistent trials were those in which preceding events were predictive of the outcome, whereas inconsistent trials were those on which preceding events were not informative as to the potential outcome. We predicted that skilled officers would outperform novice participants primarily on consistent trials only.

Methods

Participants

Two groups of male, right-hand dominant law enforcement officers (skilled and novice) were recruited as participants. Skilled officers (n = 14) had a mean total of 15.4 years (SD = 6.5) of service as a law enforcement officer, and had completed the required training for, special weapons and tactics (SWAT) or an equivalent branch of law enforcement (i.e., Tactical Command; TAC). The mean age of the skilled officers was 38.7 years (SD = 6.3). Novice officers (n = 14) were academy trainees and on average, had undertaken approximately four weeks of mandatory initial training. Their mean age was 24.7 years (SD = 4.4; excluding two participants for whom age was not provided). A rigorous process was implemented to ensure participant anonymity. Informed consent was obtained from participants prior to participation and American Psychological Association ethical guidelines were followed throughout.

Materials and Apparatus

A simulated task environment (STE) was developed to assess participant performance on representative tasks. The STE was driven by LabVIEW and allowed participants to interact with near life-size, video simulations digitally projected on to a 9 ft (2.73 m) x 12 ft (3.64 m) screen. Custom-made video simulations provided scenarios that were representative of law enforcement ranging from domestic disputes to a terrorist attack. Each scenario was shot from a first person perspective allowing meaningful interaction with the actors.

The response interface was a modified, blank firing F-92 Beretta handgun (Netlink Enterprises Inc, Fredericksburg, VA). The handgun included trigger sensors and a precision-mounted laser sight (Lasermax, Rochester, NY) allowing aim point data and time the handgun was fired to be recorded. Three additional digital video cameras (Panasonic AV-DVX100A), an audio microcassette recorder, and miniature lapel microphone were used to capture verbal and behavioral responses.

Simulation Trials

Participants were given an overview of the experiment, a demonstration of the STE, and completed a biographical information sheet. Participants were given directions adapted from Ericsson and Simon (1993, pp. 375-379) for giving a retrospective verbal report. Participants practiced giving verbal reports with feedback by solving generic problems for approximately 20 minutes to ensure that the criteria for omitting type III reports had been met (see Ericsson & Simon, 1993).

For each trial, participants were informed that a simulated law enforcement scenario was about to be presented and were asked to respond to the scenario just as they would in the real world (e.g., calm the suspect down, un-holster their weapon). If the situation did not necessitate any action or response from the participant, the participant was asked to act accordingly. Following these instructions, participants were presented with a blank screen and an audio message giving a brief description of the context to which they would be required to respond and then the simulation video began.

Three practice trials in the STE allowed participants to respond to the simulated scenarios and to give a retrospective report with additional feedback where necessary. Participants undertook 20 test trials. Approximately, half of the trials (n = 9) were "no-shoot" trials (i.e., the perpetrator(s) gave up peacefully or the event did not require a lethal force response) and the other half (n = 11) were "shoot" trials (e.g., a perpetrator drew, and eventually fired, a lethal weapon). The preceding events on 4 of the shoot trials were consistent with the outcome. If the participant fired the weapon, the video simulation was occluded upon gunshot and the screen went blank to avoid any further feedback. Three of the clips were two-event trials, which continued until the second event. Two-event trials were occluded upon response (i.e., gun shot) to the second event.

Participants were instructed to give a retrospective verbal report immediately after performance on seven of the shoot, and three of the no-shoot scenarios. Retrospective reports were elicited in random order, except for two trials that always occurred at position 9 and 19 in the serial order. These were independently rated a priori by five researchers as the two most stressful trials. Pearson's product moment correlations (r) between individual and mean stress ratings for all trials ranged from 0.75 to 0.91. The mean rating (out of 10) for the most stressful trial (trial 19, inconsistent; entitled "domestic assault with baby") was 9.8 (SD = 0.45), and for the next most stressful (trial 9, consistent; entitled "school hostage") was 9.4 (SD = 0.89). The practice and test trails took approximately one hour to complete.

Data Analysis

Performance Data

For the shoot trials only, measures included time (in milliseconds; ms) taken to respond by firing a first shot. If the officer did not fire the weapon, the end-point of the scenario served as shot reaction time. Group means for the two most stressful trials were computed to determine differences on shot reaction time between skilled and novice participants. Performance data for all trials is presented elsewhere (see Tashman, et al., 2006; Ward, Eccles, et al., 2006)

Verbal Reports

Transcriptions of retrospective reports were segmented using natural speech and other syntactical markers. The data were first encoded using a predicate–argument scheme (e.g., relation [argument 1, argument 2]) using various task-specific relations (e.g., move, shoot, pick up). Subjects, objects or elements specified the arguments to which the relation referred (e.g., perpetrator, gun, or door) (Ericsson & Simon, 1993; Ward, et al., 2006).

The verbal reports were categorically coded based on a structure developed to highlight statements made about planning, cognitions, and evaluations. Planning statements were divided into two sub-categories. First, predictions were coded as options (referring to conditional statements or alternatives for future states, e.g., "could") or anticipations (referring to statements made about the expectation of future events, e.g., "would" or "will"). Second, intentions were coded as goals (referring to statements about the goal-directed future states feasibly under control of the officer, e.g., "I want to") or desires (referring to statements made about desired future states for others, e.g., "I want him to"). Cognition statements were subdivided into codes of actions, state, or speech (referring to statements about themselves) and perception of speech, perception of animate information, or perception of inanimate information (referring to statements made about others). Evaluations were subdivided into questions (statements questioning a state or action), assessments (positive or negative evaluations), or comparisons (comparative positive or negative evaluations).

Task Analysis Period (TAP) Model Satisfaction

Verbal reports previously recorded for dynamic tasks (e.g., flying an unmanned air vehicle), have generally been analyzed using content as opposed to protocol analysis methods (e.g., Purtee, Krusmark, Gluck, Kotte, & Lefebvre, 2003). Moreover, tasks performed in a relatively static or self-paced environment (e.g., chess, radiological diagnosis; for examples, see Newell & Simon, 1972) or environments not requiring one to deviate from a desired course of action have primarily been analyzed using process-based analyses. However, for many tasks, environmental changes require deviations in performance, which becomes highly dependent upon appropriate responses to the dynamic context. Thus, in many dynamic real-world tasks (e.g., law enforcement), specifying alternative courses of action for the whole task is difficult. Alternatives often become available or redundant at various points and the dynamic nature of events themselves frequently determines availability or redundancy.

A novel approach to analyzing data from dynamic situations was developed that was consistent with protocol analyses methods described in Ericsson and Simon (1993). A series of task analysis periods (TAPs) was defined by working backwards from the end of the critical period (e.g., the point at which the perpetrator shoots their weapon) in order to identify each subsequent and prior discrete event (e.g., the point at which the perpetrator pulls out his weapon) that would require an alternative course of action (i.e., different target behavior used by the participant to constrain the perpetrator). Based upon the situational demand of each TAP, a desired target behavior was identified. Two or more alternative models were specified *a priori* using a categorical scheme that denotes the ways in which participants could potentially constrain the situation. This scheme consists of target-directed actions (TDA), target-directed verbalizations (TDV), non-target directed actions (NTDA), and non-target directed verbalizations (NTDV). Therefore, this approach treated a dynamic situation as a series of events such that an *a priori* task analysis could then be applied to each event in series.

The verbal report data corresponding to each TAP were then analyzed by looking for intermediate products (i.e., reports, behaviors) that were consistent with one or more *a priori* specified models relative to the target behavior for each TAP. In addition, where skill groups' verbal reports satisfied the same model, a subsequent analysis was performed to identify the time at which model satisfaction took place. In the future, prior model satisfaction (e.g., model X from TAP 2) will be examined to determine whether it is predictive of, or influences subsequent model satisfaction (e.g., model Y in TAP 1) and, ultimately, performance outcome.

Results

Performance Data

The mean and standard deviation for the reaction time data corresponding to when participants shot at the perpetrator are presented in Table 1. The skilled officers were significantly faster on the consistent trial (School Hostage, $p < .05$, $d = 1.62$), but not the inconsistent trial (Domestic Assault with Baby, $p > .05$, $d = .30$).

Table 1: Performance (SD) and verbal report data (%).

	Experts	Novices
Domestic Assault with Baby		
Performance Data		
Reaction Time	61.3s (.4)	61.5s (.5)
Verbal Reports		
PerceptionA	185/786 (23.5%)	114/570 (20.0%)
Assessment	132/786 (16.8%)	72/570 (12.6%)
Goal	109/786 (13.9%)	107/570 (18.8%)
School Hostage		
Performance Data		
Reaction Time	39.1s (1.0)	40.3s (.5)
Verbal Reports		
Assessment	111/495 (22.4%)	11/196 (5.6%)
Action	91/495 (18.4%)	42/196 (21.4%)
PerceptionA	78/495 (15.8%)	44/196 (22.4%)

Verbal Reports

The frequency with which the categorical codes (e.g., evaluations) occurred for each of the two trials was assessed for each participant group. The most prevalent statements for each skill group are presented as a percentage of all statements in Table 1. For the "domestic assault with baby" scenario, the preliminary findings indicate that the two most prevalent codes for the skilled officers were perceptions of animate information (PerceptionA) and assessments, whereas the novice officers more frequently reported perception of animate information and goal statements. The skilled officers reported statements coded as assessments for 132 out of 786 total statements (16.8%) compared to the novice officers who reported assessment statements for 72 out of 570 total statements (12.6%). The skilled officers reported goal statements for 109 out of 786 total statements (13.9%), whereas the novice officers reported these statements for 107 out 570 total statements (18.8%). For the perception of animate information statements, the skilled officers reported 185 out of 786 total statements (23.5%) compared to the novice officers who reported 114 out of 570 total statements (20.0%).

For the "school hostage" scenario, the preliminary findings indicate that the two most prevalent codes for the skilled officers were assessments and actions whereas the novice officers more frequently reported perceptions of animate information and actions. The skilled officers reported action statements for 91 out of 495 total statements (18.4%) compared to the novice officers who reported these statements for 42 out of 196 statements (21.4%). For perception of animate information statements, the skilled officers reported 78 out of 495 total statements (15.8%) compared to the novice officers who reported 44 out of 196 total statements (22.4%). The skilled officers reported assessment statements for 111 out of 495 statements (22.4%), whereas the novice officers reported these statements for 11 out of 196 total statements (5.6%).

Odds ratios were calculated to determine the relative likelihood that participants would provide a statement coded as a given categorical code. The most prevalent code for each scenario, as determined by participant group, was compared. The results indicated that for the "domestic assault with baby" scenario, a skilled participant was 1.18 times more likely to make a statement about perception of animate information than a novice participant. For the "school hostage" scenario, a skilled participant was 3.99 times more likely to make an assessment statement than a novice participant.

Task Analysis Period (TAP) Model Satisfaction

For both scenarios, TAPs were identified based upon evolving alternative courses of action and associated preferred target behaviors. The point at which participants terminated the scenario by firing the weapon served to identify the TAP in which the officer resolved (successfully or unsuccessfully) the situation. Preliminary analysis of the "domestic assault with baby" scenario (7 TAPs) indicated that skilled officers resolved the situation somewhat earlier (albeit slightly) during the same TAP as the novice officers. The skilled officers reported assessment statements often related to prior TAPs (e.g., "I could see something in his waistband in the back, there was some bulge…I felt like he was a threat to me…so I immediately drew."). Statistically, this did not lead to superior outcome by experts. However, the effect size, suggests that experts benefit from making prior assessments about preceding events even for inconsistent trials.

Preliminary analysis of the "school hostage" scenario (3 TAPs) indicated that skilled officers resolved the situation (i.e., stopped the gunman from entering the school) in a grossly different manner from the novice officers. Skilled officers overwhelmingly resolved the situation during TAP 1 (the final identified TAP from scenario onset), the novice officers overwhelmingly failed to resolve the situation (i.e., the gunman entered the school) with one exception from each participant group. Additionally, the skilled officers primarily reported assessment followed by action statements, supporting the skilled officers' successful rapid resolutions of the scenario. The actions of the skilled officers are also indicative of target directed actions (TDA), which constrain the scenario. This constraining behavior allows the skilled officers to resolve the scenario more rapidly than novice officers. Conversely, the perception of animate information followed by action statements of the novices primarily reflected un-holstering their weapon after seeing the gunman, but without firing (i.e., a failure to resolve the situation).

Discussion

Although preliminary, the current findings indicate that skilled officers engage in more evaluation (i.e., assessments) and monitoring (i.e., perceiving animate events) than novice officers that result in anticipating the outcome, particularly on consistent trials. This process allows them to either more effectively satisfy the demands identified within the TAPs or successfully resolve the presented scenarios than the novice officers.

For the "school hostage" scenario (consistent trial), skilled officers primarily reported assessment statements and action statements (e.g., "So, I fired a shot- or two at him") came in second. These statements are indicative of skilled officers integrating contextual information into meaningful representations that allowed them to anticipate the outcome and then intervene in a proactive manner. This finding is consistent with the assumption that experts can generate an on-line situation model from which predictive inferences can be made. Novice officers, on the other hand, failed to stop (i.e., did not shoot) the perpetrator prior to entering the school indicating their inability to rapidly generate an online situation model that would allow sufficient predictive inferences to be made. The TAP methodology supports these claims indicating that experts typically satisfy the current model earlier than their novice counterparts, frequently make reference back to prior TAPs, and use current information to predict outcome and inform their actions. These findings are inconsistent with stimulus-activation and recognition-type models that do not require storage in LTM and integration of information over time.

As predicted, the inconsistent trial, "domestic assault with baby", did not afford an expert advantage. Information integrated over time in this trial was presumably only minimally relevant for predicting the outcome and an effective resolution, irrespective of skill level. However, despite a lack of significant performance difference, a small to moderate effect size was observed. Even when situations do not lend themselves to anticipating the exact nature of the outcome, experts appear to be able to still glean a small advantage that may be all that is necessary in the real-world

Additional analyses are underway to further explore the structure and mechanisms of expert performance in these types of dynamic, and often stressful, situations. The present results are indicative of storage of information in LTM (as predicted by LTWM; Ericsson & Kintsch, 1995) as opposed to transient storage as suggested in theories proposing recognition (Klein, Calderwood, & MacGregor, 1989; Gobet & Simon, 1996), intuitive (Dreyfus & Dreyfus, 1986) or automatic (Schneider & Chen, 2003) explanations of performance. By using the TAPs methodology to apply protocol analysis to these types of situations, more evidence can be found that LTM representations allow on-line, dynamic situation model construction and subsequent memory support for performance. Additional measures of performance and behavioral data as well as verbal reports from all participants are anticipated to buttress this hypothesis.

The implications of this research extend beyond the domain of law enforcement. Ideally, the TAPs methodology will become as ubiquitous as alternative content and protocol analysis techniques currently used for less dynamic tasks. Furthermore, by extending the methodologies traditionally used to study expert performance to dynamic tasks, additional domains can be explored to better understand the structural mechanisms of expert performance.

Acknowledgments

We gratefully acknowledge the assistance of the Office of Naval Research and the FSU Learning Systems Institute for grant and other support during this research.

References

Ericsson, K.A., & Delaney, P. (1999). Long-term working memory as an alternative to capacity models of working memory in everyday skilled performance. In A. Miyake & P. Shah (Eds.), *Models of working memory: Mechanisms of active maintenance and executive control* (pp.257-297). New York: Cambridge University Press.

Ericsson, K. A., & Kintsch, W. (1995). Long-term working memory. *Psychological Review, 102,* 211-245

Ericsson, K.A., & Lehmann, A.C. (1996). Expert and exceptional performance: Evidence of maximal adaptation to task constraints. *Annual Review of Psychology*, 47, 273-305.

Ericsson, K.A., & Smith, J. (1991). *Toward a general theory of expertise: Prospects and limits*. Cambridge: Cambridge University Press.

Ericsson, K.A., & Simon, H.A. (1980). Verbal reports as data. *Psychological Review, 87,* 215-251.

Ericsson, K.A., & Simon, H.A (1984). *Protocol analysis: Verbal reports as data*. Cambridge, MA: MIT Press.

Ericsson, K.A., & Simon, H.A (1993). *Protocol analysis: Verbal reports as data* (Rev. ed.). Cambridge, MA: MIT Press.

de Groot, A.D. (1946/1978). *Thought and choice in chess*. The Hague. Mouton.

Gobet, F., & Simon, H.A. (1996). Templates in chess: A mechanism for recalling several boards. *Cognitive Psychology*, 31, 1-40.

Hoffman, R. R., Crandall, B., & Shadbolt, N. (1998). Use of the critical decision method to elicit expert knowledge: A case study in the methodology of cognitive task analysis. *Human Factors*, 40, 254-276.

Kintsch, W. (1988). The use of knowledge in discourse processing: A construction-integration model. *Psychological Review*, 95, 163-182.

Klein, G. A., Calderwood, R., & MacGregor, D. (1989). Critical decision method for eliciting knowledge. *IEEE Transactions on Systems, Man, and Cybernetics*, 19, 462-472.

Newell, A., & Simon, H.A. (1972). *Human problem solving*. Englewood Cliffs, NJ: Prentice-Hall.

Miller, G.A. (1956). The magical number seven, plus or minus two. *Psychological Review*, 63, 81-97.

Nisbett, R.E., & Wilson, T.D. (1977). Telling more than we can know: Verbal reports on mental processes. *Psychological Review, 84*, 231-259.

Purtee, M. D. Krusmark, M. A., Gluck, K. A., Kotte, S. A., & Lefebvre, A. T. (2003). Verbal protocol analysis for validation of UAV operator model. *Proceedings of the 25th Interservice/Industry Training, Simulation, and Education Conference*, 1741-1750. Orlando, FL: National Defense Industrial Association.

Richman, H.B., Staszewski, J.J., & Simon, H.A. (1995). Simulation of expert memory using EPAM IV. *Psychological Review*, 102, 305-330.

Richman, H.B., Gobet, F., Staszewski, J.J., & Simon, H.A. (1996). Perceptual and memory processes in the acquisition of expert performance: The EPAM model. In K.A. Ericsson (Ed.), *The road to excellence: The acquisition of expert performance in the arts and sciences, sports and games*. Mahwah, NJ: LEA.

Simon, H.A., & Chase, W. (1973). Skill in chess. *American Scientist, 61*, 394-403.

Tashman, L.S., Harris, K.R., Ward, P., Ramrattan, J., Eccles, D.W., & Ericsson, K.A. (2006). Expert performance in law enforcement: Are skilled performers more effectively constraining the situation to resolve representative dynamic tasks than novices? *Paper to be presented at the 50th Annual Meeting of the Human Factors and Ergonomics Society*, San Francisco, CA.

Ward, P. (2002). *The development of perceptual-cognitive expertise*. Unpublished doctoral dissertation. Liverpool John Moores University, UK.

Ward, P., Eccles, D.W., Ericsson, K.A., Harris, K.R., Williams, A.M., Tashman, L.S., & Ramrattan, J. (2006). Cognitive mechanisms supporting superior expert performance in a dynamic representative task: An example from law enforcement. *Manuscript in preparation.*

Ward, P., Ericsson, K.A., & Williams, A.M. (2006). Identifying mechanisms of perceptual-cognitive expertise in an applied domain using think aloud reports. *Manuscript submitted for publication.*