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Cue Integration in Dynamic Decision Making

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Abstract

Defence Research and Development Canada (DRDC) Toronto is interested in researching training techniques to prepare Canadian Forces (CF) commanders and staff for decision making in complex and dynamic environments. The complex and dynamic nature of various types of operations (e.g., effects-based operations, stability operations, counter-IED, counter-insurgency) pose specific cognitive challenges on the decision-making process that the current training regimen of military commanders does not directly address. This project serves to provide understanding of underlying cognitive mechanisms within DDM as a contribution to determining how best to improve the DDM process and training. A brief review of four recognition processes, namely pattern recognition, cue integration, heuristics, and biases, was conducted as Phase I of a two phase process. Based on this review, cue integration was selected as an area of key interest and was the focus of a more comprehensive review (Phase II). Results from this review indicated that the cue integration literature within DDM is sparse. A significant amount literature concerning more simplistic decision making thus was used to infer the role of cue integration within DDM. Particular aspects of cue integration, namely perception, working memory, long term memory, and feedback were considered to play an important role in DDM. Training implications including recommendations of what and how to train are considered. Concluding remarks and future recommendations are also discussed

Résumé

Recherche et développement pour la défense Canada (RDDC) Toronto s'intéresse à la recherche sur les techniques de formation destinées à préparer les commandants et le personnel des états-majors des Forces canadiennes (FC) à prendre des décisions dans des environnements complexes et dynamiques. La nature complexe et dynamique de différents types d'opérations (p. ex., les opérations basées sur les effets, les opérations de stabilité, la lutte aux IED, les mesures anti-insurrectionnelles) pose des défis particuliers au niveau cognitif dans le processus de prise de décisions qui ne sont pas abordés directement dans le cadre de l'actuel régime d'instruction des commandants militaires. Le présent projet sert à comprendre les mécanismes cognitifs sous-jacents de la prise de décisions dynamique (PDD) en tant qu'éléments contribuant à déterminer quelle est la meilleure façon d'améliorer le processus de PDD et la formation. La première des deux phases de ce processus était une étude brève de quatre processus de reconnaissance, à savoir la reconnaissance des tendances, l'intégration des indices, les heuristiques et les biais. En fonction des résultats de cette étude, l'intégration des indices a été choisie comme domaine d'intérêt clé et a fait l'objet d'une étude plus détaillée dans la Phase II. Les résultats de cette étude indiquaient qu'il y avait peu de documentation sur l'intégration des indices dans le domaine de la PDD. Une quantité importante de documentation relative aux contextes de prise de décisions plus simples a donc ainsi été utilisée pour induire le rôle de l'intégration des indices dans la PDD. On estime que des aspects particuliers de l'intégration des indices, c'est-à-dire la perception, la mémoire de travail, la mémoire à long terme et la rétroaction, jouent un rôle important dans la PDD. Les implications au niveau de la formation sont abordées. Des recommandations sont examinées sur ce qui devrait faire l'objet de la formation et la façon de former les gens. Le présent document se termine par un commentaire de conclusion et des recommandations sur les recherches à venir.

Executive Summary

Cue Integration in Dynamic Decision Making

Lisa Rehak, Tamsen Taylor, Cheryl Karthaus & Lora Bruyn Martin; Human*systems*® Incorporated

DRDC Toronto No. CR2010-047; Defence Research and Development Canada – Toronto; July 2010.

Defence Research and Development Canada (DRDC) Toronto is interested in researching training techniques to prepare Canadian Forces (CF) commanders and staff for decision making in complex and dynamic environments. The complex and dynamic nature of various types of operations (e.g., effects-based operations, stability operations, counter-IED, counter-insurgency) pose specific cognitive challenges on the decision-making process that the current training regimen of military commanders does not directly address.

In the psychology literature, decision making in complex and dynamic environments is generally referred to as dynamic decision making (DDM). Unique challenges associated with DDM are the uncertainties within the situation (e.g., ambiguous information), time constraints, high levels of risk, ill structured problems, high levels of complexity, situation changes, and delays in feedback. In working through such intricate problems there is a significant need to take multiple variables into account and to integrate numerous pieces of information gathered over time, in order to make appropriate decisions in a timely manner. Accordingly, much of the research conducted on DDM assumes that recognition processes are crucial to successful DDM (see, e.g., Brehmer, 1990; Gonzalez, Lerch, & Lebiere, 2003). Four recognition related processes include pattern recognition, cue integration, heuristics, and biases.

In efforts to understand particular challenges within these processes this project examines the psychological literature of underlying cognitive mechanisms of DDM. Specifically, objectives of this review were to identify and review relevant literature on role of pattern recognition, cue integration, heuristics, and biases in relation to DDM, in particular to identify challenges to and failures of normative reasoning; to review more thoroughly the literature on one particular area; to construct a (or build upon an existing) conceptual framework for relating the selected area to DDM, identifying gaps in the literature, guiding areas for future research, and identifying constraints and implications for DDM training.

This project was conducted in two phases. Phase I consists of a brief review of the literature on pattern recognition, cue integration, heuristics, and biases, as they relate to DDM. A total of 60 articles were initially reviewed to satisfy the requirements of Phase I. Within each of these four areas general themes, challenges, and training implications are discussed.

Through a brief analysis, cue integration was selected as the area of focus in Phase II. In this phase an additional 17 articles specific to cue integration were reviewed. Findings indicated that the cue integration literature within DDM is sparse. A significant amount literature concerning more simplistic decision making thus was used to infer the role of cue integration within DDM. Particular aspects of cue integration, namely perception, working memory, long term memory, and feedback were considered to play an important role in DDM. Training implications including

recommendations of what and how to train are considered. Concluding remarks and future recommendations are also discussed with a specific focus on the CF.

Overall, this project serves to provide understanding of underlying cognitive mechanisms within the DDM as a contribution to determining how best to improve the DDM process and training for the future CF.

Sommaire

Intégration des indices dans la prise de décision dynamique

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Recherche et développement pour la défense Canada (RDDC) Toronto s'intéresse à la recherche sur les techniques de formation destinées à préparer les commandants et le personnel des états-majors des Forces canadiennes (FC) à prendre des décisions dans des environnements complexes et dynamiques. La nature complexe et dynamique de différents types d'opérations (p. ex., les opérations basées sur les effets, les opérations de stabilité, la lutte aux IED et les mesures anti-insurrectionnelles) pose des défis particuliers au niveau cognitif dans le processus de prise de décisions qui ne sont pas abordés directement dans le cadre de l'actuel régime d'instruction des commandants militaires.

Dans les écrits en psychologie, la prise de décisions dans les environnements complexes et dynamiques est habituellement désignée sous le nom de *prise de décisions dynamique* (PDD). Les défis propres à la PDD sont les incertitudes présentes dans la situation (p. ex., des renseignements ambigus), les contraintes de temps, les hauts niveaux de risques, la mauvaise structuration des problèmes, les hauts niveaux de complexité, les changements de situation et les retards de la présentation de rétroaction. Lorsqu'on travaille avec des problèmes si compliqués, il est nécessaire de tenir compte de nombreuses variables et d'intégrer un grand nombre d'éléments d'information recueillis sur une certaine période de temps afin de prendre les décisions appropriées en temps opportun. En conséquence, une grande partie de la recherche menée sur la PDD présume que les processus de reconnaissance sont cruciaux à la PDD (voir, p. ex., Brehmer, 1990; Gonzalez, Lerch, & Lebiere, 2003). Parmi les processus liés à la reconnaissance, on retrouve la reconnaissance des tendances, l'intégration des indices, les heuristiques et les biais.

Dans un effort visant à comprendre les défis particuliers propres à ces processus, ce projet examine les écrits liés au domaine de la psychologie sur les mécanismes cognitifs sous-jacents à la PDD. Plus précisément, les objectifs de cette étude étaient d'identifier et d'examiner la documentation pertinente portant sur le rôle de la reconnaissance des tendances, l'intégration des indices, les heuristique et les biais en relation avec la PDD et plus particulièrement d'identifier les défis et les défaillances du raisonnement normatif; d'étudier plus en profondeur les écrits sur un domaine en particulier; de construire (ou d'élaborer à partir d'un base existante) un cadre conceptuel pour lier le domaine choisi à la PDD, dresser la liste des lacunes de la documentation, établir les domaines de recherches futures et identifier les contraintes et les implications pour la formation en PDD.

Ce projet était divisé en deux phases. La Phase I consistait en une brève recension des écrits sur la reconnaissance des tendances, l'intégration des indices, les heuristiques et les biais en relation avec la PDD. Un total de 60 articles a d'abord été examiné afin de répondre aux exigences de la Phase I. À l'intérieur de ces quatre domaines, les thèmes généraux, les défis et les implications au niveau de la formation ont fait l'objet de discussion.

Après une brève analyse, l'intégration des indices a été choisie le domaine d'intérêt particulier de la Phase II. Dans cette phase, 17 nouveaux articles touchant précisément à l'intégration des indices ont été étudiés. Les résultats de cette étude indiquaient que la documentation sur l'intégration des indices était rare dans le domaine de la PDD. Une quantité importante de documentation relative aux contextes de prises de décisions plus simples a donc ainsi été utilisée pour induire le rôle de l'intégration des indices dans la PDD. On estime que des aspects particuliers de l'intégration des indices — c'est-à-dire la perception, la mémoire de travail, la mémoire à long terme et la rétroaction — jouent un rôle important dans la PDD. La discussion sur les implications au niveau de la formation comprend notamment des recommandations sur ce qui doit faire l'objet de la formation et la façon de former les gens. Le document se termine par un commentaire de conclusion et des recommandations sur les recherches à venir axées sur les FC.

Dans l'ensemble, ce projet sert à expliquer les mécanismes cognitifs sous-jacents de la PDD en tant qu'élément contribuant à déterminer la meilleure façon d'améliorer le processus de PDD et la formation dans les FC de l'avenir.

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1. Introduction

1.1 Background

The Canadian Forces (CF) are increasingly called to serve in operations where commanders and staff are required to apply high-level dynamic decision making skills. In order to support these skills, Defence Research and Development Canada (DRDC) Toronto is interested in researching training techniques to prepare CF members for deployment in complex, dynamic environments. These environments are characteristic of military operations such as effects-based operations, stability operations, counter-IED, and counter-insurgency. It is believed that the complex and dynamic nature of these various types of operations pose specific cognitive challenges on the decision-making process which are not directly addressed by the current training regimen of military commanders.

In the psychology literature, decision making in complex and dynamic environments is generally referred to as dynamic decision making (DDM) in contrast with the more "static" decision making approach traditionally researched in psychology. The research area of DDM is typically presented as being an entirely different field than traditional decision making. This seems illogical, thus there is a desire to explore established psychological research, in particular, related to difficulties and challenges in decision making that have been documented in the "traditional" decision making literature, and exploit those findings for their potential to identify areas of research for training DDM.

DDM refers to situations that require a series of interrelated decisions made in real time with the aim of controlling or influencing a situation. In DDM, the state of the problem changes continuously, both autonomously and as a consequence of the decision-maker's actions, and the decision-making environment is opaque (i.e., it is not possible for a decision maker to know all aspects or variables of the environment, and therefore some characteristics of the system must be inferred) (Brehmer, 1992).

At the heart of DDM lies the need to take into account multiple variables and integrate numerous pieces of information gathered over time, in order to make appropriate decisions in a timely manner. Accordingly, much of the research conducted on DDM assumes that recognition processes are crucial to successful DDM (see, e.g., Brehmer, 1990; Gonzalez, Lerch, & Lebiere, 2003). However, the DDM literature does not provide much information on the cognitive mechanisms that would underlie DDM. Specifically, the literature on processes such as cue integration and pattern recognition, inherent to recognition processes, is largely ignored. Similarly, very little reference is made to the literature on classical decision making, including the literature on heuristics and biases. As there is no compelling reason to assume that these cognitive mechanisms, which are well documented in "traditional" decision making research, do not play a role in DDM, examining how they intervene in DDM will likely improve our understanding of the mechanisms underlying DDM. This in turn will help us begin to understand how to improve DDM through training.

1.2 Scope and Objectives

In order to understand and determine how best to improve the DDM process, the objective of this work is to evaluate what role pattern recognition, cue integration, heuristics, and biases play in the

DDM process, and what implications they can have on training DDM. Building on a previous report on mental models in DDM (Brown, Karthaus, Rehak, & Adams, 2009) we first examine DDM as it relates to information processing, and DDM challenges. From there, we conducted a broad literature review of pattern recognition, cue integration, heuristics and biases in relation to DDM. The aim was to identify the roles that each of these four factors play in DDM, and whether these four areas pose challenges specific to DDM. We then focused our efforts and conducted a more comprehensive literature review of cue integration and the role it plays in DDM. The goal was to explore cue integration in depth with the purpose of identifying how it relates to challenges in DDM. As training can be used to influence mental processes involved in decision making (see, e.g., Hubal et al., 2007) and minimize the negative impact of the difficulties and biases involved in recognition processes, our final objective was to identify training challenges related to the selected area.

This project was divided into two phases. The goal of the first phase was to select and review research into the psychological concepts of cue integration, pattern recognition, heuristics and biases in order to better understand the role that these four concepts play in DDM. Specifically, we examined aspects of DDM that provide cognitive challenges and that are potentially relevant for training.

In the second, and final, phase of the project one of the four concepts (cue integration) was selected for further examination. The goal of this phase was to conduct a comprehensive review of articles specific to cue integration to gain a deeper understanding of the role it plays in the DDM process as well as difficulties it presents. Gaps within the literature, as it pertains to DDM, are also identified.

1.3 Outline of report

This report describes the methods used and outcome of a two-phase literature review of recognition processes in DDM. The first phase involved a broad review of literature on cue integration, pattern recognition, heuristics and biases to better understand the role these four concepts play in DDM. The second phase involved a more comprehensive literature review of cue integration with the goal of understanding how it relates to DDM and the difficulties it can present in a DDM environment. This report has 7 main sections that describe this two phase literature review:

1. Introduction
2. Methods
3. Results of Phase I
4. Results of Phase II
5. Training Implications
6. Conclusions
7. Future Research Recommendations

First, a brief introduction to dynamic decision making is provided below.

1.4 Dynamic Decision Making

DDM generally refers to situations that require a series of interrelated decisions made in real time with the aim of controlling or influencing a situation. Thus in military DDM environments, the situation changes continuously, in a complex, hard to predict manner. It may change autonomously and as a result of a decision-makers' actions. In these types of environments it is not possible for the decision maker to know *all* aspects of the variables (e.g., of the task, enemy and environment) involved. Inevitably, some characteristics of the system must be inferred (Brehmer, 1992).

To further characterize DDM we identify four defining elements therein (Brehmer & Allard, 1991; Busemeyer, 1999; Clancy et al., 2003; Fu & Gonzalez 2006):

- There are a series of decisions;
- These decisions are interdependent;
- The environment changes both autonomously and as a function of the decision maker's actions; and,
- Timing is a key element, where decision makers have little control over exactly when dynamic decisions must be made (Brehmer, 2000).

In the CF, these decisions are made within a complex environment in attempts to achieve one or more tasks (Brown et al., 2009). Within these decisions a number of cognitive challenges are often encountered. Challenges concerning general cognitive capacities and limitations (e.g., perception), the DDM tasks (e.g., information uncertainty), and the DDM environment (e.g., feedback delays) are most relevant. Specific challenges which appear to be unique to DDM are described in the sections the follow.

1.4.1 Challenges Unique to Dynamic Decision Making (DDM)

DDM involves multiple, interdependent decisions within a complex, changing environment where timing is a key element that effects the decision maker's control over decisions and outcomes (Brehmer, 1992, 2000; Brown et al., 2009).

There are multiple characteristics in DDM which can be cognitively challenging (Brown et al., 2009). Some which are particularly challenging include uncertainty, time pressure, high levels of risk, ill-structured problems, complexity, fast rate of change, feedback delays and lack of adequate feedback, distributed decision making and making predictions (forecasting). Each of these challenges is discussed below, and relevance to military DDM is introduced. In later sections we will discuss how these particular challenges interact with the "traditional" decision making mechanisms presented above.

1.4.1.1 Uncertainty

There are many possible types of uncertainty which apply in DDM, some of which are covered in other points (i.e., ill-structured problems and lack of adequate feedback). Some other aspects of uncertainty include lack of knowledge about some important variables, lack of knowledge about the validity of information, and lack of knowledge about when new information can be acquired. It is generally challenging to make decisions without adequate information available, and the decision maker will have to compensate for uncertainty by either making a decision with incomplete information (increasing risk of error) or delaying making a decision (increasing time pressure and the likelihood that adequate intervention in a situation may no longer be possible). Understanding the implications of making decisions with incomplete information or delaying decision making requires understanding a great many factors and is highly challenging.

Uncertainty is a key component of military DDM. Often, the primary function of military actions is to reduce uncertainty, such as reconnaissance operations and other intelligence-gathering missions. Even when gathering information is not the primary purpose of a mission (e.g., combat missions), a great deal of information is often unknown (e.g., the exact location of the enemy forces; the exact weapons that the enemy possesses). Thus, training military personnel how to deal with uncertainty during decision making is critical for successful performance.

1.4.1.2 Time Factors

Time is often limited in DDM, both in terms of acquiring information and making the decision itself. Time pressure creates a demand to acquire information quickly, integrate that information quickly, make inferences about the information within various time constraints, and determine an appropriate course of action quickly. Thus, time pressure puts a higher level of demand on all aspects of decision making.

There are situations in military DDM where decisions have to be made extremely quickly (e.g., how best to respond when under attack). However, time factors in military DDM are not limited to decisions which have to be made quickly; military scenarios can involve very long time horizons. In circumstances with long time horizons (e.g. military strategic planning), it can be challenging to understand the relationships between events and correctly determine causal linkages. It is also important to note in military DDM that there are time windows in which actions could have optimal effects, and these time windows can be very short (e.g., a military target is within range for only a short period of time). So, in military DDM contexts, personnel have to be able to deal with short and long time horizons, and also be able to detect the optimal time to act.

1.4.1.3 High levels of risk

It has been found that the level of risk can change how decisions are made; risks are often especially high in military DDM. Notably in military DDM contexts there are opportunities which can easily be lost and threats which will come into play. The cost of losing opportunities or experiencing negative events can change the focus of decision makers and the way that problems are conceptualized. These can lead to biases in decision making. As well, the level of stress experienced in military situations can place more burdens on the decision maker, requiring them to spend resources on dealing with the stress (theirs and others, particularly for leaders) and reduce the cognitive resources available for making other decisions. Military training often involves high stress and therefore CF personnel are generally familiar with operating in high-risk situations; however, training should also take into consideration how risk perception actually influences decision making. Training should ensure that personnel understand and can mitigate any decision-making problems that are likely to surface in high-risk (or low-risk) situations.

1.4.1.4 Ill-structured problems

Decision makers in DDM often are managing multiple goals. This means that the current conceptualization of goals, prioritization of those goals, and the assessment of the current situation (and the impact on those goals) will influence what decisions should be made at a given point in time. Any shift in any of these factors will influence the current goal to be accomplished and therefore could change the appropriateness of decisions. Managing multiple goals is challenging because there are often many factors to consider, and goals are often interdependent, meaning that moving toward accomplishing one goal will often impact other goals.

Managing multiple goals is ubiquitous in military DDM. A good example is in submarine operations; submariners have to constantly and simultaneously manage the goals of maintaining the safety of the crew, maintaining the safety of the platform, maintaining covertness, and accomplishing mission goals. In military DDM, ill-structured problems could also come about because of direction from others in a leadership position (i.e., commander's intent). If directions are not clear or understanding of those directions is incomplete, cognitive resources have to be spent clarifying what the problem is so that a solution can be found, which directs resources away from making other decisions. Military training must ensure that CF personnel are comfortable with managing multiple goals and dealing with ill-structured problems.

1.4.1.5 Complexity

Most DDM environments involve many different factors, and this can make decision making complex (although how to operationally define complexity is not clear in the literature). According to Brown et al. (2009), the complexity of an environment is considered relative to the capacity of a human to control that environment. Aspects of the environment that could be controlled include the processes, goals, action alternatives, side effects, and feedback. Increases in the number of things that must be controlled, as well as lags and other factors which impair the ability of decision makers to understand the environment and make good decisions, tend to increase complexity.

One problem with decision making in complex environments is determining which factors are important for making a decision and selecting these from the many factors which are irrelevant or non-predictive. The necessity of dealing with and classifying many different pieces of information, along with the requirement of acquiring this information, can be cognitively overwhelming. The literature shows that task effects such as complexity and goal conflict are negatively associated with performance; however, unexpected interactions between such variables have been found. For example, Elser (1993) found that the highest levels of task complexity and goal conflict produced the worst performance, but the highest level of goal conflict produced better performance than an intermediate level of goal conflict with lower and intermediate levels of task complexity.

Most environments in military DDM are complex, with decision makers having to integrate many different kinds of information in a context with an abundance of information that may or may not be relevant for the decisions they are trying to make. Military decision makers often speak of dealing with incoming information as "trying to drink from a fire hose". Add to the complexity produced by an overabundance of information the fact that military decision makers are often responsible for making many decisions concurrently and it is clear that training in military DDM must take complexity into consideration.

1.4.1.6 Changing environments

Many DDM contexts involve a situation that changes rapidly, both spontaneously and because of decision-maker input. This means that the decision maker not only has to gather initial values for important information, but also constantly update their knowledge, putting great demands on attention and working memory. In military DDM contexts, change can be extremely rapid, and it is a major challenge keeping up with what is occurring and the impact on plans. For example, in a combat situation both friendly and enemy forces manoeuvre, and it is generally important to track the location of your own and enemy forces, both in an absolute sense (e.g., if you want to call for assistance) and a relative sense (e.g., if you are attempting to fire on the enemy). Training must include training in how to deal with highly dynamic environments if personnel are to effectively operate.

1.4.1.7 Feedback delays and lack of adequate feedback for learning

Both feedback delays and lack of adequate feedback for learning are often aspects of DDM environments. Without adequate feedback it is very difficult to learn the relationships between inputs and outcomes, as well as information such as cue validity. Receiving appropriate feedback and interpreting it correctly is a major problem in military DDM. It is often difficult to gain access to ground truth (i.e., the actual state of the environment), and there are often long delays between actions and their consequences (e.g., in psychological operations effects may take a long time to manifest), or at least knowledge of their consequences (e.g., it may take a long time to know what the effects of a bomb were, even though those effects occurred quickly). Military decision makers must learn how to interpret the environment and gain knowledge about the effects of their actions and the actions of others in order to make the best decisions as well as to gain more knowledge in the field.

1.4.1.8 Making predictions (forecasting)

One of the key things that decision makers must do to be successful in a DDM context is make predictions, both about the current direction of a situation without input, and also on the likely impact of actions by the decision maker. This is an incredibly challenging task in most cases, largely because of issues already discussed above, including the fact that the situation involves nonlinearities in the variables to be forecasted that are rapidly changing and difficult to learn. All of these problems combine to make forecasting extremely challenging.

One of the major tasks in military DDM is to make predictions. Military operations such as reconnaissance and surveillance are intended to gather information about the current situation; however, the real power of this knowledge is to use this information about current and past events to determine what future events are likely to occur. Because the majority of strategic and operational military decision making functions are done far in advance, the accuracy of these forecasting functions is critical for supporting these long time horizon activities. Thus, it is incredibly important that military decision makers learn to make effective predictions.

2. Phase I

A structured process was applied in conducting the Phase 1 literature review. The process included identifying keywords, searching relevant databases using the keywords, finding relevant articles through extensive searching, filtering relevant articles, reviewing the articles and then performing the final analysis and synchronization of the literature. More details on the process used to search for, identify and filter relevant articles can be found below.

2.1 Phase I: Identification, selection, and review of articles

To structure the literature search, a keyword list was created. This list was sent to the Scientific Authority for feedback after which minor changes were made. These keywords were then used to search relevant databases. They keywords used in the search can be found below in Table 1. The databases searched using the keywords can be found in Table 2.

To maintain a record of the process, the following information was documented in a spreadsheet throughout the search process:

- Database searched (e.g., PsycINFO);
- Keyword combination (e.g., cue integ* AND decision);
- Number of hits;
- Number of possible articles;
- Articles downloaded; and
- Articles/books that require purchase.

Relevant literature was collected based on abstracts available at the time they were found. At this stage there were 374 titles of relevant literature. All abstracts were complied into a database and reviewed by the research team. Each abstract was ranked A, B, C, or D based on its relevance (A being highly relevant and D being not relevant at all). The research team collaborated to reach consensus on the evaluation of each abstract. A total of 27 pieces of literature were ranked as A, having very high relevance, and 27 as B, having high relevance. The complete database was then provided to the SA who provided feedback on the rankings and literature collected. From this, 55 titles (including articles and books) were identified as very highly relevant and should be considered for review, 25 were identified as relevant and should tentatively be considered for review if required, and the remaining articles were noted as less relevant and should not be considered for inclusion in this project.

Table 1: Keywords used in Phase I

Core Concept	Primary Keywords	Secondary Keywords
Decision Making	reasoning, judgement, problem solving, intuitive, rational, naturalistic, choice, assessment, evaluation, information processing	Creativity, deductive, inductive, inference, analytic, counter-factual
Dynamic Decision Making	risk, complex*, uncertain*, ambiguity, problem space, opacity, feedback delays, misperception of feedback D3M (distributed dynamic decision making),	
Systems theory	system dynamics, complex systems, emergence, emergent behaviour	Nonlinearity, stock and flow, feedback, causal loop
Cognitive	mental, knowledge, intellectual, ability, logic, process*, model, sensory, perception, attention, workload, learning, memory, language, communication	training, forgetting, retention, recall, maintenance, CECA, OODA, recognition-primed, support theory
Cue integrat*	cue, store, identif*, together, information, combin*, indicat*, event, data fusion	
Pattern recognit*	classif*, instance based models, memory, mental model, judgment, choice, trend analysis	
Heuristics	availability, representative, affect, take-the-best, anchoring and adjustment, rule of thumb, assumptions, fast and frugal	
Biases	error, systematic, illogical, fallacy, probability judgement, preconception, human, motivation, misuse	Statistical, non statistical, confirmation, conjunction fallacy, base rate, regression to the mean, congruence, overconfidence, framing, loss aversion, hindsight, illusory correlation, response bias, illusion of control, clustering illusion, optimism, fundamental attribution error, egocentric, false consensus effect, halo effect, in-group stereotypes, prejudice, herd instinct, just-world phenomenon, self-serving
Contexts	military, emergency, fire fighting, search and rescue, crisis, operational, strategic, command and control, C2, effects based operations, 2nd/3rd order effects, planning, nuclear, police	Uncertain, critical, pressure, risk

A variety of databases were searched. These are summarized below in Table 2.

Table 2: Databases searched

Database	Description
PsycINFO	The PsycINFO database is a collection of electronically stored bibliographic references, often with abstracts or summaries, to psychological literature from the 1800s to the present. The available literature includes material published in 50 countries, but is all presented in English. Books and chapters published worldwide are also covered in the database, as well as technical reports and dissertations from the last several decades.
NTIS	NTIS is an agency for the U.S. Department of Commerce's Technology Administration. It is the official source for government sponsored U.S. and worldwide scientific, technical, engineering and business related information. The 400,000 article database can be searched for free at the www.ntis.gov. Articles can be purchased from NTIS at costs depending on the length of the article.
CISTI	CISTI stands for the Canada Institute for Scientific and Technical Information. It is the library for the National Research Council of Canada and a world source for information in science, technology, engineering and medicine. The database is searchable on-line at cat.cisti.nrc.ca. Articles can be ordered from CISTI for a fee of approximately $12.
STINET	STINET is a publicly-available database (stinet.dtic.mil) which provides access to citations of documents such as: unclassified unlimited documents that have been entered into the Defence Technology Technical Reports Collection (e.g., dissertations from the Naval Postgraduate School), the Air University Library Index to Military Periodicals, Staff College Automated Military Periodical Index, Department of Defense Index to Specifications and Standards, and Research and Development Descriptive Summaries. The full-text electronic versions of many of these articles are also available from this database.
Google Scholar	The World Wide Web was searched using the Google Scholar search engines (scholar.google.com).
DRDC Research Reports	DRDC Defence Research Reports is a database of scientific and technical research produced over the past 6- years by and for the Defence Research & Development Canada. It is available online at pubs.drdc-rddc.gc.ca/pubdocs/pcow1_e.html.

After this selection process was complete, an initial 60 articles were reviewed by the research team. The articles were selected based on the Scientific Authority's recommendations and also the availability of the articles. Each article was summarized, and a short critique of the article was performed. For each article, the relevant core concept(s) (cue integration, pattern recognition, heuristics, and/or biases) were identified and recommendations whether to include the article in the final literature review and analysis were provided. The template used to summarize the articles is provided in Table 3:

Table 3: Template used for article reviews

Title: <>
Author(s): <>
Source: <>
Year: <>
Abstract: <>
Notes: <A paragraph including one to two sentences on each of the following: the main purpose of the article, conclusions, criticisms/limitations of the article (if there are any), brief evaluation of the article. The content of this "analysis" paragraph needs to be geared specifically towards identifying cognitive and/or training challenges in DDM. For instance, it could include a brief analysis of how the findings/conclusions/models reported in the article identify or document cognitive/training challenges, how these challenges are relevant for DDM, and if there are any limitations to the article with regards to how it can apply to DDM. Basically the idea of the lit review in the first phase is to extract implications for cognitive and/or training challenges in DDM, so that we have an idea of what area is particularly worth pursuing further in the second phase>
AREA: CAN BE USED TO SUPPORT INVESTIGATING: <HEURISTICS, BIASES, CUE INTEGRATION, AND/OR PATTERN RECOGNITION>
To be used? – Select one of the following: "Include, if relevant" – These are well written articles that we think would be excellent additions to the second phase of the project if the area (e.g., biases) written about in the article is to be pursued. "For consideration" – These are interesting articles, that would be satisfactory additions to the second phase. "Do not include" – These articles are either poorly written, provide no insights or are completely irrelevant to the project.

All article summaries are presented in Annex A. These summaries include a general review of each topic and overall findings.

2.2 Results of Phase I

Having reviewed all Phase I articles (see Annex A), it was found that cue integration, pattern recognition, heuristics and biases each contribute differently to the overall understanding of DDM. Below are definitions that we used as guidelines in our review. Note that there are many different definitions in the literature and so these definitions are not to be taken as consistently held by other authors.

- Cue integration is the process by which information is selected from the environment, weighted, and combined to serve as the input to a decision (see Sections 4.1.1 and 4.1.2 for more of a discussion about the definitions of "cue" and "cue integration").
- Pattern Recognition is the process of applying knowledge about the relationships between aspects of the environment (e.g., patterns). Pattern recognition is usually thought to be a function of the similarity between the state of the environment and the patterns stored in memory, which are usually learned through experience.

- <u>Heuristics</u> are shortcuts in decision making, generally designed to find a decision that is "good enough" (i.e., satisficing). Heuristics are often contrasted with analytical methods which systematically examine all possibilities and are intended to arrive at an optimal decision (definition adapted from Adams, Rehak, Brown, & Hall, 2009).
- <u>Biases</u> are systematic (i.e., non-random) errors in decision making (Adams et al., 2009).

In general, there seemed to be a greater selection of literature about heuristics and biases and their effects on (dynamic) decision making compared to pattern recognition and/or cue integration (see Table 1 below); although literature related specifically to improving decision making through the use of heuristics or training to overcome biases is not prevalent. On the other hand, the literature related to pattern recognition and cue integration in (dynamic) decision making was spotty at best, although opportunities for training and improvement are possible, but not fully explored.

The quality of the literature we reviewed varied considerably. Much of the literature we reviewed was of high calibre; however application to DDM specifically is lacking in all four areas as a significant portion of the literature focuses on simpler decision making tasks. In Phase 2 of the project, these simpler tasks were used as building blocks to explore various aspects of DDM.

The literature review revealed that cue integration, pattern recognition, heuristics and biases are highly interrelated. For example, biases are tightly linked with heuristics. Much of the literature describes a dependent relationship in that heuristics inevitably produce biases (Janser, 2007; Rothrock & Kirlik, 2003; Adelman & Bresnick, 1995). To a lesser extent, pattern recognition has been found to overlap with heuristics. Specifically, research suggests that the use of a heuristic can be considered a form of pattern recognition depending on the context and resources (e.g., information; Cohen, Thompson, Adelman, & Bresnick, 1999). Pattern recognition was also seen to be related cue integration, whereby the integration of cues is done prior to the recognition of patterns.

It should be noted that the literature identified and reviewed was dependent on the specific terms used by authors. That is, our literature search would have identified research that used key terms such as "pattern", "cue", "heuristic", and "bias" rather than other synonyms. Acknowledging that the definitions for each of these terms overlap and are highly variable, the project teams did specifically attempt to see through the "words" and note relevant "concepts".

Annex B contains summaries of the general themes of each of the four areas, specific cognitive challenges related to DDM, and training issues gleaned from the literature that we reviewed.

2.3 Selecting an area of focus

At the end of the first phase of the project, cue integration was selected as the concept to undergo further examination. A number of factors were considered in selecting this area for future research First, the tight coupling in the literature between heuristics and biases, as well as the cause and effect relationship between them, meant that attempting to separate the two concepts seemed futile (e.g., Janser, 2007). Thus, heuristics and biases were merged and considered as one category. This reduced our consideration to three categories, from which one needed to be selected for more in-depth research. Given that the focus of this project was on identifying trainable cognitive challenges in DDM, we considered the eight categories of challenges associated with DDM listed above (see Section 1.4.1). Then the three remaining areas (cue integration, pattern recognition, and heuristics/biases) were considered for their relevance to the DDM challenges identified. Table 4 shows "yes" or "no" responses to the question "*will improving your skills in [category name] (e.g.*

cue integration) lead to better decision making considering the following challenge (e.g., uncertainty)". To answer these questions, we used knowledge gained from Phase I.

The answers to the questions are presented in Table 4. In filling out the table, it is important to note that it was not assumed that decision makers would have none of these processes at their disposal before training; rather, improving skills would simply make the decision maker better at them in some way. For example, it was not assumed that training in heuristics would allow a decision maker to use heuristics, but that perhaps using a set of relevant heuristics could be made more automatic so that they would require fewer cognitive resources. This is because basic cue integration, pattern recognition, and heuristics and biases have been shown to be used in novice decision-making, although expertise and training may provide additional competence (e.g., see Costello, 1992 for the use of heuristics in novices).

Another assumption was made that simply arguing that a cue integration strategy, pattern used in pattern recognition, or heuristic could be taught that would be able to address a particular challenge (e.g., a heuristic that would deal with complexity) would not be a useful or practical approach. This is largely because training would have to be more general (i.e., it would not be known ahead of time what particular heuristic, what cues, or what pattern should be used by the decision maker). The idea was to assess which process(es), if generally improved, would show the most promise in addressing the DDM challenge being considered.

Table 4: Anticipated improvements in cue integration, pattern recognition, and heuristics/biases in DDM

Challenging DDM situations	Cue Integration	Pattern Recognition	Heuristics/ Biases
Uncertainty	Yes	Yes	No
Time factors	Yes	No	No
High levels of risk	Yes	No	Yes
Ill-structured problems	No	Yes	No
Complexity	Yes	Yes	Yes
Changing Environments	Yes	No	No
Feedback delays and lack of adequate feedback	Yes	No	No
Making predictions/forecasting	Yes	Yes	Yes
Total "Yes"	**7**	**4**	**3**

Examining each of these challenges and their effects on the processes led to a number of conclusions about how well the challenges could be addressed by the different processes.

The challenge of uncertainty is generally due to having to make a decision without sufficient information about what the best decision would be. Heuristics are already intended to result in a decision without using all of the information which might be used (i.e., as compared with analytical decision making), so there would not likely be a significant improvement if heuristics were trained.

On the other hand, both cue integration and pattern recognition tend to suffer without adequate information (e.g., see Bakken, 2008). Improving how people seek out information or what information is selected might improve performance, so training in cue integration might be useful. Improving matching between information in the environment and increasing the number of patterns in memory might also improve performance, so training in pattern recognition might address this challenge.

Time factors are a challenge in DDM; this can be a problem because decision makers have to respond quickly, or to hold an action until the ideal time window (or just for a long time). The challenge of holding an action for a long time does not seem to be well addressed by any of the three processes. Challenges related to making a decision quickly or recognizing that an ideal time window has been reached (which in essence is also making a decision quickly) can be addressed by cue integration. Cue integration is potentially a lengthy process, as it involves the search for information (e.g., see Famewo et al., 2007). If this process were sped up, it is possible that the time factor challenge could be somewhat improved. On the other hand, both pattern recognition and heuristics may be relatively fast processes, and improving them might improve the actual decision, but it is not clear whether that decision could actually be sped up. For example, Wickens and Carswell (2006) note that decision making is faster with familiar patterns (i.e., context effects) and heuristics are often used to speed up decision making (e.g., Costello, 1992). Thus, only cue integration appears to be a process that could particularly benefit from training.

High levels of risk are often a problem in DDM, both because perception of risk can change decision making behaviour, and also because high risk tends to result in stress, and dealing with stress can limit the amount of resources that a decision maker can devote to decision making. If decision making could be made more automatic (i.e., use fewer resources), presumably this could improve performance. Pattern recognition is not assumed to require many cognitive resources, and so it is unlikely that pattern recognition training would significantly lower the number of resources it uses, and so this challenge may not be effectively addressed by pattern recognition training. On the other hand, different heuristics use different amounts of resources (e.g., see Gigerenzer, 2008), and cue integration can be resource-intensive (e.g., see Bryant, 2005), so training in either heuristics or cue integration could help to address this challenge.

Ill-structured problems are a challenge because of changing goals; that is, the task which is to be performed may change. Cue integration and heuristics typically require that the task is known, and it is likely that changing the task will change what cues are used, how they are integrated, and what heuristics are appropriate (e.g., see Juslin, Olsson et al., 2003). Thus, training in cue integration or heuristic processing will not likely address the challenges posed by ill-structured problems. On the other hand, it is possible that pattern-recognition processes could recognize what task is appropriate in what situation, and therefore recognize when goal shifting is required. Thus, training in pattern recognition might address the ill-structured DDM challenge.

Complexity, while not well defined, is often a challenge in DDM. Different factors which could increase complexity include some challenges which are addressed separately (e.g., ill-structured problems, changing environments), but there are also other factors that make a situation complex (e.g., information overload, non-linear relationships). Interestingly, complexity is a challenge which may be addressed by training in any of the three processes. For example, information overload could be addressed by improving information-search processes through cue integration training, by improving pattern-matching processes through pattern-recognition training, or by reducing the amount of resources used when applying heuristics (so that more resources are available for dealing with things like managing information) by training heuristic processing.

Changing environments is a challenge in DDM because important information used for decision making can change rapidly. One way of dealing with this challenge would be to speed up decision making so that it can be repeated often and therefore changes in the environment might be detected more quickly. Thus, a similar rationale applies here as applies to the time factors challenge above (training cue integration appears to offer the most potential to address this challenge by increasing decision-making speed).

Feedback delays and lack of adequate feedback is a challenge in DDM because feedback is generally very important for learning. Treating feedback as a cue, training cue integration processes to more appropriately deal with feedback could be one way of addressing this issue. The processes for incorporating feedback into pattern recognition and heuristics would heavily overlap with cue integration processes as we have defined them for this project. Thus, it seems most appropriate to argue that cue integration training is the most appropriate for dealing with feedback, and that training in other aspects of pattern recognition and heuristics would not likely appropriately address the use of feedback.

Making predictions (forecasts) is often a goal in DDM environments. That is, rather than understanding a situation as it is, decision makers often have the (additional) goal of understanding how the situation is likely to evolve, including how their own actions might impact the environment. Making inferences about the current situation and how actions of the decision maker might change the situation is a core component of pattern recognition. That is, pattern recognition processes are intended to make a match between the current situation and preferred decisions; if decision makers could be trained so that pattern recognition processes were aimed predicting future rather than understanding current situations, this might address this challenge. The focus of cue integration is on selecting and integrating information to be used in a decision rather than on the output of that decision, so it is less likely that training in cue integration would be generally useful for increasing the ability of a decision maker to make predictions. Likewise, heuristics are shortcuts in decision making, and it is not clear how they could be trained to increase the prediction accuracy of a decision maker. However, there is evidence in the literature that the task that decision makers are attempting to perform does change how they integrate cues (e.g., see Juslin, Olsson, et al., 2003), and it also seems reasonable to suggest that which heuristics are used will also change based on the task being performed (e.g., see Gigerenzer, 2008). Thus, although training in pattern recognition is the most promising for addressing this challenge, perhaps training in cue integration or heuristics could also be useful for making predictions.

Thus, while all three areas are suitable for further exploration, cue integration was determined to have the most potential for improving DDM given the challenges associated with DDM. (i.e., cue integration had the most "yes" answers in Table 4). Therefore it was agreed by the SA, members of the DRDC research team and members of the HSI research team that cue integration is the most relevant to all DDM challenges discussed and that cue integration should be the focus of the second phase.

3. Method of Phase II

In the second phase, the first step was to conduct a literature selection process, similar to that in Phase I, in order to identify relevant articles for a more in depth review of cue integration. A new list of key words was generated and discussed with the SA (see Table 5 below). These keywords were then used to search for articles using the same databases as for Phase I (see Table 2).

Table 5: Keywords used in Phase II

Core Concept	Primary Keywords	Secondary Keywords
Dynamic Decision Making	risk, complex*, uncertain*, ambiguity, temporal, delay*, feedback, rate of change, time pressure, ill-structured problem*, distribute*, predict*, forecast*	judgement, problem solving, intuitive, rational, naturalistic, NDM, assessment, evaluation, information process*
Cue integrat*	data, store, identif*, together, information, combin*, indicat*, fusion, event, information aggregat*, weight*, information integrat*, cue validity	contingency learning, probabilistic cue*,
Training	knowledge, attention, workload, learning, memory, language, communication, assumpt*, training transfer, skill retention, learning	challenge, problem
Contexts	military, emergency, fire fighting, search and rescue, crisis, operational, strategic, command and control, C2, effects based operations, 2nd/3rd order effects, planning, nuclear, police	uncertain, critical, pressure, risk

Fifteen additional articles related to cue integration were selected and again approved by the SA. All fifteen articles were read and summarised. Summaries for each article were completed using the same structure as outlined in Phase I (see Section 2.1). A total of 40 articles were examined in more detail to gain a deeper understanding of the role, difficulties, and issues cue integration plays in DDM. All findings, including gaps within the literature, as it pertains to DDM, are discussed.

The following sections provide our findings and discussions based on the literature reviewed in both Phase I and Phase II.

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4. Results of Phase II

Through an analysis of the literature, qualitative assessment, and discussion with the SA, cue integration was selected as the area of focus for Phase II (see Methods, Section 2). This section provides an introduction to and comprehensive discussion of cue integration, especially as it relates to DDM.

4.1 Introduction to Cue Integration

Before we get into the details of cue integration we first address basic definitions as well as limitations of this work.

4.1.1 What is a cue?

The definition of the term "cue" is an obvious starting point to understand cue integration. Shah and Oppenheimer (2007) suggest that cues are the pieces of information available to aid in the process of making decisions and judgments. Most other authors leave the definition of a cue to be inferred. For our purposes, a cue can be considered any piece of data used in decision making. This includes data about the current situation (e.g., what is present in the environment), data internal to the decision maker (e.g., what has been learned about the task), and data from the context (e.g., time constraints). Different types of cues are potentially used differently, changing the resulting decision (Famewo et al., 2007; Kerstholt & Willems, 1993; Schroeder, 2005). For example, doctors will examine the patient, ask about their family history and look at lab results. Stockbrokers consider company profit margins, recent activity and quarterly projections. In the courtroom, jurors include testimony from witnesses and evidence presented (Shah & Oppenheimer, 2007).

In further understanding cues we may be inclined to look at categories or "types" of cues. Some obvious categories may be the information source such as that internal to the decision maker or external within the environment or situational context. This distinction, however, is not clear within the research; there seems to be little agreement within the literature of how best to categorize cues. Cues may also be categorized as task-related or context-related. Our definition considers both possibilities understanding that the source of cues (internal to the decision maker vs. external) as well as the type of information (task vs. context-related) may impact the process of cue integration.

It should be noted that some researchers may identify cues as only initial inputs rather than any piece of data within the decision making process. This would in turn change the way in which cues are discussed and significantly impact the interpretation of integration. For our purposes in investigating DDM, it seems most logical to consider all data gathered within the DDM process a cue. For example, feedback, by our definition, is considered a cue to be integrated as required within a DDM context (e.g., Bois, 2002) as DDM environments are cyclical or continuous in nature. Others investigating simple decision making may consider feedback as information that contributes to learning rather than a "cue" as it is not an initial input.

4.1.2 What is cue integration?

For our purposes, we define cue integration as the process by which information is selected from the environment, weighted, and aggregated to serve as the input to the decision making process. Further decomposing this definition helps to understand the different aspects and components of cue integration necessary for our comprehensive review. It is quite challenging to identify a recognized definition of cue integration as cues are discussed differently by many different researchers. We support Shah and Oppenheimer's (2007) definition of a cue however, as it identifies that all data within DDM should be considered for integration and utilization within the decision as deemed appropriate by the decision maker. By our definition then, the process of cue integration spans the entire DDM process.

The literature review revealed that there are many factors involved in the way cues are used in decision making. First, there is evidence that decisions can be influenced by the way in which cues are presented. For example, the order as well as the number of cues presented at one time can effect emerging decisions (e.g., Adelman & Bresnick, 1995; Adelman, Tolcott, & Bresnick, 1991). At another level, the relationships between cues, as well as the relationship of the cue to the criterion (desired goal) are very influential in the use of cues in decision making. Challenges in decision making arise when there are multiple, complex relationships. A third factor is related to cue properties. Information may be unknown and/or dynamic. When cues are affected by new or unknown information, relationships pertaining to that cue (within the particular context) are difficult to establish. Also relevant is the strength, or weight, of the cue. All of these factors will be discussed in more detail in the remainder of the report.

4.1.3 Limitations

Considerable limitations of this review must be noted. Specifically, there is insufficient literature that integrates and discusses the mechanisms of cue integration within DDM explicitly. In managing this constraint, the project team utilized more simplistic decision making literature that seemed to best relate to DDM. In order to achieve this there was a significant dependence on the specific terms used by the authors of the literature. Once the defining components of DDM were established they were used in searching and selecting articles. In reviews investigating more simple forms of decision making, aspects of DDM were sought out in order to infer how cue integration may play a role in a dynamic context. Terms solicited pertained to "uncertain" situations; "time pressure" or "time limitations" tasks; "high risk" situations; "ill structured problems"; "complex" tasks and situations; dynamic "rate of change"; delays in feedback; and forecasting or "making predictions". Definitions of these particular terms may vary thus, the project teams put in specific effort to see through the "words" and note relevant "concepts". Throughout this review there are interpretations of the role of cue integration as it is proposed to take place in DDM. Particular caution should be taken when making deductions from these findings.

Overall the literature review highlighted the scarcity of literature that discusses the mechanisms of cue integration within DDM. From the literature available, we therefore draw on Wickens and Carswell's (2006) information processing model, and DDM associated contexts in order to surmise the role of cue integration in DDM. Such contexts include investigating high time pressure environments, uncertain situations, and complex, dynamic tasks.

4.2 Understanding Cue Integration in DDM

The role of cue integration in decision making, as well as the impact of its limitations on the effectiveness of decision making, has been extensively studied in "traditional" decision making research. In order to better understand cue integration, and its role in decision making it is helpful to use a model of human information processing. The most widely accepted model of information processing is provided by Wickens and Carswell (2006), and is shown in Figure 1: Model of

human information processing
(adapted from Wickens & Carswell, 2006).

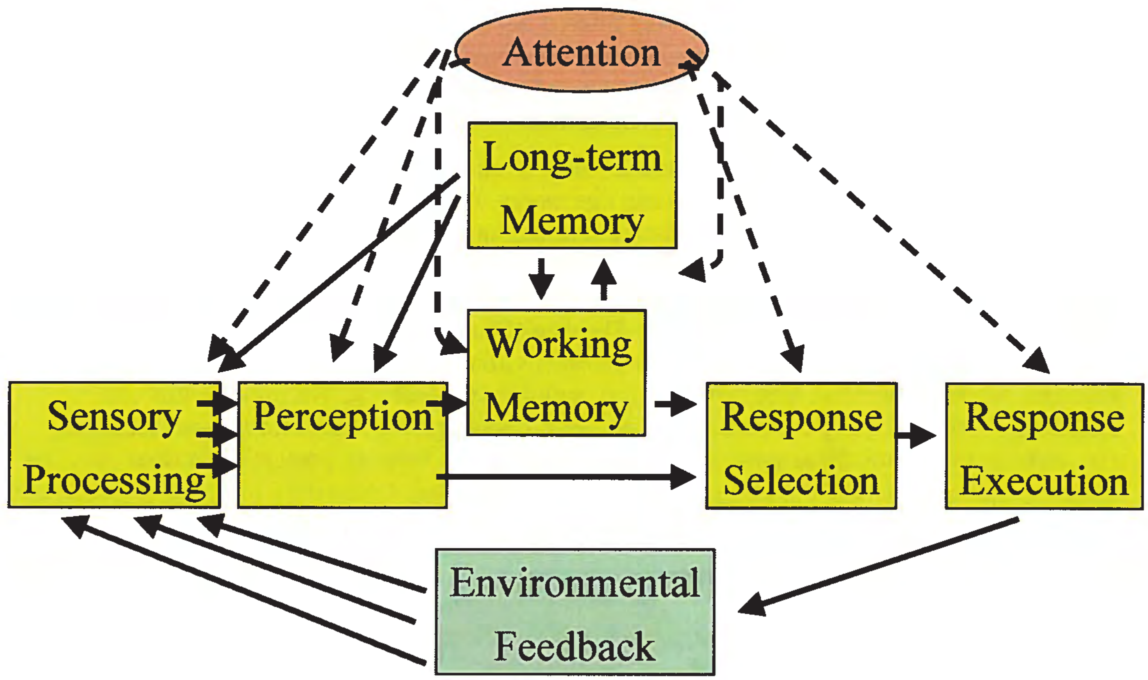

Figure 1: Model of human information processing (adapted from Wickens & Carswell, 2006)

This model represents information processing as the following set of stages:

1. Information enters the information-processing system from the environment (this may be through several processes such as unintentional observation, searching, etc.).
2. Information is processed by the sensory systems and perceptions are created (electrical impulses are translated into information that can be processed further, some of which is available to consciousness).
3. Information then enters into working memory, where it is processed; this is also called short-term memory and holds a limited number of items.
4. Information may move from working memory into long-term memory if certain conditions are present (e.g., information is rehearsed). Likewise, information may move from long-term to working memory. Long-term memory is a large-capacity storage system which can maintain information for a long duration.
5. Information from the processing in working memory is evaluated by a response selection system (e.g., there may be a record made of how much evidence there is for a particular decision, and a criterion for when something will be considered the "right" decision).
6. The response selection system sends information into a response execution system (e.g., the motor system) which will translate the decision into the appropriate motor action.

7. Response execution will have an impact on the environment; this information will then feed back into the sensory system and the cycle will continue.

8. Note that attention affects information processing at many levels, including but not limited to: what information is focussed on (or filtered out of processing); what information is retrieved from long-term memory and what is entered into long-term memory from working memory; what responses are considered options, and the effectiveness with which response selection is translated into the correct execution.

Building on the information processing model introduced above, the next section discusses the role of cue integration in the various steps within this model. Based on the literature reviewed, we propose that cue integration is involved in the information processing steps contained within the rounded-cornered box outlined below (blue) shown in Figure 2: Cue integration within the information-Processing Model
(adapted from Wickens & Carswell, 2006). The role of cue integration in each of these steps will be discussed particularly in the context of a DDM environment. First, we discuss perception, then attention, working memory, long term memory and finally, feedback. We propose that cue integration is not a primary component of sensory processing, response selection and response execution and therefore these steps are not discussed further. Sensory perception is what provides inputs into perception, and therefore inputs into cue integration. Conversely response selection and eventually response execution can be considered outputs of cue integration.

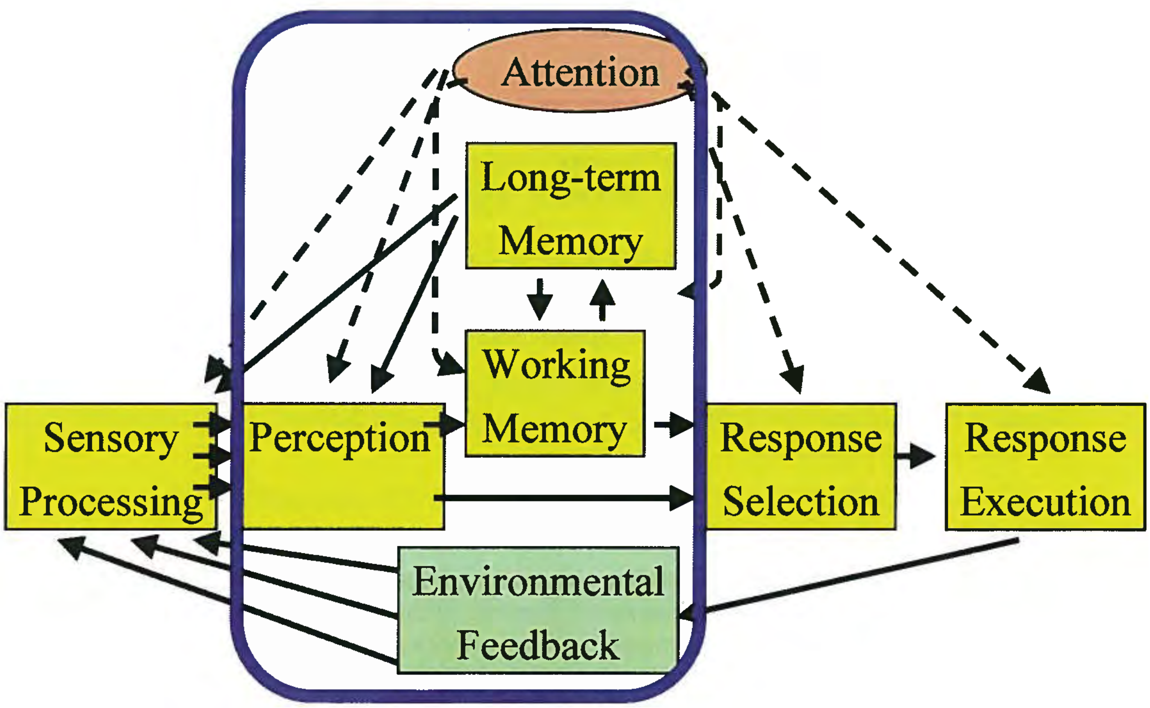

Figure 2: Cue integration within the information-Processing Model (adapted from Wickens & Carswell, 2006)

4.3 Attention and Cue Integration in DDM

We propose that attention is a part of cue integration. Though there was no literature found that explicitly dealt with the role of attention in cue integration, a number of specific challenges related to attention are discussed. DDM contexts involve a situation that changes, both spontaneously and as a result of decision-maker input. This means that the decision maker constantly has to reassess the current situation, putting great demands on attention and working memory. Furthermore, attention is required for many purposes but is a limited-capacity system; this means that parts of decision making which require attention (e.g., maintaining information in working memory) often cannot perform optimally (e.g., Bois, 2002). Attention can be directed in a way that is unintended by the decision maker (e.g., attentional capture); this means that the information which is incorporated into decision making might not be optimal and might not be the information that the decision maker wants to influence the decision (e.g., Bois, 2002). Another challenge is that attentional resources can fluctuate with time (e.g., vigilance performance decreases over time) and other factors such as fatigue. Decision making performance, therefore, can be influenced by factors such as the amount of time the decision maker has been working, the context (e.g., how boring their task is), etc.

One area in which attention is related to cue integration is when the decision maker is searching for cues. As noted, attentional resources can be directed to particular cues unintentionally (Bois, 2002) which may result in poor performance. As well, one difference between experts and novices is that experts seem to direct their attention to (i.e., select) cues which are more helpful in their decision making (e.g., Salas, Cannon-Bowers, Fiore, & Stout, 2001; see Section 5.1 for further detail). At this point, it is unknown whether the selection of cues is a deliberate or automatic (i.e., conscious or unconscious) process, and this is possibly a topic for future research.

4.4 Perception in DDM

A first step of cue integration is perception as cues must be perceived before they can be incorporated into the decision making process. Perception involves processing information collected by the sensory systems. The process of perception is unavoidable; however, cue perception is not a straightforward recording of reality. Instead, "perception is a choice of which people are not aware, and people perceive what has been chosen" (Kahneman, 2003, p. 701). This means that one's perceptions are believed to be constructed (Jones, 2005), and that the construction process is affected by internal cues and environmental cues; thus, "perception is reference-dependent" (Kahneman, 2003, p. 705). There are large top-down processing influences of long-term memory (e.g., experience, expectations) on processing in the perceptual system. This is done both consciously and subconsciously[1].

Perception is not perfect and is associated with its own set of challenges. For example, only information which has been processed by the sensory system can be entered into cognitive processing. This means that some information can be missed, and unavailable information cannot be used (e.g., Bakken, 2008; Bois, 2002). This is especially the case in DDM situations where the quantity of task cues is large, and the interrelationship between cues can be complicated.

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[1] The role of consciousness in cue integration was not specifically explored in this project. This could be a relevant area for future research.

4.4.1 Different Cue Types

Research suggests that there are different types of cues. Some cues are task-related and taken from the environment and other cues are internal to the decision maker. Each of these cues is perceived differently. Schwartz and Norman (1989) suggest that environmental cues are taken into account if "a) it truly varies within the ecology, and decision makers attend to this or b) some aspect of the situation surrounding the decision causes the perception of cue variation" (p. 383). In both circumstances, the perception of variability is what determines cue usage.

Other cues are internal to the decision maker and include natural reactions to stress (perhaps from time pressure). Another major source of internal cues is affect, or emotion/mood. For example, when making decisions, people sometimes use their current emotional state as a cue in the judgment process. Take the following two questions: "How happy are you?" and "How many dates did you have last month?" The order in which these questions are asked has implications for how the questions are answered. Kahneman (2003) showed that there was little correlation between responses to these two questions when asked in this order; however, when the order was reversed the correlation rose to 0.66. In other studies, the intensity of fear has been found to impact a variety of judgments, such as rating the probability of a disaster (Kahneman, 2003). These simple examples show a more complex phenomenon; namely that people's affect influences how they perceive the world and how they make decisions. These studies point to the concept that emotions (or affect) can be considered cues. People performing in time pressured, complex, applied DDM environments should be subject to these same affect biases which can impact their performance. See Section 5.2 for a discussion of cue types in the context of training.

4.4.2 Tasking Effects

Other research has looked at the effect of what is being asked of decision makers on cue integration. These studies show that the strategies used and conclusions arrived at can vary greatly depending on the specific tasking of the decision maker, even though the same cues are presented. Evans, Clibbens, Cattani, Harris, and Dennis (2003) found differences when decision makers were asked to integrate cues together and provide general assessments between poor and good (called multicue judgements) versus when asked to select between two cases (forced choice). It is assumed that DDM scenarios tend to involve both of these types of decision making. The authors discovered that performance was much better on the standard multi-cue judgment task versus the forced-choice task.

In the same series of experiments, Evans et al. (2003) introduced cues that predicted criterion negatively (negative predictors) and increased the complexity of the task by increasing the number of cues. Results suggest that irrelevant cues do not prevent people from acquiring linear judgment models but simply render these models less accurately matched to the criterion. The role of implicit and explicit cognitive processes in these judgments was also reviewed. Overall, the authors found that both implicit and explicit processes influence multicue judgements. Specifically insight measures (implicit processes) dropped when a multicue judgment task is more difficult, however, explicit knowledge does not appear to be impacted by task difficulty. Implicit learning is also impaired by the presence of irrelevant cues in the environment. Both these effects suggest that explicit knowledge should continue to increase in DDM situations, though implicit learning may not.

In another example, judgments regarding the custody of a child were assessed based on parental descriptions (Kahneman, 2003). One description was much richer, in both negative and positive attributes. Subjects were either asked to judge which custody request should be accepted or rejected. Under both "accepted" and "rejected" conditions the richer description was selected. This means that the same parent who was accepted in the "accept" condition was the parent that was rejected in the "reject" condition. Clearly the subject's focus was shifted based on the question asked even though the same information was presented (Kahneman, 2003).

Finally, Juslin, Olsson, and Olsson (2003) found that different cognitive processes are used to determine categorization (i.e. allocating between two or more categories) versus multiple cue judgments of a continuous variable (e.g., probability of precipitation given weather information). Based on three experiments, Juslin, Olsson et al. concluded that differences between the categorization and multiple-cue judgment tasks actually produce qualitatively different cognitive processes. Mental cue abstraction is favoured when a continuous criterion is used, whereas a binary criterion tends to be interpreted via exemplar memory.

In DDM, it is likely that different types of outputs will be appropriate for different decisions. For example, if a risk assessment is being performed, it may be appropriate to make a categorical assessment (e.g., an approaching individual is a risk or not), or it may be appropriate to make a proportional judgment (e.g., deciding the relative riskiness of entering different parts of a city). Because the tasking can influence decision-making processes, DDM contexts should be examined to determine potential tasking types and the implications of these different tasking types on the way that information should be presented and the types of processing that need to be supported. As well, consideration about how performance should be evaluated is also needed, including whether assessment of performance across different kinds of tasks is appropriate (see Section 5.3.4 for a discussion of evaluating performance during DDM training).

4.4.3 Information Presentation Effects

In addition to what is asked of a decision maker, the way in which cues are presented to a decision maker has also been shown to impact how they are perceived. The effects of information presentation (e.g., framing) of cues on decisions have been extensively researched. The order, format, salience, context, and affect of cues impacts how and whether a cue is incorporated into decision making (Adelman and Bresnick, 1995; Bois, 2002; Dunwoody, Haarbauer, Mahan, Marino, & Tang, 2000; Famewo et al., 2007; Jones, 2005; Payne, Bettman and Johnson, 1992; Tolcott, Marvin and Bresnick, 1996). Some of these studies conclude that the effects of framing occur outside of consciousness, such as the tendency to judge absolute numbers (e.g., 20 out of 100) as more likely to occur than probabilities (20%) (e.g., Slovic, Peters, Finucane, & MacGregor, 2005); while decision makers can be made aware of other effects such as the tendency to be risk seeking or risk adverse (Schulz, 1996). Collectively, these effects may lead to: neglecting potentially relevant problem information, ignoring values when they are difficult to estimate, inaccurately weighting cue validity, and the "general tendency to accept problems as given and the segregation of the decision problem at hand from its broader context" (Payne, Bettman, & Johnson, 1992, p. 116). In general, each of these effects can be expected to impact military scenarios as well drawing attention to the importance of the presentation of information to military decision makers. Accessibility and gain/loss framing are specifically discussed below in addition to other general information presentation effects (for a discussion of information presentation during training, see Section 5.3.1).

4.4.3.1 Accessibility

Accessibility refers simply to "the ease (or effort) with which particular mental contents come to mind" (Kahneman, 2003, p. 699). Accessibility is not a dichotomy but a continuum where some operations demand more effort than others. The more accessible a cue is, the more it will tend to be used in decision making or other tasks. Highly accessible cues can also become steady anchors. A number of perceptual examples are used to illustrate how certain characteristics are more "accessible" than others to provide some perceptual examples of the effects of accessibility. Figure 3, for example, shows how the height and surface area of blocks are more obvious (and hence, accessible) depending on the way they are presented. It is easier to see that the volume is equivalent between A and C in Figure 3 because the columns are the same height and width, compared to assessing the volume between B and either A or C. Thus, desired information can be easier or more difficult to perceive.

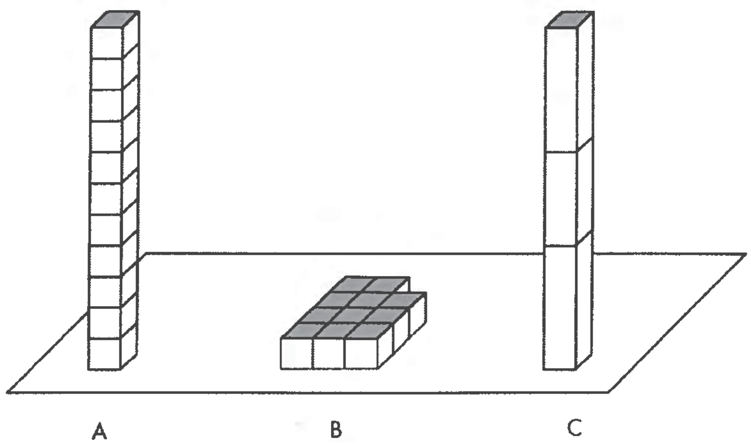

Figure 3: The selective accessibility of natural assessments (Kahneman, 2003)

In contrast to one piece of information being more or less difficult to perceive as in the previous example, it is also possible that different perceptions of an ambiguous piece of information can be differently accessible depending on the context. Figure 4 shows an example of how the context in which objects are embedded can also influence the accessibility of different interpretations.

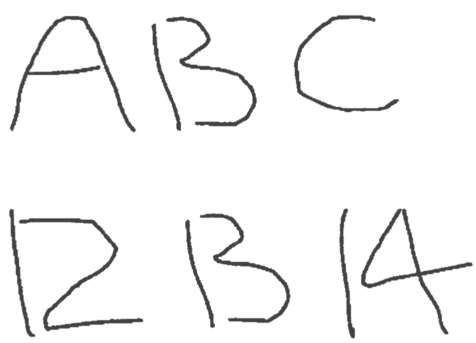

Figure 4: An effect of context on the accessibility of interpretations (Kahneman, 2003)

One's interpretation of the middle figure in both lines is dependent on the objects on either side. With the middle figure embedded between "A" and "C", we are more likely to see it as a "B", rather than as a "13" (as in the lower row).

Salience also directly relates to accessibility. Thus, if a large green letter and a smaller blue letter are presented simultaneously, "green" will first come to mind. This effect can be mitigated – for example, if told to look for smaller letter, then the blue letters features will be enhanced. Kahneman and Frederick (2002; as cited in Kahneman, 2003) listed natural assessments which they argue are perceptually registered with little effort. These include size, distance, loudness, similarity, causal propensity, "surprisingness", affective valence and mood (Kahneman, 2003).

The accessibility of cues can impact how they are used in decision making. Shah and Oppenheimer (2007) suggest that decision makers use cue fluency (i.e., how easily the meaning of the cue is accessed) to determine cue weights by "placing more weight on information that feels easy to process" (Shah & Oppenheimer, p. 371). Different types of fluency are described, including perceptual fluency (i.e. how easily information is perceived) and retrieval fluency (i.e. how easily information is recalled from memory). The authors argue that the ease of processing itself (i.e., cue accessibility) becomes a cue that is weighted and directly affects decision making.

Cue fluency can also affect decision making indirectly, by influencing which decision making strategy is selected. Part of the argument for this is that fluency is correlated with objective validity in the real world, making fluency an obvious basis for cue weighting. Two experiments examining the effect of perceptual fluency were conducted. The first experiment had subjects view a negative consumer review and then suggest a price to be paid for the reviewed product. Some subjects read reviews written in smaller italicized font and the other review was easier to read. Subjects were willing to pay more when the negative review was more difficult to read, indicating that subjects weighed this information less than the fluent, easy to read review. The second experiment was a between-subjects design that also included easy and harder to read information, though this time the information was a rating score (either numeric or semantic). Again, the fluent cue was used more in decision making than the less-fluent cue (Shah & Oppenheimer, 2007). Thus, experimental findings indicate that cues which are more accessible appear to be weighted more heavily in cue integration.

The reasons for these results are discussed. Shah and Oppenheimer (2007) postulate that perhaps it is an increase in attention to the fluent items that leads them to be more heavily weighted. Alternatively, they propose that "people simply select accessible or fluent information until they feel that they have enough information and then disregard the rest of the information" (Shah and Oppenheimer, p 377). Though, the clustering of results around the midpoint of both the fluent and disfluent ratings in the second experiment suggest that in fact both cues were considered; just the fluent cue was more heavily weighted. Though not yet tested, Shah and Oppenheimer hypothesized that if the use of fluency for cue weighting minimizes cognitive effort then this strategy should be applied more often when decision makers are placed in situations where there are high cognitive demands.

The importance of accessibility, salience and fluency on a decision makers' ability to select cues has wide ranging effects in DDM. Notably, in complex, uncertain military DDM environments it can be assumed that important cues are not necessarily going to be salient. Cue values will also be changing often making the current value of cues less accessible.

4.4.3.2 Gain versus Loss Framing

In addition to the potential impact of accessibility, intuitive processes can also be susceptible to framing effects. Depending on the way in which a problem is framed, respondents can be more risk averse or risk-seeking even though they are asked essentially the same question. This phenomenon has been studied in detail in the context of a disease problem. This problem can be summarized as follows (Tversky & Kahneman, 1981):

> "Imagine that the United States is preparing for the outbreak of an unusual disease, which is expected to kill 600 people. Two alternative programs to combat the disease have been proposed. If Program A is adopted, 200 people will be saved. If Program B is adopted, there is a one-third probability that 600 people will be saved and a two-thirds probability that no people will be saved. Which one of the two programs would you favor?"

When presented with this problem, most respondents favor A (risk aversion). Alternatively, if presented: "If Program A is adopted, 400 people will die. If Program B is adopted, there is a one-third probability that nobody will die and a two-thirds probability that 600 people will die", the majority favors B (risk seeking). This tendency is reinforced by Kahneman (2003): "A basic principle of framing is the passive acceptance of the formulation given" (p. 703).

The impact of framing on decision making has also been shown in real-world healthcare examples in which outcomes depend on whether survival or mortality rates are shared. Thus, healthcare decisions changed based on whether or not patients were presented with the survival rate or the mortality rate (Kahneman, 2003). It is clear that the way in which the cues are being integrated varies greatly based on the gain/loss presentation, even though essentially the same information is being presented.

Schultz (1996) discusses how each of these example outcomes can be thought of as changes from a reference point. The reference point (which can be thought of as a cue) is itself changed by how the decision maker evaluates and edits the decision problem. Editing and framing the problem are dynamic processes, which can change the assessment of a particular outcome from a gain to a loss, and vice versa. Thinking of an outcome as a gain or a loss will influence the assessment of risk, which will in turn influence decisions.

"Gain" or "Loss" therefore appears to be a significant cue in decision making that is easily manipulated. This finding supports the idea that cues are commonly interpreted in a binary format (i.e., Yes or No, Gain or Loss), even for cues are that continuous (>50 years old or <50 years old) (Newell et al., 2004). Applying the gain/loss framing effect to military applications would have strong implications on all levels of military decision making from tactical up to strategic. For example, a losing commander may be inclined to accept more risks that one who is winning (Schultz, 1996).

4.4.3.3 Other Framing Effects

There are many other framing effects relevant to cue integration and decision making that have been studied. For example, cue presentation can even determine the decision making strategy used by a decision maker. For example, Dunwoody et al. (2000) show that different decision making strategies were induced by an iconic information display compared to a numeric information display. Also, there appear to be differences in how cues are integrated depending on whether cues are presented all at once or serially. With evidence suggesting that better decisions are made when cues are presented simultaneously; however, this likely depends on factors such as number of cues as well as the nature of cues. Further, when cues are presented serially, cues can be weighted differently, resulting in different decisions (e.g., Adelman & Bresnick, 1995; Adelman, Tolcott, & Bresnick, 1991). Unfortunately, while a great deal of information can be presented simultaneously to military decision makers, the mission scenario will continue to change. This means that cues will not remain static as their values, proper weight, etc. vary. As such, changing cues will be required to be also presented to military decision makers. It is reasonable to presume that this forced serial presentation of cues (and changing cues) contributes to the challenge of DDM.

Additionally, one study explored the usage of unimportant cues. Schwatz and Norman (1989) found that cues that are unimportant can be considered relevant and used by decision makers. For these studies, job applicant evaluations were performed by subjects. In their decisions, unimportant cues (e.g., height) were shown to be used in decision making. The use of these cues was increased when it was subtly suggested to subjects that the provided cues were known to be relevant to job evaluations. The authors argue that situation context determines whether or not the cues are used to make decisions. In DDM environments, decision makers rely on various means to suggest relevance and this study shows how easily relevance can be misguided.

The second experiment included unavailable (i.e., missing) and unknown (i.e., stated "unknown") cues as part of a similar job applicant tasking. The authors hypothesized that missing information could be utilized in three possible ways: 1) participants infer the missing values; 2) missing dimensions could draw more attention than those with values; and 3) dimensions without missing information could be more heavily weighted. Again, some participants received distinct instructions. They were informed that "unavailable" information was not included and the supervisor did not care to know the values, and further that "unknown" information was also not included but those values were desired. Results showed that subject preference for job applicants decreased similarly with unavailable and unknown information; though there was more variability in preference ratings for unknown information than for unavailable information. This is a somewhat surprising conclusion, as one would expect unavailable information to be disregarded and unknown information to be heavily weighted. See Section 5.2 for a discussion of how framing effects might be considered and mitigated during DDM training (e.g., through critical thinking training).

4.4.4 Perception Summary

In conclusion, the preceding sections suggest that cue perception is not consistent or commonsensical. How cues are presented can bias cue integration, unimportant cues can be considered in the decision making process, and a lack of cues (e.g., cues marked as "unknown") can affect cue integration and decision making in ways that one may not expect. These results have been found in experiments using relatively simple judgment tasks. One can therefore presume that the effects will be compounded in complex, uncertain dynamic military environments that are characteristic of DDM.

A specific challenge in military scenarios involves perceiving the presence of critical cues (detection). In most laboratory experiments, cues are explicitly presented to participants and participants do not have to perform a visual (or other perceptual sense) search for cues. That is, perceptual detection tasks are often not a part of decision making tasks. In contrast, in military environments, decision makers are often acquiring information over long periods of time, and important information must be detected and can be missed (e.g., changes on a visual display could be overlooked). There is some evidence that decision makers do miss perceptual cues, and that helping decision makers detect important cues can improve decision making (e.g., Kirlik, Walker, Fisk, & Nagel, 1996; see Section 5.3.1 for further discussion about training perceptual processing).

Cues themselves are likely to be much more ambiguous in military DDM scenarios than in the laboratory experiments which are typical of the research reviewed here. Cues in laboratory experiments most often have unambiguous values which are easily discriminated (e.g., in Juslin, Jones, Olsson, and Winman's (2003) experiment in which the toxicity of frogs had to be evaluated, frogs were either clearly brown or clearly green) but military decision makers there are many different values which overlap and are ambiguous and thus much more difficult to discriminate (e.g., there are green frogs with brown spots, brown frogs with green spots, greeny-brown frogs, etc.). Thus, even when a relevant item in the environment is identified, it is often a perceptual challenge to determine relevant information about that item (i.e., is the frog green or brown?). It has been shown that training in how to set thresholds for continuous variables can improve DDM performance (see Section 5.2 for a discussion of training implications).

4.5 Working Memory and Cue Integration in DDM

Next, we examine the role of cue integration in working memory specifically in DDM contexts. Working memory is the powerhouse of processing, where the links between pieces of information are made. We assume that it is in this function that that the main decision making strategies are selected and applied. This stage of processing has extremely limited capacity. Working memory performs both storage and processing functions and these are generally not independent. This means that the more things that have to be remembered the fewer resources that are available for processing, and vice versa, which means that information can be lost and inferences can be missed. Finally, attention is required to maintain information in working memory. This means that if attentional resources are allocated elsewhere information is likely to be lost. Below we focus on the number of cues available and the possible ways in which these cues are weighted and integrated within working memory. The role of cues in mental models is also discussed.

4.5.1 Large quantity of cues

It has been found in relatively simple decision making tasks that as the number of cues increases, performance drops. For example, one study found that judgment accuracy was highest with two cues and as the number of cues increased accuracy decreased (Karelaia & Hogarth, 2008). In real world military dynamic decision making tasks, however, there will most certainly be more than two cues; so many more that the sheer quantity of cues can exceed the cognitive limitations of the decision maker (e.g., Adelman & Bresnick, 1995; Jones, 2005). The limitations of working memory restrict the ability to process, and integrate multiple sources of information (e.g., Famewo et al., 2007; Gibb, 2000; Jacobs & Gaver, 1998). This means that links between ideas can only be made if they are active within working memory at the same time. The result could be that many inferences are missed (e.g., Adelman & Bresnick, 1995; Bakken, 2008).

Although it might be expected that expert decision makers might be better decision makers because of an ability to use more cues, it has been found that experts do not use more cues than novices. Rather, experts appear to be able to determine which cues are the more useful for decision making, and therefore can select more appropriate cues than novices (e.g., Salas et al., 2001). This finding will be discussed more thoroughly in the training section (Section 5.1).

In cases where a large number of cues must be integrated such as in DDM, one strategy is to divide the decisions among different people. In such distributed decision making, different experts are responsible for making sub-decisions. This information is then passed to a central decision maker who must integrate these cues, along with information about the validity of cues and the skill level of the experts. These central decision makers are then responsible for making the larger decision (e.g., Brehmer & Hagafors, 1986). The cues in these scenarios therefore increase in number as central decision makers must be aware of these additional factors. Unfortunately, distributing cues to different decision makers is often not a practical option. Thus decision makers have to develop ways to effectively integrate the cues together. To do this a number of different strategies are postulated to be applied.

4.5.2 Different Cue Integration Strategies

There are a variety of decision making approaches that can be applied in any given situation. Commonly researched are compensatory and non-compensatory decision strategies. Cue integration plays a central role in both these approaches. Compensatory strategies involve integrating all information to be used in the decision. This means compensatory strategies weigh information and opposite values can cancel each other out. As well, the presence of a cue with high value (weight) can compensate for an absence of cues with low weight (e.g., evidence for the decision can still be considered strong). Non-compensatory strategies are strategies where the "trading off" property doesn't apply. For example, every cue must have a high value for evidence for the decision to be considered strong (Rothrock & Kirlik, 2003). Thus, non-compensatory strategies involve disregarding certain information (e.g., in the "choose the best" heuristic only the most valid cue is considered) (Pachur & Hertwig, 2006). Dunwoody et al. (2000) suggest that neither compensatory nor non-compensatory strategies are inherently better. What makes one or the other more appropriate has to do with the nature of the task (e.g., whether judicious decisions will have to be made), the nature of the inputs (e.g., whether cues should be weighted equally; how many cues must be integrated); the way information is given (e.g., framing); and other factors. Non-compensatory cue usage strategies seem to be prevalent in dynamic tasks (Rothrock & Kirlik, 2003), which is reasonable given that non-compensatory strategies often yield very good results, are generally faster, and require fewer resources compared to the more cognitively demanding compensatory strategies (Rothrock & Kirlik, 2003).

In other research, Martignon and Hoffrage (2002) reviewed models of paired comparisons (e.g., choosing one of two options) from several domains. Computational complexity was one of the key variables examined. The authors report that a simple heuristic, "take the best" (TTB) is extremely simple yet surprisingly robust, and adequately allows the application of knowledge to new data. This specific non-compensatory strategy has been studied extensively.

The TTB heuristic can be used when a decision maker must choose between two options using one criterion (Gigerenzer & Goldstein, 1999; as cited in Adams et al., 2009). When the cues have been learned through observation, the order of cues can be estimated from the number of times the cue has predicted the criterion in the past. This information is used to conduct a limited search using a step-by-step process.

> Step 1: Guiding search. Choose the cue that seems to be the most valid. Then look at the values of each option.
>
> Step 2: Stopping rule. If one option has a higher value than the other, stop the search. If not, go back to step 1 and find another cue. If no further cue is found, guess.
>
> Step 3: Decision rule. Choose the object with the higher cue value.

In comparing the TTB heuristic, a non-compensatory model, to the weighted additive (WADD) strategy, a compensatory model, and different optimal scenarios were identified for each. WADD is better at predicting decision making when information acquisition is costly, time pressure exists, or when information must be retrieved from memory. TTB, on the other hand, is suited for predicting when information acquisition costs are low, there is no time pressure and when information is provided simultaneously (as opposed to sequentially). This supports the concept that people apply both compensatory and non-compensatory strategies effectively, changing the model applied based on task and environmental factors (Ayal & Hochman, 2009).

Other TTB versions have also been explored. Garcia-Retamero, Hoffrage, and Dieckmann (2006) conducted a series of studies that investigated strategies used in decision making. The TTB strategy employs one reason decision making (i.e. only focuses on a single cue at a time) and is non-compensatory. These one-reason decision strategies, however, cannot deal with compound cues (e.g., two variables that together create an effect and individually do not have the same effect) which are likely to happen in DDM. TTB-Configural is a strategy that provides a method through which compound cues are processed. The underlying theory presents the idea that compound cues (e.g., two substances appearing in conjunction with one another) that have high validity in predicting the criterion are identified as such. For example, when individually these cues may not have any validity (x has 30% validity, y has 20% validity), but as a compound cue they do (combined xy has 90% validity), participants appropriately search for cues that jointly constitute the criterion (Young, Wasserman, Johnson, & Jones, 2000; as cited in Garcia-Retamero et al.). In studying these strategies, Garcia-Retamero et al. hypothesized that individuals would consider that two compounds may interact with each other when they both act through a common causal mechanism in determining an effect. They provided participants with three different types of instruction that attempted to manipulate participants' causal mental models. In the configural model instructions included that two substances acted through the same mechanism (e.g., the blood stream). The elemental model provided instruction that stated two substances acted through different mechanisms (e.g., the blood stream and the nervous system). Finally, in the neutral causal model condition participants were not given any instruction about the causal mechanism.

Findings showed that when participants were given instruction that cues acted through the same causal mechanism the majority of participants made decisions best modelled by the TTB-Configural strategy. When instructions suggested cues were acting independently their decisions were best modeled by the elemental TTB. This was also the case for the neutral causal model condition. In an environment with no compound cues, no participants were categorized as using TTB-Configural, but instead were modelled best by the TTB. Thus, the hypothesis was confirmed that in situations where compound cues have high validity, the TTB-Configural is the best model of the strategy used. When no compound cues are present, participants tended to revert to strategies best modeled by TTB.

Research on additional alternative TTB strategies has also been conducted. A version of the TTB strategy used for classification (TTB-C) is described by Bryant (2007). In the context of threat classification, consider the case where there is an unclassified contact. Using TTB-C, an operator would search for the single most valid cue which would serve as the basis for classification (cue validities would have to be determined during some learning phase). When the most valid cue available is located, there is an assessment about the appropriateness of the threat classification, and then a determination about which has the greater probability of being true. If no valid cue is found then there is a random guess.

Other possible ways of using cues to perform this task include:

- Weighted Pros Rule: counts bits of evidence for an alternative; examines each cue value and assigns evidence for each classification. A running sum is maintained and after all available cues have been inspected and weighted, a decision is made about the classification for which there is more evidence.

- Unweighted pros rule: the same as the weighted pros rule except all cues have the same weight.
- Bayesian strategy: conditional probabilities of classifications given the cue pattern and select the higher-probability alternative – the cue configurations matter.

Bryant (2007) found that no participants appeared to use the Bayesian strategy. While many strategies were unclassifiable, the majority of participants appeared to use either the TTB-C strategy or a Pros Rule (most users of the Pros Rule used the Unweighted Pros Rule when the distinction could be made in Experiment 2). When participants were explicitly instructed about the Bayesian strategy, many participants used that strategy when they had the time to do so (i.e., in the low time pressure condition) showing the possibility for increased application of a Bayesian strategy for cue integration through proper training (e.g., Bryant, 2005).

Still, TTB is far from being accepted in the literature as the commonly applied approach. Newell, Rakow, Weston, and Shanks (2004) consider different strategy types for cue acquisition:

- Cues which stop and make a choice on the first discriminating cue that is found (i.e., "one-reason" decision strategies:
    - Take the Best (TTB): search cues in descending order of validity
    - Draw the Discriminator (DTD): search cues in descending order of discrimination rate
    - Select the Successful (STS): search cues in descending order of success
- Strategies that stop if no discriminating cues is found by a particular point (e.g., after 1, 2, or 3 cues)
- Weighted additive model (multiple linear regression) created during learning block of trials
- Bayesian calculation (works out to the same as the weighted additive model)

The authors found that the STS strategy is highly accurate and more frugal than the TTB strategy. The authors also note that participants did not select as many cues as they probably would have if cues had not been so expensive (each cue selected dropped the expected financial reward of the participants).

It is possible that participants do not consistently choose the same strategies. Factors such as cue salience and other differences on trials could have influenced strategy choice for individual trials. Individual participants would also have experienced different levels of the variables early in the experiment (e.g., cue validities) because of probabilistic selection of items.

More studies have also found support for compensatory strategies over non-compensatory strategies. Newell and Shanks (2004) conduct two studies that indicate decisions may be more compensatory in nature. They discuss the non-compensatory strategies of recognition information proposed by Goldstein and Gigerenzer (2002) and argue that results from their studies indicate participants do continue to search above and beyond recognized, high validity cues. The experiments were conducted within the context of financial investment. One may argue that the situation and investment risks significantly impacted participants' willingness to use non-compensatory strategies. It is not expected that these results would transfer well to a DDM context where time limitations and high uncertainty are prevalent, as this study was done in a static environment.

Prescriptive models suggest that decision makers should look at *every* cue that might affect a judgment. Each of these cues must then be weighed based on "how successfully the cue predicts the outcome (Shah & Oppenheimer, 2007, p. 571). This complex weighing process does not appear to have been applied in all the studies summarized above, where prescriptive approaches have been abandoned for simpler non-compensatory valuations. While this does seem to be an effective approach in the environments, and also appears to serve decision makers well in day-to-day reasoning (Klein & Crandall, 1996), the question remains about whether or not this is an effective approach in DDM situations. Explicitly exploring these approaches in DDM should prove interesting.

4.5.3 Making Inferences

Making inferences, or connections between ideas, is one function of working memory. One such inference that is important in cue integration is making inferences about cues and criteria; that is, predicting the future state of the DDM environment based on its current state (including the decision maker's own actions). Challenges in making inferences about the relationships between cues and criteria are pervasive in DDM contexts. Understanding what cues should be used when making decisions is generally a function of understanding cue validity; that is, how predictive of an outcome is a given cue? As well, one of the most important types of cue-criterion relationship that must be perceived and understood in order to improve decision-making performance is the relationship between the action of the decision maker and the results of those actions (i.e., feedback). In non-DDM environments, feedback about performance or other variables is often given separately after a decision and acts only as an output of rather than an input to decision making (see Section 4.1.1 for a more detailed discussion about why we are treating feedback as a cue in DDM environments, and Section 5.3.3 for a discussion of providing feedback during DDM training). Because feedback is such an important type of cue it is dealt with in its own section (Section 4.7).

4.5.3.1 Cue Validity

Determining cue validity (i.e., how much weight to assign to each cue) is a crucial part of cue integration. Newell and Shanks (2004) conducted two experiments that investigated cue validity in decision making. It was found that the validity of the cues was the primary factor in determining if it would be used as the main information in the decision-making process.

This study demonstrated that, when the validity of a cue is kept consistent across trials, over time participants are able to identify its validity and use the information in making accurate decisions. This evidence is presented in the context of simple decision making where the dynamic of the situation does not change the cue validity across trials. One would expect that the uncertainty associated with this type of change will have a significant impact on the ability of people to grasp the validity of a cue in a particular situation. This study indicates that in order for cue validity to be understood, multiple trials are required where the cue validity is kept constant. This is evidence for the fact that expertise in decision making might be a function of learning cue-criterion relationships, and that training such relationships could improve DDM performance. The specific application of this in military DDM environments should be more explicitly explored.

4.5.3.2 Mental Models

Another way in which inferences between cues are made is through the formation of mental models. Mental models are created, accessed and manipulated in working memory and cues and cue integration play a central role in this process. Thus, a brief discussion on the use of cues in mental models is required. Cohen et al. (1999) argued that optimal performance in DDM contexts rely upon appropriate mental models about organizational purpose, own and others' intent, degrees of initiative, team member reliability, and action sequences. To make the best use of this information, the ability to think critically about these mental models and apply them to novel situations is also required. According to the authors, a fundamental skill is related to separating grounds (what is given) from conclusions (what is inferred). The relationship between grounds and conclusions is generally not 100% certain, so this is a way of identifying assumptions that may have to be tested. This can be understood as organizing and understanding how different cues (e.g., ground information and conclusions) are integrated within a conceptual system used in DDM.

From a mental models' perspective of understanding situation awareness, Endsley (1995, p. 43) describes a situation model as "a schema depicting the current state of the mental model of the system". A situational model is a dynamic representation of a person's knowledge and understanding of the *present state* of a system (Endsley, 2000; as cited in Brown et al., 2009). It may incorporate the value of different cues (e.g., level of fuel gauge); an integration of the cues to understand the dynamics of the system (e.g., rate of change) developed from changes in cues from the situation model over time; higher level comprehension (e.g., understanding the state of the system in a Gestalt form in relation to human goals); and projections of future states. A situation model may also assign well understood situations to prototypical classifications of the system state (Brown et al.)

As developing mental models is mainly cognitive, methods on how this is accomplished can only be theorized. Of importance to our discussion are the three levels that make up situation models (Endsley et al, 1995). The first level is perception of cues. One needs basic perception of important information in order to form a correct picture of the situation. The second level is comprehension, which refers to one's ability to integrate multiple pieces of information and determine their relevance to one's goals. The final level is projection, which refers to the ability to project future events from current events and dynamics. It is specifically the second level that identifies the importance of cue integration within the development of a mental model. The relevance lies in the connection that mental models are identified as a key component of decision making in DDM situations (Brown et al.)

Another perspective comes from Richardson, Andersen, Maxwell, and Stewart (1994; as cited in Brown et al., 2009) who examine the concept of mental models in the field of system dynamics. Incorporating ideas from the Brunswickean lens model into a feedback theory model, a representation of mental models is developed. Within the Brunswickean lens model, the "perceived state" is a complex process involving true descriptors of the state of the system, cues and measurements derived from the descriptors, and subjective cues. Subjective cues are a combination of objective cues unconsciously assembled by the observer (Richardson et al, 1994; as cited in Brown et al, 2009). They are the result of scanning a field for all possible cues, selecting combinations of cues to attend to, and gauging the cues. These cues are then subjectively interpreted in light of experience, memory, and perceptions. Assessments of the current system state and predictions for future states are made from these subjective cues.

Within the model developed by Richardson et al. (1994; described by Brown et al., 2009), an observer scans the system, selects and interprets cues from it, and subjectively interprets them as a basis for assessing and predicting the state of the system. Assessments and predictions are based on the observer's cognitive model of the system. Comparisons of the desired state and the current state result in the selection of strategies, tactics, and policy levels. Also included in this model were mechanisms for learning as state that learning is the mix of processes that allow people to change their mental models.

Brown et al.'s (2009) review of mental models within DDM understands the integration of cues within a dynamic environment as effortful. This is reflective of the requirement for the decision maker to constantly integrate new cues to update their mental model and decipher ambiguous cues in establishing coherence. It is proposed that establishing a new mental model requires much more effort and is more complex relative to simply adding new information into a model. The effort then required to integrate cues may vary depending on previously established mental models which may come from experience within similar problem solving situations. In addition, Brehmer and Allard (1991) discuss complexity (as is found in DDM) as having a relevant effect on the amount of information that must be integrated. Additional challenges within DDM (e.g., time constraints) would be expected to also have a significant impact on the use of cues in developing mental models.

Although there is a vast literature on mental models, very little literature exists that provides a description of the cognitive processes involved when mental models are formed (Brown et al., 2009). The role of cue integration within the development of mental models, at this point, can only be hypothesized. The ideas reviewed here however, suggest that mental models are built from the perception and integration of cues such as knowledge required to pursue a goal and the data perceived from the environment (Besnard, Greathead, & Baxter, 2004; as cited in Brown et al.) Mental models are formed after an observer scans the environment of interest, selects cues from this environment, and subjectively interprets the cues (Richardson et al., 1994, as cited in Brown et al.). There is evidence that suggests cue integration plays a key role in DDM through mental models. The resources and cognitive effort required for the process of cue integration may depend on the state of established mental models as well as the complexity of the problem. For a more detailed discussion about the role of mental models in dynamic decision making refer to Brown et al.

4.6 Long Term Memory and Cue Integration in DDM

Long-term memory is a large-capacity storage system which can maintain information for a long duration. Recall from the information processing model presented earlier (Figure 1) that information may move from working memory into long-term memory if certain conditions are present, for example if information is paid attention to. Likewise, information may move from long-term to working memory (i.e., information may be remembered).

Note that long-term memory and learning are closely linked. Information has to be stored in long-term memory before it can be used to influence later behaviour, and so anything that provides a challenge to long-term memory performance is also likely to be a challenge for learning and training.

The research reviewed for this project identified challenges related to long-term memory, including:

- Forgetting
- Biased recall
- Resources required to purposefully recall information
- Unintentional recall of information which influences decisions in ways not intended (or even noticed by the decision maker)

Although long-term memory has a large capacity and stores information for a long duration, getting information out of long-term memory and into working memory is often an effortful procedure (i.e., it requires cognitive resources) and often fails (i.e., we forget). Important cues can, therefore, fail to be included in decision making and learning effective decision-making strategies can be difficult (e.g., Bakken, 2008; Bonifay, 2000).

It has been found that the manner in which information is retrieved from long-term memory can be biased by the order in which cues were learned, and how long ago they were learned. For example, Stout, Amundson, and Miller (2005) investigated potential changes in trial order effects as a function of retention interval in a predictive judgment task. Specifically, the authors wanted to know whether a long retention interval before a judgment task would affect the cue-outcome relationships that are used to make a judgment. In this experiment, the investigators used cue-outcome relationships similar to those from Pavlovian experiments (i.e., non-reinforced and reinforced trials) and changed the order in which they were presented (i.e. non-reinforced both preceding and following reinforced trials). Participants performed the judgment task and were tested either immediately or 48 hours after the experiment. Results showed that trial order and retention interval interacted to influence the predictive ratings. Specifically, participants tested right after the experiment gave predictive ratings that reflected most recently experienced trial types thereby showing a recency effect. On the other hand, following 48 hours, predictive ratings were congruent with first-experienced trial types thereby showing a primacy effect. Overall, the results show that people are influenced by the order of events when making future predictions (Stout et al., 2005) It is likely that the demonstrated switch between recency and primacy effects over time would still be present in a DDM environment, and when decision making takes place relative to learning could impact how and what cues are used. This could impact the consistency of decision making in an extended DDM task (e.g., for more than 48 hours such as in many military operations) if different information is used at different times.

Long-term memory has a large impact on other processes through the influence of experience. This is often unnoticed by decision makers (i.e., it is unconscious), and so decision makers are left unaware of factors that influence decision making. This means that consciously influencing the decision-making process can be difficult, and learning and teaching decision making strategies can be challenging.

The literature we reviewed related to long-term memory and cue integration did not involve DDM tasks. However, it is reasonable to suggest that similar effects related to forgetting, biased recall, difficulties in deliberate recall, and unintentional recall would be relevant in DDM. If anything, these challenges are likely to play an even bigger role in DDM than in simple decision making tasks, as DDM is likely to be more cognitively demanding.

Although deliberately retrieving information from long-term memory can be effortful, often information is retrieved without any desire by the decision maker and can interfere with decision making (e.g., intrusive thoughts). This means that information which the decision maker does not want to be a factor in the decision could influence the decision regardless. One type of knowledge that is stored in long-term memory that has been examined is causal knowledge.

4.6.1 Causal Knowledge

It is important to remember that cue integration in DDM takes place in context; not only the context provided by the specific task and circumstance in which the task is taking place, but also a context provided by the background knowledge of the decision maker. This background knowledge, stored in the long-term memory of the decision maker, can influence cue integration. One type of background knowledge which has been examined in the context of decision making is causal knowledge; that is, the role of causes and effects and how they influence one another. Causal knowledge has been shown to influence the type and amount of cues which are sought, how cues are interpreted, how easily relationships between cues and criteria are remembered, and the type of cue integration strategy that is used. Essentially, causal information acts as a "meta-cue" or a cue about cues to help determine what is helpful (Garcia-Retamero et al., 2006). An important question is whether the influence of causal knowledge is automatic or controlled. This will have implications for whether causal knowledge could be accessible to consciousness and modifiable through training.

Causal knowledge has been found to influence the perceived strength between cues and outcomes. According to Garcia-Retamero et al. (2006), people intuitively believe that cues with causal relationships with decisions being made have stronger relationships with potential outcomes (i.e., they are more valid), and so causal cues are more likely to be selected than non-causal cues, although more valid non-causal cues will be selected over causal cues which are much less valid. This indicates both the relationships between cues and decisions as well as overall actual cue validity are used when selecting cues.

Garcia-Retamero et al. (2006) found that causal knowledge can influence whether participants would search for more information, as well as which cue integration strategy they choose. The authors examined how participants deal with compound cues. Participants were given a task that required them to make a decision about what substance patients ingested based on symptomatic information. Classification of participants according to the strategies they used was based on the number of cues used and decision outcomes. Results showed that when participants were given instruction that cues acted through the same causal mechanism, the majority of participants made decisions best modelled by the TTB-Configural heuristic (searching for a particular set of cues). When instructions suggested cues were acting independently their decisions were best modeled by the elemental TTB heuristic (searching for only the most valid cue). Participants given causal mechanism instructions sought out more cues during the experiment as they may have been more uncomfortable making the decision due to their original "mental model" that did not prove useful in an environment with no compound cues. This study demonstrates that confidence in decision making and comfort level with the amount and quality of the information, seems to be a factor in determining whether to search for more information in attempts to use a more analytic strategy, or simply to use fast and frugal heuristics with minimal information. When cues have a more direct, causal relationship to the criterion, the strategies used imply a type of "mental model" (what the authors define as a mental representation of the problem solving strategy structure) that gathers and processes individual pieces of information as well as compound pieces of information (combinations of cues) rather than individual cues. If the same type of finding applies to DDM, then understanding how decision makers represent the situation (e.g., the extent to which they rely on mental models) would be important for predicting how they integrate cues, and whether they would seek individual cues or cue combinations with which to make their decisions.

Causal knowledge can also influence how easily cue-criterion relationships can be learned which seems to interact with the type of task being performed. For example, Cobos, López, and Luque (2007) investigated the effect of causal reasoning on whether or not there is interference when learning that multiple cues are related to the same outcome. The problem in the real world is that causal relationships have to be inferred, and an assessment of when they are and when they are not applicable must be made. The authors use retroactive interference to investigate this process. Retroactive interference occurs when learning something new interferes with something already learned, for example when you get a new phone number and then can't remember the one you used to have. In this context, participants are learning cue-outcome relationships. Once a cue-outcome relationship is learned, learning a new relationship between a different cue and the same outcome interferes with the previous learning. The initial cue-outcome is not "unlearned" as proper contextual effects can reinstate the memory. Rather, the initial cue-outcome is harder to retrieve without these contextual "hints". Cobos, López, and Luque interpreted this finding to mean that the first relationship is deemed to not be valid in the same situations as the second relationship. Note that in the situation described here there is no reason to actually assume that the two relationships cannot coexist (as there would be if the same cue predicted two different outcomes). This finding would be particularly relevant in DDM contexts in which relationships between cues and outcomes change over time. More research needs to be done to understand under what conditions cue-criterion relationship changes are actually detected, and under what conditions old cue-criterion relationships are deemed to be relevant again.

Cobos, López, and Luque (2007) suggested that there are differences in cue interpretation in prediction tasks (e.g., see how many clouds are in the sky and predict whether it will rain) where cues are causes (i.e., clouds), and in diagnostic tasks (e.g., need to determine the cause of a rash) where cues are effects (i.e., the rash). The authors found an initial retroactive interference effect in the diagnostic task in the same-outcome group compared to the different-outcome group (i.e., performance was worse when different cues were related to the same outcomes in the two phases). They also found the interference effect was larger for the diagnostic than predictive condition. Finally, findings suggest there is no significant interference effect in the predictive condition. Thus, the type of task (predictive versus diagnostic) influences how easily causal links between cues and criteria can be learned.

Vandorpe, Houwer, and Beckers (2007) attempted to determine the extent to which the use of causal knowledge is automatic or controlled in the context of causal learning tasks. In causal learning tasks, participants are presented with combinations of cues that are potential causes of an outcome. After learning, participants are asked to assess for each cue separately the probability that it causes the outcome. The cue competition effect refers to the finding that a causal judgment about the likelihood that a target cue will produce a particular outcome is not only determined by the probability that that target cue predicts the outcome, but also by the probability that the outcome was caused by another cue that co-occurred with the target cue during learning. Typical cue-competition effects include the following:

- Forward blocking: presenting cues where A+ trials (cue A presented alone which predicts the outcome) are followed by AX+ trials (cue A and cue X are presented and together they predict the outcome) – causal judgements for cue X will be lower than when only AX+ trials are presented
- Backward blocking: AX+ trials are followed by A+ trials – causal judgments for cue X will be lower than when only AX+ trials are presented
- Reduced overshadowing: B- trials (cue B is presented and it does not predict the outcome) are followed by BY+ trials – the causal judgment for cue Y will be higher than when no B- trials precede the BY+ trials
- Release from overshadowing: same effect as reduced overshadowing but trials occur in opposite order (BY+ trials then B- trials)

Cue-competition effects are thought to result from inferences being made, and manipulations of outcome maximality (when the outcome occurs with the highest intensity possible) and additivity (when two associated cues occurring together mean that the outcome was more intense than when either cue occurred alone) influence the conditions under which inferences will be valid. Thus, these manipulations should have an influence on the blocking effects to the extent that these are controlled processes. However, these manipulations are not related to the overshadowing effects. Findings have demonstrated that maximality and additivity influence blocking effects but not overshadowing effects; however, these have heretofore used very few cues and events. Findings largely support the theory that higher-order reasoning plays a prominent role in human causal learning. However, findings were not as strong as expected, indicating that some of the effects of causal reasoning may occur automatically.

In summary, causal knowledge is used as a context for understanding the relationships between cues and criteria. Causal knowledge increases the perceived validity of cue-criterion relationships, perhaps through the mechanism of mental models which are used to explain relationships between environmental variables. When cue-criterion relationships are consistent with likely causal relationships, they appear to be easier to remember. In addition, whether causal links between cues and criteria are perceived or not may influence the cue integration strategy which is chosen. The use of causal knowledge may be partially controlled, but there is also evidence that the use of causal knowledge is not under complete conscious control; thus causal reasoning may play an important role in cue integration and may not be amenable to changes during training. Components of long-term memory such as experience (i.e., learning) and causal knowledge playing a role in selecting and interpreting cues will likely be more important for military decision makers, as military scenarios typically involve complex environments in which cues may have to be actively sought and may be more ambiguous than in the types of decision making tasks used in the experiments reviewed here.

4.7 Feedback and Cue Integration in DDM

Feedback is a very important type of cue to consider in cue integration. In the information processing model discussed in Section 4.2 (see Figure 2), feedback is represented by inputs to the sensory processing system from the environment. In an examination of the model, it can be seen that the actions of the decision maker (i.e., response execution) influences the environment. Feedback is generally interpreted as information relating to the impact that the decision-maker's actions have on the environment. It is important for understanding the current situation (which has been affected by the previous actions of the decision maker) as well as learning the relationship between the actions of the decision maker and outcomes. It should be noted that in a typical DDM environment, information feeding into the sensory processing system from the environment (called "environmental feedback" in the model) will also change due to factors other than actions of the decision maker. In this section, we will consider the types of feedback that are relevant to DDM.

Feedback is critical for learning the relationship between actions and their consequences. However, in DDM feedback delays as well as ambiguous feedback can complicate this learning process. In addition to the actual lack of unambiguous feedback and feedback delays in DDM, it is also true that decision makers do not seem to make ideal use of the feedback that is available. Bois (2002) has discussed the fact that, with "perfect" feedback, people should be able to perform perfectly (after some amount of learning). However, most often, the availability of "perfect information" is an assumption, and how participants interpret the information (i.e., in a manner consistent with the experimenter's interpretation) is not investigated. In fact, there is evidence that, when the understanding of participants is actually tested, although "perfect" information has been presented, participants do not actually have a perfect understanding.

There is other evidence that understanding and incorporating feedback in a DDM context may not be done optimally. For example, Sterman (1989) found that in DDM situations, subjects showed a general lack of consideration of feedback, including misperceptions of time delays, misperceptions of feedback from decision to the environment and a tendency to think in causal single strand series (i.e., people oversimplify the relationship between actions and outcomes). Further, Gonzales et al. (2003) found that when modelling behaviour, models without feedback were more accurate at representing human performance that those with feedback. Collectively, these studies suggest that feedback may not be readily incorporated as a cue in dynamic decision making.

Another important factor to consider regarding feedback in DDM is whether there are different types of feedback and whether these have different effects on DDM performance. Balzer, Sulsky, Hammer, and Sumner (1992) investigated the role that different kinds of feedback play in improving performance in multiple-cue probability learning (MCPL) tasks. The components of cognitive feedback were proposed to be:

- Task Information (TI): information about the task system (e.g., relations between cues and criteria)
- Cognitive Information (CI): information about the subject's cognitive system (e.g., information about judgment consistency)
- Functional Validity Information (FVI): information about the relationship of the task system to the cognitive system (e.g., correlation between judgments and the actual value of the criterion)

In simple terms, TI represents how they should be performing the judgment task, CI represents how they are doing the judgment task, and FVI represents the "success" of the judgment strategy.

Dividing feedback into types like this is useful as it helps to uncover which types of information actually can be used to improve performance, and also allows an examination of what happens when multiple types of feedback are combined.

Balzer et al.'s (1992) findings supported earlier research, which indicated that TI plays the most important role in improving performance. TI feedback alone was superior to the no-feedback condition. Unless TI feedback was received, performance did not significantly differ from conditions in which no feedback at all was received. The addition of either type of feedback to the TI feedback (i.e., CI and/or FVI feedback plus TI feedback) did not significantly improve performance above TI feedback alone.

Essentially, there are different types of feedback, and information about the task itself (i.e., relationships between variables) appears to have the most beneficial impact on performance. An important consideration when attempting to apply these findings to DDM is that it might be very difficult to determine what TI is and how it may change. As well, it seems a bit odd to not receive any feedback about the success of one's performance (i.e., FVI). In essence TI appears to be modelling (i.e., showing how something should be done) rather than a more traditional understanding of feedback (i.e., giving information about one's own performance).

Other findings indicate that providing feedback about relationships between variables improves performance more than feedback about performance itself. According to Karelaia and Hogarth (2008), people learn best from feedback that instructs them about the characteristics of the tasks they face. Haynie and Shepherd (2007) described an experiment to determine the effects of cognitive feedback (i.e., instruction about the underlying relationships between variables; this corresponds to task information rather than cognitive information as described by Balzer et al., 1992) versus performance feedback (i.e., feedback about overall decision quality only; this corresponds to Balzer et al.'s functional validity information) on performance in a dynamic environment. They found that cognitive feedback was more effective in improving performance than performance feedback.

In much of the training research, feedback on performance is often provided to participants; however, there is some evidence that participants may be able to make effective use of occasional feedback when they seek it out. Klayman (1988) found that gradual learning with feedback that was sought out by the participant on a limited number of trials facilitated the learning of cue-criterion relationships, although there appeared to be no direct comparison with a constant-feedback condition.

Individual differences also appear to affect the degree to which feedback is used to improve performance. Haynie and Shepherd (2007) proposed that metacognitive awareness would affect the ability of a decision maker to make use of feedback. They found that metacognitive awareness moderated the relationship between feedback and performance, with participants with more metacognitive awareness benefitting more from cognitive feedback (i.e., feedback about the variable relationships).

According to Juslin, Olsson et al. (2003), the type of feedback provided can affect how a task is performed. They propose that mental cue abstraction (e.g., information from cues are added, and optimal weights are also remembered and used in making the judgment) as a cue integration strategy is favoured when a continuous criterion is used, whereas a binary criterion tends to be interpreted via exemplar memory (e.g., and example is remembered and the current pattern is compared to it, and a match or no match decision is made). The authors indicate that this might be due to more informative feedback in the continuous judgment paradigm. The authors propose that if feedback is sufficient to infer relations between cues and the criterion used for judgment, then multiple cue abstraction will be favoured. With insufficient feedback, rules cannot be inferred so exemplar memory is the most appropriate guide. From the results of the experiment by Juslin, Olsson et al., it appears that the level of feedback in different important tasks should be examined to determine whether cue abstraction is a viable method of making decisions. Although cue abstraction might be a preferred method of making decisions, there may not be adequate information for it to be used effectively. As well, as there are individual differences in decision-making preference between the two methods, perhaps people should be trained in their natural style, or they may otherwise not perform optimally, especially under stress and time pressure.

Juslin, Olsson et al. (2003) also provided evidence that the type of feedback provided can affect which cue integration strategy is used. The authors compared three different possible models of how people categorize:

1. Cue abstraction model: abstraction of cue-criterion relations which are then used to make judgments
2. Lexicographic heuristic: uses only the most valid cue (that can discriminate between options; basically, the same as the "take the best" heuristic discussed elsewhere)
3. Exemplar-based model: retrieve entire exemplars and use those to make categorization judgments (this seems to basically be pattern recognition)

The authors found that exemplar memory seems to be preferred when feedback is poor, but when feedback is adequate for people to extract cue-criterion relations they tend to do so.

Another reported effect of feedback was reported by Gough (1992). Giving feedback (note that the workload assessed was the workload of the person giving the feedback, not receiving it) increased perceived workload, instead of lowering it as predicted (although this difference was not statistically significant). There was also no clear relationship between feedback and error rate; in fact, in some conditions there was an increase in errors with feedback. Feedback appeared to increase confidence so that people were willing to make faster decisions on less evidence, meaning that error rates increased even as confidence in the decisions increased. In other words, feedback appears to add to confirmation bias. Feedback can increase perceived workload, especially for the people who have to provide it, and feedback can increase biases such as confirmation bias. As workload is often high in military environments, increasing workload will have to be balanced with any benefits provided by getting feedback.

5. Training implications

The previous sections have detailed the large body of established psychological research, in particular, related to difficulties and challenges in cue integration that have been documented in the "traditional" decision making literature. DDM further complicates these difficulties through its uncertain, complex, changing nature. This points to major challenges for military decision makers performing DDM; nonetheless, proposals for improvements via training are discussed below.

What separates a good decision maker from a poor decision maker should be understood. This will be discussed in the context of expert versus novice decision makers. Once characteristics of good versus poor decision makers are understood, it will then be possible to uncover the skills that may be acquired to improve decision making performance. How best to train these skills in a military DDM context must also be considered.

5.1 Expert/Novice Differences

In determining what to train and how to evaluate training in military DDM, it is useful to examine the differences between inexperienced decision makers (i.e., novices) and experienced, successful decision makers (i.e., experts). There appear to be differences between novices and experts with regards to cue selection and judgment accuracy. Specifically, experts tend to be better at cue selection, focusing on critical cues which are more useful for decision making. For example, Salas et al. (2001) argued that experts learn which cues are critical cues for the decision being made. One similarity between experts and novices should also be highlighted. That is, experts and novices appear to select the same number of cues when making decisions (Salas et al., 2001). As discussed previously (Section 4.5.1), one of the challenges typical of DDM environments is that there are a large number of cues which are potentially relevant for decision making. Experts do not appear to use more cues than novices, but they are better than novices at choosing which cues to use. Whether the choice of better cues is a deliberate one or part of automatic processing is not currently known.

Research suggests that expertise also influences judgment accuracy, although in some cases the relationship is negative. For example, in a meta-analysis of decision-making studies, Karelaia and Hogarth (2008) found that expertise was negatively related to judgment accuracy. They noted that different studies reported very different findings; in some studies experts performed very well, and in some studies experts had very poor performance. One possible reason for this finding is that there was a much higher error (noise) rate in studies which included both experts and novices than studies which included only novices. The finding of a negative relationship between expertise and performance was made more complex by the fact that learning usually does occur over multiple trials in the same experiment (i.e., in the short term, experience improved performance). Experts also tend to have more consistent judgments than novices (e.g., Karelaia & Hogarth, 2008).

Expert decision making also tends to be more automatic. For example, Salas et al. (2001) argued that cues can automatically trigger appropriate (or inappropriate) behaviours when enough learning takes place. One problem with such automatic decision making is that experts cannot reliably report how and why they are making decisions. For example, Evans et al. (2003) show that experienced decision makers use both explicit and implicit cognitive processes, and so people have only partial conscious access to their decision making.

There are different types of experience that a decision maker could possess; several of these have been shown to make a difference in decision making performance, particularly related to DDM. In DDM, experience is needed that is related to the task, the cues themselves, as well as information about the level of expertise of the people providing cues (e.g., Brehmer & Hagafors, 1986).

Gonzales et al. (2003) noted that important aspects of learning which experts possess include learning the knowledge base (declarative knowledge), recognition (ability to identify familiar versus unfamiliar stimuli), strategies (adaptive production systems), and evaluation functions (ability to assess alternatives). How the decision maker determines when to intervene is also highly dependent on learning.

Team situation awareness is often relevant in DDM. According to Salas et al. (2001), a critical component of team situation awareness is having knowledge of the informational requirements of team members and knowing when to exchange that needed information. Note that this would likely influence cue integration as this information passed between team members would be vital cues used in the decision making of the team. Salas et al. also stressed the role of experience (including knowledge of effective strategies in the context) which is important for interpreting cues. The authors stressed that it is important both to know what information is critical and what information has to be communicated.

Juslin, Olsson et al. (2003) proposed that learning may take the form of learning appropriate weights for cues or from rule-based to exemplar-based decision making, depending on the task characteristics (e.g., feedback type; repetition of exemplars). Cohen et al. (1999) discussed pattern recognition as one type of expertise; they also argued that the ability to create solutions when faced with new problems (i.e., when pattern recognition would be inadequate) is also another characteristic of expertise.

In summary, expert decision makers tend to select more appropriate cues, have more automatic decision making processes, and have more consistent judgment than novices. Thus, these skills should probably be incorporated into military DDM training. However, there is mixed evidence about judgment accuracy between experts and novices, and experts and novices do not appear to differ in the number of cues used in making decisions. There are many forms that expert knowledge may take including knowledge of effective cue-integration strategies, contextual information, and information about cue-criterion relationships.

An important issue to be considered when developing a military DDM training program is the fact that experts may not have conscious access to their decision-making processes. This lack of conscious awareness of decision-making processes indicates that understanding how experts differ from novices cannot be achieved through means that access conscious processes alone (e.g., interviews), but that actual observations and other means which can reveal unconscious factors and processes will also be required. Unfortunately, most of the research we reviewed included tasks that were not performed in a DDM context; however, it is likely that many of the same findings would apply (e.g., that experts are generally better decision makers, show more automatic decision making) but the impact and relevance of these findings need to explicitly be explored in the military DDM context.

5.2 What to train

There have been many different approaches taken to train cue integration processes in an attempt to improve decision-making performance. Training of several aspects of cue integration has been investigated, including training on:

- Which cues are important
- Thresholds for cues with continuous values
- Cue validity
- Cue contingencies (pattern recognition)
- Mental models (background knowledge)
- Critical thinking
- Cue integration strategies

The importance of training these different aspects of cue integration on performance need to be considered when developing a military DDM training program.

Clearly, learning which cues are most relevant for decisions is likely to improve decision-making performance. For example, Salas et al. (2001) proposed that cue-recognition training is a potential training strategy for enhancing team situation awareness. It is intended to focus team members on the cues that are most relevant for their respective tasks. This may be a very important strategy relevant for military DDM training, as much of military DDM is done in a team context. Kirlik et al. (1996) investigated the utility of providing displays which emphasized perceptual cues, and provided evidence that searching and selecting the information within the environment is often difficult. Methods that assist in identifying relevant cues within the environment can significantly improve decision making performance. This is particularly relevant in conditions with an increased workload. See Section 4.4.1 for a discussion of different cue types. Perceptual search is often a critical component of cue integration in military DDM contexts, both for military personnel in the field (e.g., searching for indications that an enemy is nearby) and for operators (e.g., searching for a new contact on a radar display).

An additional factor on which training could improve performance would be training on thresholds for cues with continuous values (rather than cues with two discrete values) as this has shown to have improved performance. For example, Wiggins and O'Hare (2003) found an improvement in determining when flight paths should be changed based on training in nine cues plus cue thresholds (e.g., sky darkening and degree of darkening). See Section 4.4.4 for a discussion about the perceptual challenges involved in discriminating between cues with continuous values.

Although learning that a cue is related to a criterion is important, it is unknown which aspects of cue-criterion relationships should be trained to produce the largest increases in performance. Learning not only that cues and criteria are related, but the validity of that relationship, appears to improve performance. For example, Bois (2002) found that if you provide participants with a decision rule that focuses their attention on proper cues and how to weigh their importance, subject performance was improved, at least for motivated participants.

Whether relationships between single or multiple cues and outcomes should be trained was a question investigated by Bryant (2005), in a military context (contact classification). Bryant compared training of two different types: pattern-based training (typical patterns of cues are learned) and cue-based training (diagnostic information about each cue is learned). Both types of learning improved decision-making performance, although slightly better performance was obtained with cue-based training.

Training in metacognition about cue integration and other forms of critical thinking are likely to be of benefit in military DDM. Background knowledge can also aid cue integration, including helping with cue selection and interpretation. Thus, training in background knowledge such as causal relationships and mental models (which can contain causal relationships) could improve DDM performance. Cohen et al. (1999) argued that optimal performance in DDM contexts relies upon appropriate mental models about organizational purpose, own and others' intent, degrees of initiative, team member reliability, and action sequences. To make the best use of this information, the ability to think critically about these mental models and apply them to novel situations is also required. The focus of training should therefore be the development of a moderately-sized set of mental model types (e.g., purpose, intent, team member reliability) and critical thinking strategies that should be used to critique and correct those mental models when pattern recognition is inadequate (i.e., novel situations).

There are other researchers in addition to Cohen et al. (1999) who advocate the training of critical thinking strategies related to DDM. Kahneman (2003) shows that the interpretation and integration of cues can be strongly influenced by the context, including whether information is presented in terms of a gain or a loss (i.e., framing effects, see Sections 4.4.3.2 and 4.4.3.3 for further discussion). Schultz (1996) argues that training cannot change the tendency to be influenced by perception of risk, but critical thinking training might mitigate the effects on the actual decisions made.

There are many different cue integration strategies which can be used (see Section 4.5.2 for a review). Researchers have found that the cue integration strategies used by decision makers can be influenced by training. For example Bryant (2007) found that participants could use a resource-intensive cue integration strategy when explicitly instructed about that strategy. However, there is evidence that more resource-intensive strategies are not necessarily more robust (e.g., Dunwoody et al., 2000). In addition, there is significant evidence that expert decision makers do not use more resource-intensive strategies than novices. For example, as already discussed, experts do not appear to use more cues than novices (e.g., Salas et al., 2001). Thus, although it is possible that effective cue integration strategies could be trained, a thorough evaluation of what cue integration strategies are actually most appropriate for a specific context will have to be performed.

There is reason to believe that training should not focus on analytical strategies to the exclusion of intuitive strategies. Dunwoody et al. (2000) argued that intuitive decision making is more robust than analytical decision making, as long as errors can occur. Because of the nature of errors made in analytical versus intuitive decision making, errors may occur more frequently in intuitive decision making, but errors tend to be closer to the optimal answer than when errors occur in analytical decision making. This is an encouraging result, as studies have shown that military decision making tends to be more intuitive in nature (Klein & Crandall, 1996).

In summary, many aspects of cue integration could be taught in order to improve military DDM, including cue-criterion relationships and their validity, background knowledge, and cue integration strategies. Although some of these different training strategies have been compared, most have not and further research should be done to determine which aspects are most important to decision-making performance, particularly in a military DDM context. For example, it may enhance decision making performance to perceptually highlight important cues; however, this may not be feasible in uncertain DDM tasks where there is no overseer who knows what information is relevant to the decisions that need to be made. Decision makers need to be trained in order to reduce their uncertainty about what is important in the military DDM environment, and how information should be interpreted. Thus, understanding what to train related to cue integration in military DDM requires more knowledge about the military DDM contexts themselves as well as general DDM processes and training methods.

5.3 How to train

When it is determined what aspects of cue integration should be trained in military DDM, aspects of the training program itself must be decided. Issues include:

- Presenting information
- Level of difficulty
- Providing feedback
- Evaluating performance

These issues will be discussed in the following sections.

5.3.1 Presenting Information

There is evidence which suggests that information should be actively processed and interacted with during training. Klayman (1988) found that participants who were allowed to experiment in order to determine relevant cues were more successful decision makers than participants that only observed. The participants demonstrated the ability to structure experiments during information acquisition in a way that made learning more effective. This indicates that military DDM training will likely be more effective if trainees can learn in an interactive environment and direct some of their own learning such as hypothesis testing about which cues are important for a decision.

Kirlik et al. (1996) provided evidence that information should be presented in the form of rules, and also that decision makers can be trained in making perceptual identification of important cues. Kirlik et al. investigated the benefits of rule-based training and perceptual enhancement. Participants were asked to make decisions about when the receiver in a football game became open. Groups were provided different types of instruction, and further divided into those who were provided with perceptual enhancement displays, and those who were not. Results showed that participant groups who learned a list of rules before training versus those that did not receive the rules made more accurate decisions. Furthermore, those who received the rules before training and used enhanced perceptual displays performed the best. When the perceptual augmentation (highlighting the information) was removed after training, performance was not diminished; however, how transferable this may be to dissimilar situations is unknown.

Although these findings were not investigated within a DDM context, the findings are likely relevant to military DDM. When training in military DDM, it is reasonable to suggest that training would be more effective if decision makers interact with the environment during training and do not simply passively observe. While it is interesting that the use of enhanced perceptual displays improved decision making even after the perceptual enhancements were removed, the question of whether the important perceptual components of a military DDM environment could be discovered and enhanced during training has not been adequately answered. Likewise, it is not known whether this would be a useful military DDM training strategy. Likely the considerations of the perceptual components of DDM would have to be done on a situational basis, as the perceptual components of different military DDM environments would likely be differentially relevant for decision making.

5.3.2 Level of Difficulty

There appear to be different levels of difficulty that should be considered during the development of a military DDM training program. The first is the difficulty of the task itself (e.g., how many, and which cues are relevant?), and the second is the complexity of the environment in which the task is presented (e.g., how many irrelevant cues are presented?). The difficulty of perceptual tasks is one area which is likely to need further study (see Section 4.4 for a discussion of perceptual challenges in cue integration).

There is evidence that task difficulty should be increased during training. Salas et al. (2001) note that the difficulty of the task is important for learning; in fact, the more difficult discriminations are, the more transfer actually takes place. However, there is evidence that tasks should not begin at an extremely difficult level, but difficulty should be increased during training. Costello (1992) reports the result of an experiment using an actual DDM context which allows interaction and concrete evaluation of performance (managing software development projects). It shows an effect of the anchoring and adjustment heuristic on cue integration, situations under which it may have a greater effect, and some factors which may influence overall performance. Performance appeared to be better when the easier of the two projects was managed first. This result supports a training method in which difficulty is increased.

Kass, Herschler, and Companion (1991) provided evidence that simplifying the environment during training can improve performance, even when tasks are performed in complex environments during testing. Participants were trained to identify tank muzzle flash patterns in both simplified (i.e. only the opposing tank in the horizon and no sound) and complex (i.e. sound was on and other vehicles were present) environments. When later tested in the complex environment, subjects trained in the simplified environment were the top performers. Kass et al. (1991) suggested that the better performance was due to increased stimulus-response matching efficiency, causing increased cue salience in the complex test condition. These results counter state-dependent learning theories which suggest that performance is better when training and testing environments are similar.

One of the challenges of military DDM environments is that they are often complex; therefore understanding how complexity should be controlled during training is highly relevant. Evidence suggests that introducing complexity during training is important so that training can be transferred to complex environments; however, training on a simplified environment also shows promise. Applying this research to military DDM training would require further research to determine which aspects of the military environment are critical for DDM and which are simply extraneous and adding to the difficulty of the task. Without such knowledge, it would be difficult to create a DDM training program that could effectively use a simplified military environment.

5.3.3 Providing Feedback

How to present feedback during military DDM training is a key issue. Feedback is important for learning, as decision makers must understand how their actions affect the environment. However, as previously discussed (see Section 1.4.1.7) there is often either inadequate feedback presented, and decision makers often have difficulty using the feedback that they do get.

Feedback can be provided either continuously (i.e., feedback for every action can be provided) or occasionally. Klayman (1988) provides evidence that occasional feedback can lead to effective learning, but there is no direct comparison with continuous feedback.

Recall from Section 4.7 that the type of feedback presented is also critical for improving performance. Information about relations between cues and criteria seems to be the most important type of feedback for improving performance (Balzer et al., 1992). Information about the participant's cognitive system or actual performance results does not appear to be as helpful.

As well as the content of the feedback, the method in which feedback is presented also appears to influence how well it can be used to improve performance. Providing information verbally about relevant cues does not appear to be the best method for providing feedback. For example, Salas et al. (2001) found that simply verbally coaching people about which cues are relevant does not improve their cue selection; however, highlighting physical cues on a visual display can improve performance.

The proper interpretation of feedback is usually a difficult process in military DDM. This difficulty is at least partially due to the fact that there are delays between the actions of the decision maker and the impacts on the environment, and also due to the fact that effects can be probabilistic (i.e., the same actions don't always have the same effects). Although the research reviewed here provides some evidence that feedback does not have to be continuous to be effective, and that feedback about the relationships between cues and criteria should be provided, much more research needs to be done to investigate the best way to present feedback to facilitate its use for military DDM training.

5.3.4 Evaluating performance

How to evaluate performance during military DDM training is an important question, and may not be as straightforward as one might assume. For example, should performance be evaluated in a certain situation or a wide variety of situations (i.e., robustness)? How can actual performance be evaluated (i.e., what should be used as a benchmark)? An extremely important issue during military DDM training program development is balancing the desired expertise of the trainees with the amount of resources which can be devoted to their training. These issues are discussed below.

There are several researchers who have argued that robustness should be the goal of training. Busemeyer and Pleskak (2008) argued that DDM decision makers should be trained in a way that increases robustness (i.e. in strategies that are suitable across a wide variety of options due to variability in the way the system could evolve) rather than for optimality given the current or predicted situation. It is also possible that robustness across tasks should be considered, as different output requirements may influence cue integration. For example, requiring a categorical (e.g., a yes/no response; is there an enemy behind the next hill?) response versus a probabilistic response (e.g., what is the likelihood that there will be an enemy behind the next hill?) can affect the number of cues used to make a decision and how they are integrated (e.g., Juslin, Olsson et al., 2003; for further discussion of task effects in cue integration, see Section 4.4.2). There are situations in which categorical or probabilistic responses might be the most useful in a military DDM context; thus, which type of decision is required should be taken into account when creating a training program.

Dunwoody et al. (2000) argued that analytical decision making is often used as a benchmark or "ceiling" for performance, and that this is not actually a good approach. It is often assumed that analytical processes can be used as a "ceiling" for performance, and participants' performance can be evaluated with respect to that, presumably optimal, performance. However, Dunwoody et al. argued that, because of the nature of errors made in analytical versus intuitive decision making, errors may occur more frequently in intuitive decision making, but errors tend to be closer to the optimal answer than when errors occur in analytical decision making; thus, intuitive decision making tends to be more robust. Therefore, assuming that analytical decision making should be considered as a "ceiling" for performance is not correct if errors in decision making can occur. This is consistent with the findings of Klein (1998; cited in Kahneman, 2003) who found that under pressure, experienced decision makers do not necessarily need to choose between options as generally only one option comes to mind. Thus, it may be important in military DDM training to emphasize that intuitive decision making is not to be avoided.

In considering the amount of resources to devote to training, Bakken (2008) notes that different levels of training require different amounts of time and other resources, so an assessment of the required level of task competency need to be made before a training program is designed. He discusses "high road" versus "low road" training, and uses the medical profession as an example. A "high road" approach is geared toward producing an expert surgeon which requires about 10 years of schooling and an additional 10 years of performing under supervision before true mastery is obtained. In contrast, a "low road" approach is similar to someone learning first aid – very basic training is supplied, the time and resource commitment is relatively low, but the person is only limited in competence. As the amount of desired skill increases and the amount of possible time to devote to learning increases, the need to spend time initially on analytical-type processing (which will gradually become intuitive with practice) increases. For example, an inability to incorporate feedback has to be overcome, but the extent to which this is required depends on the desired level of skill.

Note that there are many challenges in military DDM which should be considered when evaluating performance. For example, in many of the experiments reviewed here, participants were given as much time as they desired to make relatively simple decisions. In military DDM environments, there are often time factors which are challenging; decisions may have to be made quickly, and there may be vigilance components such that decisions must be implemented at exactly the right time.

5.4 Training Cue Integration in Military DDM

Applying the research related to training cue integration in decision making to a military DDM context is not a simple undertaking. In many cases, factors investigated in the literature are not likely to be available in a military DDM context (e.g., using actual cue validities to train participants). However, there are several important factors that have been highlighted and these should be considered.

Perhaps the most important is the consideration of how many resources are available for training and how proficient the decision maker is expected to be once training is complete. These questions will likely have to be answered separately for different military DDM contexts.

Evaluation of performance is another main issue which will need to be considered. Is knowledge of "ground truth" possible? If not, then providing people with information about facts such as cue validity would not be possible. Furthermore, should people be trained to make robust predictions, or is analytical reasoning preferred?

Understanding what needs to be trained to improve military DDM will also have to be addressed; this again will be affected by the specific task and context being trained. One important issue involves understanding what makes a decision maker effective in a particular task. For example, in a team-based situation, understanding the roles of teammates is likely to positively impact performance, but this would be irrelevant if decision makers act independently. Because much of military DDM occurs in a team context, team knowledge is likely to play an important role, and therefore explicit training about teammates' roles may prove valuable and significantly improve military DDM.

As previously mentioned, it is difficult, and may be impossible, to know ahead of time which cues will be important for making particular decisions within military DDM. This is partially the result of military DDM involving multiple groups of intelligent, autonomous agents. One of the implications of the fact that military DDM usually involves an opposing force or forces is that the enemy generally wishes to remain as unpredictable as possible, becoming adaptive adversaries. For example, insurgents in Afghanistan who plant Improvised Explosive Devices (IEDs) always want to plant them in new ways and therefore avoid IED detection until the weapons can be used effectively. Thus, once the military's ability to forecast becomes somewhat accurate, the enemy is motivated to change their behaviour such that the old cues that were predictive will no longer be useful (or even result in actions which previously would have been effective resulting in poor outcomes). Because of the difficulty of predicting which cues will be useful in decision making, it is likely that military DDM training should incorporate critical thinking (metacognitive) skills, as well as low-level training in cue perception and selection. Training about which cues are likely to be useful will probably benefit the decision maker, but in a military DDM context such skills need to be paired with critical thinking skills to encourage decision makers to take a broader view and not blindly use the cues and cue integration strategies which have previously worked.

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6. Conclusions

There is a great deal of potential benefit to designing a training program for CF military decision makers that explicitly seeks to improve cue integration. Before summarizing some specific training suggestions, cognitive challenges associated with the steps of the information processing model (Wickens & Carswell, 2006) are reviewed below with explicit linkages back to military DDM contexts.

Perception

Dynamic decision makers are extremely vulnerable to the way in which information is presented. This means that important cues that are not accessible/salient will most likely be ignored. Whether training can be effectively applied to overcome this is unknown.

In general, different types of cues affect decision making differently – with evidence for sub-conscious effects being prevalent but not well understood. For our purposes internal cues (i.e. cues from within a decision maker) versus external cues (i.e. those in the environment around a decision maker) were discussed. Notably, affect is an internal cue that plays a major role in how decision makers perceive their world. Preliminary studies indicate that this is a key cue in decision making; however, its application to DDM has not been fully explored.

How cues are selected remains elusive, with unimportant cues affecting decision making, and the information presentation of cues playing a crucial role in cue selection. Further study of the cue selection process is warranted, specifically in military DDM scenarios. Specifically, "gain" versus "loss" framing is an external cue that seems to have unique effects on decision making. Applying the gain/loss framing effect to military DDM applications should have strong implications on all levels of military DDM from tactical up to strategic (e.g., a losing commander may be inclined to accept more risks that one who is winning, Schultz, 1996).

Working memory

There exist an extremely large number of cues in dynamic decision making environments. This includes informational cues from the environment, as well as cues about cues (i.e. cues about how valid other cues are). All this leads to potential overloads of working memory. Thus, it is postulated that decision makers have developed strategies to integrate the cues available. Take-the-best (and variations on this approach) are discussed. Research suggests that these strategies are not optimal, do not weight cues perfectly, and that changing cue values are hard to incorporate. Yet, these strategies appear to be efficient and successful approaches to meet day to day decision making challenges (Klein & Crandall, 1996). The extent to which these strategies are applied in DDM has not been fully researched; however, studies showing far from optimal results in DDM environments suggest that whatever cue integration strategies are being applied are not very successful (Brown et al., 2009).

Further, previous research on the use of mental models in DDM is discussed. Mental models appear to be a way in which decision makers might be able to simplify their environment (Brown et al., 2009). Although there is a vast literature on mental models, very little literature exists that provides a description of the cue integration processes involved in mental models.

Long term memory

The literature we reviewed related to long-term memory and cue integration did not involve DDM tasks. However, it is reasonable to suggest that the effects of forgetting, biased recall, difficulties in deliberate recall, and unintentional recall found would be similar (if not in made worse so) in DDM environments.

Further, cues that change over time are a central part of DDM. This means that cues have to be accessed and changed in long term memory for successful decision making. However, studies show that once a cue-outcome relationship has been learned, learning a new relationship between a different cue and the same outcome interferes with the previous learning. More research needs to be done to understand under what conditions cue-criterion relationship changes are actually detected, and under what conditions previous cue-criterion relationships are deemed to be relevant again.

Finally, causal knowledge is used as a context for understanding the relationships between cues and criteria. The use of causal knowledge may be partially controlled, but there is also evidence that the use of causal knowledge is not under complete conscious control. Therefore causal reasoning may play an important role in cue integration and may not be amenable to changes.

Feedback

Feedback is critical for learning the relationship between actions and their consequences. However, in DDM feedback delays as well as ambiguous feedback can complicate this learning process. In addition to the actual lack of unambiguous feedback and feedback delays in DDM, it has also been found that decision makers do not seem to make ideal use of the feedback that is available.

One type of feedback that has been found to improve performance is cognitive feedback. This means that if decision makers can be provided instruction about the underlying relationships between variables in DDM environments (rather than being forced to determine the relationships themselves) DDM performance should theoretically improve.

6.1 Training

Finally, implications of these factors on military training in a CF context are discussed. Building on the previous knowledge, we used recent empirical research to infer opportunities for training military decision makers in dynamic decision making environments. Many aspects of cue integration could be taught, including cue-criterion relationships and their validity, background knowledge, and cue integration strategies.

Evidence suggests that introducing complexity during training is important so that training can be transferred to complex environments; however, training on a simplified environment also shows promise. Applying this research to DDM training would require further research to determine which aspects of the environment are critical for DDM and which are simply extraneous and adding to the difficulty of the task. Without such knowledge, it would be difficult to create a training program that could effectively use a simplified environment.

There are additional limitations on training in military DDM situations specifically. Notably, the need to know "ground truth" is required in order to train many things (e.g., important cues and when these cues change); however, this ground truth knowledge may be impossible to come by in military DDM. In general, military DDM decision makers should be trained in a way that increases robustness (i.e. in strategies that are suitable across a wide variety of options due to variability in the way the system could evolve) rather than for optimality given the current or predicted situation

(Busemeyer & Pleskak, 2008). This most likely means that training should entail a combination of strategies for cue integration and critical thinking as no one solution is likely to adequate in military DDM. However, by affording decision makers the proper strategies and knowledge about when to apply them performance should improve.

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7. Future Research Recommendations

In general there was not a sizable amount of work relating to cue integration in DDM found. Thus, any future research in this area is encouraged. A number of suggestions are made concerning more specific future research areas to advance the knowledge of how cue integration is performed and can be improved in DDM situations.

7.1 Future research considering internal cues

Looking at the broader picture of cognitive functioning, the role of consciousness in cue integration may be considered. Within the information processing model, consciousness is complicated. At this point, it is unknown whether the selection of cues is a deliberate or automatic process, and this is possibly a topic for future research.

Along a similar perspective, the role of attention within cue integration was not found within the literature but could prove to be a valid area of research. Specifically, the role of attention in selection of cue is especially applicable to DDM.

The role of cue integration as it is associated to mental models was briefly discussed. Cue integration seems to be a significant component of developing and maintaining updated mental models that are used within DDM. Examining this relationship in further detail however, was beyond the scope of this project. It may be that mental models are a moderating mechanism through which cue integration functions. Future research may want to consider investigating the possible relationships between these concepts and their role in DDM.

Finally, the role of military decision maker's motivations and goals on cue integration should be explored. It is presumed that with increased motivation, the decision maker is more vigilant and attentive to cues; however, verification of this (and its assumed positive effect on the resultant cue integration process) is required. Building on this within the CF, the relationship between commander's intent, common intent and cue integration should prove interesting. The role of affect in cue integration would also be relevant to this study.

7.2 Future research considering external cues

Framing effects have a distinctive role in establishing particular risk within a decision. Applying a gain/loss framing effect to military applications would have strong implications on all levels of military decision making from tactical up to strategic. It may be beneficial to further examine the role of framing effects within different military operations.

The literature highlights the dynamic aspects of DDM. Within this, new cues that are gathered must be integrated into the decision process. This can introduce and change the relationships of cues. More research needs to be done to understand under what conditions cue-criterion relationship changes are actually detected, and under what conditions old cue-criterion relationships are deemed to be relevant again.

A second component of cue relationships involves the constantly changing nature of cues. The temporal aspect of cues including the introduction of new cues, changing of cues values, and the changing relationships between cues, creates significant challenges in interpretation and integration. This is especially an issue in military decision making, when enemy units are continually on the move and other external events constantly change the lay of the land upon which missions are being planned. Yet there was no literature found discussing the best ways to provide military decision makers with skills to better deal with the temporal nature of cues. Thus, the temporal nature of cues is an important area for future research.

The nature of different DDM tasks influences decision-making processes. DDM contexts should be examined to determine how potential task types and the implications of these different tasking types influences optimal information presentation and the types of processing that need to be supported. A CF focused task typology could even be created to further develop and detail the nature of different DDM tasks. This would include examining the cue selection process to determine how and why certain cues are used and others are not.

In discussing training, a comparison of the effectiveness in training cue-criterion relationships and their validity, background knowledge, and cue integration strategies in a DDM context would be beneficial. As well, research is required to determine which aspects of the environment are critical for DDM and which are simply extraneous and adding to the difficulty of the task. Without such knowledge, it would be difficult to create a training program that could effectively use a simplified environment and maintain appropriate transfer to a dynamic context.

Also for training, the importance of feedback in learning remains a top priority. Thus, proper methods for the evaluation of feedback should be researched. For DDM, decision makers need to understand the impact that their decisions have on the environment. Though this is acknowledged and documented, enabling decision makers to properly use feedback remains illusive.

References

Adams, B. D., Rehak, L., Brown, A., & Hall, C. D. T. (2009). Human decision-making biases. Report for DRDC Valcartier.

Adelman, L. & Bresnick, T. A. (1995). Examining the effect of information sequence on patriot air defense officers' judgments. Report prepared for the United States Army Research Institute for the Behavioral and Social Sciences, ARI Report No. 95-23.

Adelman, L., Tolcott, M. A., & Bresnick, T. A. (1991). Examining the effect of information order on expert judgment. Report prepared for the United States Army Research Institute for the Behavioral and Social Sciences, ARI Report No. 91-78.

Ayal, S., Hochman, G. (2009). Ignorance or integration: The cognitive processes underlying choice behavior. Journal of Behavioral Decision Making, 22(4), 455-474.

Bakken, B. E. (2008). On improving dynamic decision-making: Implications from multiple-process cognitive theory. Systems Research and Behavioral Science, 25, 493-501.

Balzer, W. K., Sulsky, L. M., Hammer, L. B., & Sumner, K. E. (1992). Task information, cognitive information, or functional validity information: Which components of cognitive feedback affect performance? Organizational Behavior and Human Decision Processes, 53, 35-54.

Bois, J. R. (2002). Decisions within complex systems: An experimental approach using the STRATEGEM-2 computer game. Dissertation submitted to the University at Albany, State University of New York.

Bonifay, B. F. (2000). Is it time to use the right side of our brain? A comparison of analytical and naturalistic decision making processes. Paper submitted to the Faculty of the Naval War College, Newport, R. I.

Brehmer B., (2000) Dynamic decision-making in command and control. In C. McCann and R. Pigeau (Eds.), The human in command: Exploring the modern military experience (pp. 234-248) New York: Kluwer Academic/Plenum Publishers.

Brehmer, B. (1992) Dynamic decision-making: human control of complex systems. Acta Psychologica, 81, 211-241.

Brehmer, B. (1990). Strategies in real-time dynamic decision-making. In R.M. Hogarth (Eds.), Insights in decision-making: A tribute to Hillel J. Einhorn (pp. 262-279) Chicago, IL: The University of Chicago Press.

Brehmer B., & Allard, R. (1991). Dynamic decision-making: the effects of task complexity and feedback delay. In J. Rasmussen, B. Brehmer, & J. Leplat (Eds.), Distributed decision-making: cognitive models for cooperative work (pp. 319-334) John Wiley & Sons Ltd.

Brehmer, B. & Hagafors, R. (1986). Use of experts in complex decision making: A paradigm for the study of staff work. Organizational Behavior and Human Decision Processes, 38, 181-195.

Brown, A., Karthaus, C., Rehak, L., & Adams, B. (2009). The role of mental models in dynamic decision-making. DRDC Report, CR 2009-060.

Bryant, D. J. (2007). Classifying simulated air threats with fast and frugal heuristics (2007). Journal of Behavioral Decision Making, 20, 37-64.

Bryant, D. J. (2005). Training effects on the use of simple heuristics in threat assessment. Report prepared for Defence Research & Development Canada, DRDC-Toronto Report No. TR-2005-229.

Busemeyer, J.R. (1999). Dynamic decision-making. In International Encyclopaedia of the Social and Behavioural Sciences: Methodology. Mathematics and Computer science. Amsterdam: Pergamum.

Busemeyer, J. R. & Pleskak, T. J. (2008). Theoretical tools for understanding and aiding dynamic decision making. Dissertation submitted to Michigan State University.

Canon-Bowers, J. A. & Bell, H.H. (1997). Training Decision Makers for Complex Environments: Implications of the Naturalistic Decision Making perspective. In Naturalistic Decision Making. C.E. Zsambok & G. Klein (Eds.), pp. 99-110. Mahwah NJ: Lawrence Erlbaum Associates. –

Clancy, J.M., Elliot, G.C., Ley, T., Omodei, M.M., Wearing, A.J., McLennan, J., & Thorsteinsson, E.B. (2003). Command style and team performance in dynamic decision-making tasks. In S.L. Schneider and J. Shantean (Eds.), Emerging perspectives on judgment and decision research, pp. 586-619. New York: Oxford University Press.

Cobos, P. L., López, F. J., & Luque, D. (2007). Interference between cues of the same outcome depends on the causal interpretation of the events. The Quarterly Journal of Experimental Psychology, 60, 369-386.

Cohen, M. S., Thompson, B. B., Adelman, L., & Bresnick, T. A. (1999). Training battlefield critical thinking and initiative. Interim report submitted to the U. A. Army Research Institute for the Behavioral and Social Sciences.

Costello, T. P. (1992). Anchoring-and-adjustment in software project management: An experimental investigation. Thesis submitted to the Naval Postgraduate School, Monterey, CA.

Dunwoody, P. T., Haarbauer, E., Mahan, R. P., Marino, C., & Tang, C.-C. (2000). Cognitive adaptation and its consequences: A test of cognitive continuum theory. Journal of Behavioral Decision Making, 13, 35-54.

Elser, E. T. (1993). Multiple goals in dynamic decision making: An experimental approach. Thesis submitted to the Naval Postgraduate School, Monterey, CA.

Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. Human Factors, 37, 32-64.

Evans, J.B.T., Clibbens, J., Cattani, A., Harris, A., Dennis, I. (2003). Explicit and implicit processes in multicue judgment. Memory & Cognition, 31(4), 608-618.

Famewo, J., Matthews, M., & Lamoureux, T. (2007). Models of Information Aggregation Pertaining to Combat Identification: A Review of the Literature. Report prepared for Defence Research and Development Canada, DRDC-Toronto Report No. CR-2007-062.

Fu., W.T., & Gonzalez, C. (2006). Learning in dynamic decision-making: information utilization and future planning. Pittsburgh, PA: Carnegie Mellon University, Department of Social and Decision Sciences.

Garcia-Retamero, R., Hoffrage, U., & Dieckmann, A. (2006). When one cue is not enough: Combining fast and frugal heuristics with compound cue processing. The Quarterly Journal of Experimental Psychology, 60, 1197-1215.

Garcia-Retamero, R., Wallin, A., & Dieckmann, A. (2007). Does causal knowledge help us be faster and more frugal in our decisions? Memory & Cognition, 35, 1399-1409.

Gibb, R. W. (2000). A Theoretical model to attack the enemy's decision-making process. Paper submitted to the Naval War College, Newport, R. I.

Goldstein, D. G. & Gigerenzer, G. (2009). Fast and frugal forecasting. International Journal of Forecasting, 25, 760-772.

Gonzales, C., Lerch, J. F., & Lebiere, C. (2003). Instance-based learning in dynamic decision making. Cognitive Science: A Multidisciplinary Journal, 27, 591-635.

Gough, M. J. (1992). The effects of team leader feedback on situation assessment in distributed anti-air warfare teams. Dissertation submitted to the Naval Postgraduate School, Monterey, CA.

Haynie, J. M. & Shepherd, D. A. (2007). Exploring the entrepreneurial mindset: Feedback and adaptive decision-making. Manuscript prepared at Syracuse University.

Hubal, R., Staszewski, J., & Marrin, S. (2007). Overcoming decision making bias: Training implications for intelligence and leadership. The Interservice/Industry Training, Simulation & Education Conference (I/ITSEC), 2007.

Jacobs, P. A. & Gaver, D. P. (1998). Human Factors Influencing Decision Making. Naval Postgraduate School, Monterey, California. NPS-OR-98-003

Janser, M. (2007). Cognitive biases in military decision making. U. S. Army War College, Carlisle Barracks, PA.

Jones, L. (2005). Patterns of Error: Perceptual and Cognitive Bias in Intelligence Analysis and Decision-Making. Master's thesis presented at the Naval Postgraduate School, Monterey, California.

Juslin, P., Jones, S., Olsson, H., & Winman, A. (2003). Cue abstraction and exemplar memory in categorization. Journal of Experimental Psychology: Learning, Memory, & Cognition, 29, 924-941.

Juslin, P., Olsson, H., & Olsson, A.-C. (2003). Exemplar effects in categorization and multiple-cue judgment. Journal of Experimental Psychology: General, 132, 133-156.

Kahneman, D. (2003). A perspective on judgment and choice: Mapping bounded rationality. American Psychologist, 58(9), 697-720.

Karelaia, N. & Hogarth, R. M. (2008). Determinants of linear judgment: A meta-analysis of lens model studies. Psychological Bulletin, 134, 404-426.

Kass, S.J., Herschler, D.A., Companion, M.A. (1991). Training situational awareness through pattern recognition in a battlefield environment. Military Psychology, 3(2), 105-112.

Kerstholt, J. H., & Willems, P. (1993). The effect of the time restrictions on information search and information integration in a dynamic task environment. TNO Defence Research, Report No. IZF 1993 B-8

Kirlik, A., Walker, N., Fisk, A. D., & Nagel, K. (1996). Supporting perception in the service of dynamic decision making. Human Factors, 38, 288-299.

Klayman, J. (1988). Cue discovery in probabilistic environments: Uncertainty and experimentation. Journal of Experimental Psychology: Learning, Memory, and Cognition, 14(2), 317-330.

Klein, G. & Crandall, B. (1996). Recognition-Primed Decision Strategies. Report prepared for the United States Army Research Institute for the Behavioral and Social Sciences, ARI Report No. 96-36.

Martignon, L. & Hoffrage, U. (2002). Fast, frugal, and fit: Simple heuristics for paired comparison. Theory and Decision, 52, 29-71.

Newell, B. R., Rakow, T., Weston, N. J., & Shanks, D. R. (2004). Search strategies in decision making: The success of "success". Journal of Behavioral Decision Making, 17, 117-137.

Newell, B. R. & Shanks, D. R. (2004). On the role of recognition in decision making. Journal of Experimental Psychology: Learning, Memory, and Cognition, 30, 923-935.

Pachur, T. & Hertwig, R. (2006). On the psychology of the recognition heuristic: Retrieval primacy as a key determinant of its use. Journal of Experimental Psychology: Learning, Memory, and Cognition, 32, 983-1002.

Payne, J. W., Bettman, J. R., & Johnson, E. J. (1992). Behavioural Decision Research: A constructive processing perspective. Annual Review of Psychology, 43, 87-131.

Rothrock, L. & Kirlik, A. (2003). Inferring rule-based strategies in dynamic judgment tasks: Towards a noncompensatory formulation of the lens model. Report prepared for the Naval Training Systems Center, Orlando, FL. Report No. AHFD-03-5/NTSC-03-1.

Salas, E., Cannon-Bowers, J. A., Fiore, S. M., & Stout, R. J. (2001). Cue-recognition training to enhance team situational awareness. In New Trends in Cooperative Activities: Understanding System Dynamics in Complex Environments (M. McNeese, E. Salas, & M. Endsley, Eds), pp. 169-190. Santa Monica, CA: Human Factors and Ergonomics Society.

Schroeder, N. J. (2005). Using Prospect Theory to Investigate Decision making Bias Within an Information Security Context. Master's Thesis, Air Force Institute of Technology.

Schultz, J. V. (1996). A framework for military decision making under risks. Thesis presented at the School of Advanced Airpower Studies, Air University, Maxwell Air Force Base, Alabama.

Schwartz, J.P., Norman, K.L. (1989). Separating cue relevance from cue importance within models of judgment and decision making. Organizational Behavior and Human Decision Processes, 43(3), 355-384.

Shah, A. K. & Oppenheimer, D. M. (2007). Easy does it: The role of fluency in cue weighting. Judgment and Decision Making, 2, 371-379.

Slovic, P., Peters, E., Finucane, M. L., & MacGregor, D. G. (2005). Affect, risk, and decision making. Health Psychology, 24, S35-S40.

Sterman, J. D. (1989). Misperceptions of Feedback in Dynamic Decision Making. Organizational Behavior and Human Decision Processes, 43, 301-335.

Stout, S.C., Amundson, J.C., Miller, R.R. (2005). Trial order and retention interval in human predictive judgment. Memory & Cognition, 33(8), 1368-1376.

Tolcott, M. A., Marvin, F. F., & Bresnick, T. A. (1996). Situation Assessment and Hypothesis Testing in an Evolving Situation. Report prepared for the United States Army Research Institute for the Behavioural and Social Sciences, ARI Report No. 96-34.

Tversky, A. & Kahneman, D. (1981). The Framing of Decisions and the Psychology of Choice. Science, 211, 453-458.

Vandorpe, S., De Houwer, J., & Beckers, T. (2007). Outcome maximality and additivity training also influence cue competition in causal learning when learning involves many cues and events. The Quarterly Journal of Experimental Psychology, 60, 356-368.

Wickens, C. D. & Carswell, C. M. (2006). Information processing. In Handbook of Human Factors and Ergonomics, Third Edition (G. Salvendy, Ed). pp. 111-149. Hoboken, NJ: John Wiley & Sons, Inc.

Wiggins, M., O'Hare, D. (2003). Weatherwise: Evaluation of a cue-based training approach for the recognition of deteriorating weather conditions during flight. Human Factors, 45(2), 337-345.

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Annex A

The article reviewed in the first phase of this project are presented below in alphabetical order:

1. Title: Examining the effect of information sequence on patriot air defense officers' judgments
Author(s): Adelman, L. & Bresnick, T. A.
Source: Report prepared for the United States Army Research Institute for the Behavioral and Social Sciences, ARI Report No. 95-23.
Year: 1995
Abstract: This paper describes a recent experiment conducted with Patriot air defense officers and using the Patriot air defense simulators at Fort Bliss, Texas. The experimenters found that, under certain conditions, the participants made different identification judgments and took different engagement actions depending on the sequence in which the same information was presented to them. This finding was consistent with theoretical predictions regarding how operators process information and the hypothesis that their processing approach (or Heuristic) would result in biased judgments under certain conditions. Future research is directed toward investigating whether display modification can remove the observed judgmental bias. Generally, this experiment demonstrates the applied implications of basic research investigating human information processing, and the importance of understanding cognitive processes when developing computer systems.
Notes: Relevance: discusses heuristics (anchoring-and-adjustment heuristic), biases, and cue integration The goal of the authors is to show that judgments of probability and chosen actions can change depending on the order in which information is presented. This article examines heuristics and bias in decision making, particularly those which may be related to the use of computer systems by military personnel. The particular heuristic investigated was a version of the "anchoring-and-adjustment" heuristic related to decisions about "friend vs. foe" identification judgments. The authors seem to have an illogical interpretation of the effects of new information on an anchor. They state that "Since each new piece of information leads to a new anchor, recent information is weighted more than prior information" (p. 2), which is not correct according to the traditional anchoring-and-adjustment heuristic – the anchor is the first piece of information, and new information is the "adjustment" portion of the heuristic, and acts to adjust the position. The idea is that the initial anchor has a large impact on the position, which is the opposite interpretation that provided by Adelman & Bresnick, who argue that new information will have a larger impact on the position. Because Adelman & Bresnick refer to a model by Hogarth and Einhorn which is not reviewed here, it is not known whether Adelman & Bresnick misunderstand the model, or whether Hogarth and Einhorn have a different interpretation than the traditional one (i.e., by Kahneman & Tversky). The authors seem to also be ignoring the confirmation bias – they state that the more certain someone is of a conclusion, the larger effect disconfirming evidence will have on the judgment. This is not what is typically found, and the authors do not provide an adequate rationale for this prediction.

Another problem with this analysis is that they use difference scores (from one probability judgment to another). This means that floor/ceiling effects could be at play and there would be no way to know this, since the absolute proportion judgments are not provided. Another issue is that there are multiple analyses performed without apparent control for experiment-wise error, and only a few significant results, leading the reader to guess that some/all of the significant findings might be a result of experiment-wise error. Strengthening this belief is the fact that no significant results were found in an ambiguous condition which would likely have resulted in the most room for changes in probability judgments, and therefore would be suspected to lead to the larger order effects. There are serious flaws in this research; however, there may be some points worth considering. One of the challenges in supporting DDM would be deciding how to present information. One choice that would have to be made is whether information should be presented serially or be available all at once. The article supports the idea that performance may be marginally better when information is presented all at once; there were some effects of information order which led participants to incorrectly classify a friendly aircraft as unfriendly or choose to shoot down a friendly aircraft. However, this leaves the issue of whether working memory can cope with all of the information that would be required to be processed in other DDM scenarios.
CAN BE USED TO SUPPORT INVESTIGATING HEURISTICS, BIASES, AND/OR CUE INTEGRATION
To be used? INCLUDE IF RELEVANT – note that the ideas here are very similar to the other Adelman paper – this one is more recent

2. Title: Examining the effect of information order on expert judgment
Author(s): Adelman, L., Tolcott, M. A., & Bresnick, T. A.
Source: Report prepared for the United States Army Research Institute for the Behavioral and Social Sciences, ARI Report No. 91-78.
Year: 1991
Abstract: ABSTRACT DIFFERENT ON WEBPAGE AND IN REPORT – REPORT ABSTRACT FOLLOWS: For this report, researchers performed an experiment in which trained Army air defense personnel created a paper-and-pencil representation of their task to test the predictions of the Einhorn-Hogarth model for belief updating. For a simple task with a short series of information, the model predicted a significant information order by response mode interaction. The experiment supported the model's predictions. When information was presented sequentially and a probability estimate was obtained after each piece of information, the order in which the same information was presented significantly affected the final mean probability estimates. In contrast, when all the information was presented at once and a probability estimate was obtained at that time, information order had no effect. There were, however, significant individual differences. Moreover, order and response mode cumulatively accounted for less than 10 percent of the total variation in the participants' probability estimates. These findings, and their implications, are discussed in the report.

Notes:

The authors examine the effect of sequential information presentation versus concurrent information presentation. They predict effects based on a model adapted from the anchoring-and-adjustment heuristic, which fundamentally differs from the "traditional" anchoring-and-adjustment heuristic. The authors are examining the effect of different information orders when the beginning "anchor" is the same, rather than examining the effect of the same information with a different beginning value. Thus, it is difficult to argue that the significant evidence backing the traditional anchoring-and-adjustment heuristic is relevant to the logic here.

There are other problems with this study, including the possibility of sequential effects between trials (all participants complete all trials and do so in the same order within the two conditions [sequential vs. concurrent information presentation]), and possible floor/ceiling effects contributing to differences in probability adjustment with added information. They also perform a large number of analyses without apparently accounting for experiment-wise error.

Although there are fundamental flaws in this study, it does suggest that there are differences in the conclusion arrived at when information is presented in different orders versus concurrently. Due to the large amount of information that generally has to be integrated in a DDM scenario, understanding how information order affects information aggregation should be considered. This would be relevant both for training and designing support systems to facilitate information aggregation and decision making.

CAN BE USED TO SUPPORT INVESTIGATING HEURISTICS, BIASES, AND/OR CUE INTEGRATION

To be used? FOR CONSIDERATION – Note that these ideas are very similar to the other Adelman paper and that one is more recent

3. Title: On improving dynamic decision-making: Implications from multiple-process cognitive theory

Author(s): Bakken, B. E.

Source: Systems Research and Behavioral Science, 25, 493-501

Year: 2008

Abstract:

Decision environments that afford unambiguous and transparent feedback allow humans to build up corresponding mental models that give them good decision guidance. But in many complex decision situations, such feedback is not available. In such environments people not only show initial misperceptions, but also fail to learn. Education and training have therefore been proposed, but with limited success. This paper applies multiple-process cognitive theory to explain findings of poor learning and sub-optimal decision-making. The applied theory suggests that intuitive processes are default in decision-making and natural learning. Analytic processes are more seldom applied. Implications for education and training in dynamic decision-making are suggested, and in light of the primacy of intuitive processes, include massive exposure to complex dynamic decision-making in order to improve upon intuition in such environments.

Notes:

The author points out that to learn how to perform well in DDM environments people typically require a great deal of experience and unambiguous feedback; however, unambiguous feedback is seldom available. The author argues that this is why learning is typically difficult and performance poor in DDM. Also noted is the importance of appropriate mental models for interpreting feedback.

The difficulty of separating inputs and outputs in DDM is mentioned. People's difficulty in incorporating higher-order effects in mental models is a problem in DDM performance.

Author argues for a dual-processing framework, where intuitive processing is primary and analytical processing is secondary, but often concurrent.

As people gain experience, there is a shift away from analytical and toward intuitive decision making processes. This means that decisions are faster but also more prone to emotional content and other biases.

The author notes that most DDM experiments are done with novices, and so might not capture the behaviour of experts in a DDM domain. A key defining feature of decision-making expertise is knowing when NOT to trust your intuition and apply more rigorous analytical processes.

The author discusses several approaches to training in a DDM environment, depending on the level of expertise desired or required and the amount of time available. He discusses "high road" versus "low road" training, and uses the medical profession as an example. A "high road" approach is geared toward producing an expert surgeon, requires about 10 years of schooling and an additional 10 years of performing under supervision before true mastery is obtained. In contrast, a "low road" approach is similar to someone learning first aid – very basic training is supplied, but the person is only limited in competence. As the amount of desired skill increases and the amount of possible time to devote to learning increases, the need to spend time initially on analytical-type processing (which will gradually become intuitive with practice) increases.

The author notes that much more research is needed to determine how to properly design a "low road" training approach.

This is an interesting article which points out that perhaps a great deal of expertise is not always needed, and training programs should take into account the level of expertise needed which needs to be balanced with the amount of time which can be devoted to training. Important limitations in training DDM are pointed out. However, actual applicable solutions are not really offered; rather the author just points to more research being needed (although a reference for a "high road" method is offered).

CAN BE USED TO SUPPORT INVESTIGATING: HEURISTICS (?) AND BIASES

To be used? INCLUDE IF RELEVANT

4. Title: Decisions within complex systems: An experimental approach using the STRATEGEM-2 computer game

Author(s): Bois, J. R.

Source: Dissertation submitted to the University at Albany, State University of New York.

Year: 2002

Abstract:

In 1989, John Sterman published his seminal paper, Misperceptions of Feedback in Dynamic Decision Making. His misperception of feedback hypothesis deals with the difficulty people have in managing complex environments even when they purportedly have perfect knowledge and have perfect information about the system. Over the years, several authors have attempted to consider how the human failures, which are a prominent part of the misperception of feedback hypothesis, can be reduced. However, these authors have achieved mixed results in attempting to make improvements to human decision support. It is the purpose of the current research to provide meaningful decision support to managers of complex environments. Specifically, the research used the STRATEGEM-2 simulation game and purposely developed a decision support method designed to improve human performance within a complex system. The experiment required subjects to make a single decision within a dynamic system where the task involved feedback delays, nonlinearity of system processes, positive feedback loops, and multiple cues. The decision support included a decision rule and a newly developed game instruction designed to improve participant knowledge and information about the microeconomy of the STRATEGEM-2 simulation. Results of the research have discovered that the new instruction and the decision support rule produced significant results in improving decision making. Additionally, this research demonstrates that the lack of participant motivation levels can mask decision support interventions. Subjects with high self-assessed motivation outperformed those subjects with lesser motivation levels.

Notes:

The goal of this paper is to investigate errors in DDM; specifically, why errors happen even though decision makers have "perfect" information – this is related to the misperception of feedback issue. The overall goal is to determine why the errors happen so that they can be supported. A decision support rule was used, and the investigation involved determining the benefit derived from the use of this decision aid. Motivation was also used as a factor.

There is a discussion about the "perfect information" assumption – often participants were often not tested as to their actual information level, so whether or not participants actually understood the cues they were given was not actually known. Testing has revealed that often participants don't have perfect information, and their performance can be improved by improving their understanding.

Hypotheses included:

1. If information and knowledge about a system are better understood, participant performance will improve
2. If participants are provided with a decision rule that focuses their attention on proper cues and how to weigh their importance, their performance will improve
3. Participants reporting greater effort during the experiment simulation will outperform those that do not (p. 5)

In general, the hypotheses were supported.

The STRATEGEM game is a micro-economy simulation. The player acts as a manager for a capital-producing sector of an economy. Decisions are required related to how to manipulate goods and capital (processing capabilities). Complexity is added such that changes take time to be implemented and to affect their related variables.

Task complexity is also discussed. Nine variables are proposed to affect task complexity: the number of variables, interactions between subsystems, random variation, miscellaneous task characteristics (a catch-all for things not included on the list), time delay and lagged effects, effectiveness of decisions on outcomes (i.e., ability to interpret lagged effects), frequency of oscillation (stability of the system), positive feedback and gains, and real-time simulation.

Decision support was given in 2 forms. The first was the Richardson and Rohrbaugh decision rule (a strategy for making decisions in the game). A second was an on-screen tutorial which helped participants understand how the game is played and what information is being conveyed. It is an interesting question for DDM training to investigate whether training should be aimed at whether people can be taught or shown how to make better decisions. It appears to be only peripherally related to our four categories.
CAN BE USED TO SUPPORT INVESTIGATING: CUE INTEGRATION AND/OR PATTERN RECOGNITION
To be used? FOR CONSIDERATION

5. Title: Is it time to use the right side of our brain? A comparison of analytical and naturalistic decision making processes
Author(s): Bonifay, B. F.
Source: Paper submitted to the Faculty of the Naval War College, Newport, R. I.
Year: 2000
Abstract: As commanders, how do we make decisions? In scientific theory, there are two methods or models for the decision-making processes - the Analytical Decision-Making (ADM) model and the Naturalistic, or Recognitional, Decision-Making (NDM) model. The time one has to make a decision within a certain situation will influence the decision making process. With the factor of time most prevalent in this situation, a greater emphasis should be placed on intuitive decision-making processes. In developing intuition, commanders can gain a supportive experience base by immersing themselves in numerous decision-making situations. Over time, simulations expand a commander's pattern recognition ability thus improving his intuitive decision making skills. In a final analysis, the operational commander makes decisions dependent on the situation he is facing. I contend that commanders of today and future commanders need to understand and incorporate the intuitive Naturalistic Decision-Making process. The intuitive decision-making inherent in the Naturalistic Decision-Making process provides a sound basis for determining a proper course of action for a given situation. This paper is not designed to espouse that analytical decision-making processes be forgotten, but illustrates that every decision is determined by a situation.
Notes: Junior officers are taught to make decisions analytically to choose the best COA. The author notes that, due to the speed that decision making must be made and there is need for creativity and intuition; however, these have not only not been taught, but have been squelched in favour of analytical processing. The author intends to offer recommendations for using intuition as a decision-making tool. The author points out the two main decision-making processes, analytical and intuitive (or naturalistic), and points out pros and cons of each. Analytical decision making is favoured when an optimal solution is desired, and it tends to be low in bias; however, this method of decision making is cognitively demanding and requires a lot of time. It is also difficult to use in a DDM situation where the situation is constantly changing, as information must be gathered and analysed, and the usefulness of that information is fleeting if it is only valid for a little time. Discusses naturalistic

decision making as pattern recognition. Intuitive decision making is best when satisficing is adequate and time is limited. The author points out that both types of decision making can be used together; however, naturalistic decision making offers speed, which is its major advantage over analytical processing. How do we train and develop intuition? A problem is that intuition is not typically trusted within the military culture. The author suggests using an approach from business (pointing out that the military has used approaches from business before). Harvard business school uses an approach to teach decision making which uses a broad base of cases to develop an understanding of the best types of decisions. The importance of experience is emphasized. The author notes the irony in using intuitive decision making. It is most necessary when speed is an issue; this means that lower-ranking officers are more likely to need it. However, experience is the biggest way that intuition is learned; therefore, people who are most skilled (have the most experience) are generally farthest away from the points where immediate action is required. This article points out the key link between experience and intuitive decision making, as well as the times when intuitive decision making is most needed in the military context. It also clearly points out why the military context can be considered a DDM environment. It is difficult to train DDM without a great deal of experience; experience supplies the decision maker with a knowledge base of patterns and the ability to recognize those patterns. The article is better at pointing out the need for training intuitive decision making rather than providing concrete methods for doing so besides presenting people with a large number of case studies and making sure that readers attempt to understand the decisions that were made, how they were made, and the relative merits of those decisions.
CAN BE USED TO SUPPORT INVESTIGATING: PATTERN RECOGNITION
To be used? INCLUDE IF RELEVANT

6. Title: Use of experts in complex decision making: A paradigm for the study of staff work
Author(s): Brehmer, B. & Hagafors, R.
Source: Organizational Behavior and Human Decision Processes, 38, 181-195.
Year: 1986
Abstract: Presents a general experimental paradigm for the study of staff decision making based on the basic principles of social judgment theory. The paradigm was used to study a fundamental problem of staff decision making, that of judging what weight the inputs from different staff members should have in the final decision. 3 groups of 10 high school students performed a fictitious medical task that required them to learn to make judgments about the severity of a disease on the basis of 6 cues. Ss had access to 3 experts that integrated information from 2 cues. Results show that Ss were able to learn in all 3 conditions, but learning was better in the equal validity/equal ability condition than in conditions in which validity and ability differed. Differences in using the information obtained from the experts and cues across conditions indicate the difficulty in assigning weights in a judgment task.
Notes:

The authors note that complexity is often a problem in decision making; one way of dealing with this is to divide the problem into subproblems, and assign these subproblems to different experts. A central decision maker then has to integrate the information from the experts and arrive at a decision. One problem is that the decision maker has to decide how much weight to give to information about different subproblems (from different experts). Two relevant aspects to weighting are the judgment of the expert (e.g., how much the information can be trusted), and how important the subproblem is to the overall problem. The purpose of this paper is to suggest a paradigm in which staff decision-making can be investigated. A preliminary experiment was performed which investigated whether a decision maker is able to learn to give different weights to experts whose accuracy differs. Note that the participants were high-school students making decisions about a fictitious medical task. The task used nonsense names for cues and a nonsense disease. The results indicate that participants are sensitive to the validity of cues and expert validity; evidence was mixed about which set of criteria were weighted more heavily and what factors influenced this weighting. This task is relevant to DDM because information complexity is one of the major issues with DDM; as well, the approach taken here, of dividing a main problem into subproblems, is one of the strategies used in military DDM. Unfortunately, conclusions cannot be derived from this work as the experimental results are preliminary and not straightforward; as well, participants were not experts.
CAN BE USED TO SUPPORT INVESTIGATING: HEURISTICS, BIASES, CUE INTEGRATION
To be used? INCLUDE IF RELEVANT

7. Title: Risk Perception and Strategic Decision Making: General Insights, a New Framework, and Specific Application to Electricity Generation Using Nuclear Energy.
Author(s): Brewer, J. D.
Source: Report prepared for Sandia National Laboratories, Albuquerque, NM, Sandia Report Number SAND2005-5730.
Year: 2005
Abstract: The objective of this report is to promote increased understanding of decision making processes and hopefully to enable improved decision making regarding high-consequence, highly sophisticated technological systems. This report brings together insights regarding risk perception and decision making across domains ranging from nuclear power technology safety, cognitive psychology, economics, science education, public policy, and neural science (to name a few). It forms them into a unique, coherent, concise framework, and list of strategies to aid in decision making. It is suggested that all decision makers, whether ordinary citizens, academics, or political leaders, ought to cultivate their abilities to separate the wheat from the chaff in these types of decision making instances. The wheat includes proper data sources and helpful human decision making heuristics; these should be sought. The chaff includes "unhelpful biases" that hinder proper interpretation of available data and lead people unwittingly toward inappropriate decision making

"strategies"; obviously, these should be avoided. It is further proposed that successfully accomplishing the wheat vs. chaff separation is very difficult, yet tenable. This report hopes to expose and facilitate navigation away from decision-making traps which often ensnare the unwary. Furthermore, it is emphasized that one's personal decision making biases can be examined, and tools can be provided allowing better means to generate, evaluate, and select among decision options. Many examples in this report are tailored to the energy domain (esp. nuclear power for electricity generation). The decision making framework and approach presented here are applicable to any high-consequence, highly sophisticated technological system.
Notes: The author intends to provide an overview of decision-making processes and improve decision making in DDM-type contexts (i.e., complex decisions involving complex technologies in complex domains). The author tries to create a coherent and concise framework by combining information about risk perception and decision making across many domains. There is discussion of relevant factors for understanding decision types, including level of care, consequence of failure, and tolerance of failure. The author talks about "appropriate" and "inappropriate" strategies; however, the context is generally what makes a heuristic appropriate or not, and the author incorrectly implies that it is the heuristics themselves that should be used or avoided. The author also notes that his method applies when "time is available for thoughtful reflection"; therefore it may not be appropriate for many DDM domains with high stress and time pressure. There is discussion of uncertainty of information. The article contains a large list of normative biases (e.g., insensitivity to sample size), heuristics (e.g., anchoring), and individual-specific biases (e.g., loss aversion). Note that the author's understanding of heuristics may be incomplete – he seems to be confusing the availability and representativeness heuristics. The author also tends to represent heuristics as always negative. There are discussions which may prove useful, including a discussion of "critical thinking skills" which may help avoid bias, and a discussion of bias related to "spiral of stereotypes", which results in distrust between groups with different sets of knowledge/experience, resulting in accepted beliefs in each group being perceived as more credible and members of a group that support the other group being considered irrational. The author performs a useful review of heuristics, biases, and other issues that can make decision making "irrational"; however, discussions of how to deal with these challenges are of limited use for our DDM context as the mitigation strategies require significant amounts of time to implement, plus significant amounts of time to train. As well, they are not "natural", meaning that under time pressure and stress they are likely to be poorly implemented.
CAN BE USED TO SUPPORT INVESTIGATING HEURISTICS, BIASES
To be used? FOR CONSIDERATION

8. Title: The use of recognition information and additional cues in inferences from memory
Author(s): Bröder, A. & Eichler, A.
Source: Acta Psychologica 121, 275-284
Year: 2006

Abstract:

Goldstein and Gigerenzer's (2002) [Goldstein, D. G. & Gigerenzer, G. (2002). Models of ecological rationality: The recognition heuristic. Psychological Review, 109, 75–90] "Recognition Heuristic" (RH) was tested for its empirical validity in an experimental paradigm with induced recognition of objects. RH claims that upon inferring which of two objects (e.g., cities) scores higher on a criterion (e.g., city size), a recognized object will be chosen over an unrecognized one, if the recognition is a valid predictor of the criterion without considering additional object information. Trying to avoid potential shortcomings of former studies, we (a) used the city population task, (b) provided additional cue information only for recognized cities, and (c) had participants draw inferences from memory. Participants learned city names and additional information about some cities. They also learned that recognition and the additional information were valid predictors of the criterion "city size". In a subsequent decision phase, the additional information about the cities in memory strongly affected the inferences, suggesting that recognition information is clearly integrated into judgments, but by no means in a noncompensatory fashion that would dominate every other cue.

Notes:

Broder and Eichler test the empirical validity of the "recognition heuristics" (RH) proposed by Goldstein and Gigerenzer (2002). Empirical support for this theory is lacking so they did a study. They look at the claims that RH is used in a noncompensatory nature, meaning that the information of recognition is always used if it's available, and used exclusively.

The authors did a study that used the "city size" paradigm. Participants were to choose between two city names to identify which had a larger population. The test used had two conditions. One, participants learned names of cities, and the second, participants learned the names of cities and additional positive (e.g., the city *does* have a soccer stadium) or negative (e.g., the city *does not* have a soccer stadium) information about the city. Participants were then tested to see if they would use the additional information in order to deduce which city was larger, or if recognition information was used in a noncompensatory manner.

It was found that people integrate recognition information into their judgements showing that participants will choose recognized cities more often than those not recognized. Results showed that other cue information was not ignored, but rather incorporated into the decisions made. The additional information largely determined the choice regardless if the other city in the pair was recognized or new. Interestingly, recognition information seemed to be dominant in that using cue information of a recognized object in making the decision does show a noncompensatory use of RH. They argue then that the claim that RH is noncompensatory in nature is at least questionable.

This article identifies that recognition information is dominant which can lead us to investigate this type of information. They also find that cue information can be integrated as other information is used in DM, rather than to be cast aside in light of recognition information as proposed by previous researchers.

They were unable to provide evidence that disproved the noncompensatory nature of RH, however conclude that it is still questionable.

Challenges of using heuristics were not explicitly discussed, however, the literature discussed suggests that people have difficulty using information inappropriate way. When too much information is given within a particular decision it can degrade their responses, rather than those who make a similar decision with less information, as in the "*less is more*" idea.

There seems to be difficulty in using cue information in conjunction with recognized information.

There are biases in using the information appropriately, thus cognitive challenges may be in discriminating and appropriately weighting information in DM. Note that this article uses simple decision making environments.
CAN BE USED TO SUPPORT INVESTIGATING: HEURISTICS
To be used? INCLUDE IF RELEVANT

9. Title: Training effects on the use of simple heuristics in threat assessment
Author(s): Bryant, D. J.
Source: Report prepared for Defence Research & Development Canada, DRDC-Toronto Report No. TR-2005-229.
Year: 2005
Abstract: Previous research has examined the use of fast and frugal heuristics for threat classification with probabilistic cues. In all previous studies subjects learned the underlying relationships of cues to friend/foe classification through trial-and-error learning. Explicit training, however, is theoretically interesting because it potentially involves the integration of deliberate cognitive learning of the task's underlying cue structure with implicit, procedural learning of specific cue-criterion probabilities. In the experiment, subjects learned to classify contacts in a simulated naval warfare environment and then were tested on sets of contacts that were designed to contrast predictions of several heuristics, including the Take-the-Best-for- Classification (TTB-C) and Pros Rule developed specifically for the threat classification task, as well as a Bayesian strategy based on computation of the conditional probabilities of friend or foe classification given the particular pattern of cues. The interpretability of the results was limited by the large proportion of subjects who exhibited uninterpretable patterns of responding. In contrast to previous experiments, very few subjects employed TTB-C, although more did use the less frugal Pros Rule. The experiment did yield the novel finding that some subjects can, given explicit training, employ a Bayesian strategy for this task.
Notes: The goal of this paper was to investigate the cognitive processes underlying threat assessment, and determine if explicit training could improve performance. Threat assessment involves the interpretation and integration of probabilistic cues, due to the nature of the information received. Pattern-based (typical patterns of cues are learned) and cue-based (diagnostic information about each cue is provided) explicit methods of training are compared. It was proposed by the author that pattern-based training was more consistent with a Baysian strategy (where all cues are used and weighted) and cue-based training was more consistent with heuristics that use the most diagnostic cue. Overall performance seemed slightly better overall when participants received cue-based training. Several strategies are investigated, including "take the best", which means using the single most valid cue to determine the response. This strategy tends to increase in frequency of use as the cost of cue information increases. Another is a Pros Rule, which is a procedure which includes calculating the sum of cue values for each alternative and selecting the alternative with the highest score. These Pros rules can either be weighted or unweighted.

Unfortunately, many of the participants didn't produce a pattern of results that were clearly classifiable into the expected strategies, making interpretation of the results difficult. This limits the usefulness of this article. There are some hints about the impact of different training types on decision making accuracy, and one interesting finding is that in this explicit training condition, participants tended to use more resource-intensive strategies (which possibly could improve accuracy). Thus, the training may not have resulted in the use of the decision method predicted. This article is not really a DDM scenario; however, it could probably be expanded to apply.
CAN BE USED TO SUPPORT INVESTIGATING: HEURISTICS, CUE INTEGRATION, AND/OR PATTERN RECOGNITION
To be used? INCLUDE IF RELEVANT

10. Title: Tools for understanding and aiding dynamic decision making
Author(s): Busemeyer, J. R. & Pleskak, T. J.
Source: Dissertation presented to Michigan State University (note – this originally appeared in search as a Journal of Mathematical Psychology article)
Year: 2008
Abstract: Dynamic decisions arise in many applications including military, medical, management, sports, and emergency situations. During the past 50 years, a variety of general and powerful tools have emerged for understanding, analyzing, and aiding humans faced with these decisions. These tools include expected and multi-attribute utility analyses, game theory, Bayesian inference and Bayes nets, decision trees and influence diagrams, stochastic optimal control theory, partially observable Markov decision processes, neural networks and reinforcement learning models, Markov logics, and rule-based cognitive architectures. What are all of these tools, how are they related, when are they most useful, and do these tools match the way humans make decisions? We address all of these questions within a broad overview that is written for an interdisciplinary audience. Each description of a tool introduces the principles upon which it is based, and also reviews empirical research designed to test whether humans actually use these principles to make decisions. We conclude with suggestions for future directions in research.
Notes: The authors note that many tools for understanding decision making seem to fall into at least two groups: tools with which to model the decision situation (e.g., decision trees, influence diagrams) and some are tools that can be used to analyze situations and come to a (sometimes optimal) decision. The author provides a framework for understanding DDM, including a choice, time points, outputs, influences on the environment from decisions, and uncertainty. The authors describe three main frameworks for modelling human learning processes in DDM: production rule models (e.g., ACT-R) which assume that a large set of condition-action rules are incrementally learned from experience; exemplar (or case-based or instance) learning, which assume whenever an action leads to a successful outcome the situation and successful response are stored together in memory, with retrieval based on similarity to the situation; and supervised neural network models which use feedback to adjust weights which map inputs to outputs.

There is a discussion at the end of the article about the assumptions of various models which are violated (e.g., that backward induction plays a major role in decision-making, an assumption of many models which is not supported by human data). This article is heavily mathematical, and so it is difficult to understand how this could be very usefully applied to real-world DDM problems with uncertainty and time pressure. It seems more geared toward understanding general DDM rather than ways of specifically improving DDM, and also seems to focus on utility functions which other articles have described as not being suitable for describing actual human performance. The article does make an interesting point, which is that decision making in DDM should primarily aim for robustness (e.g., being suitable across a wide variety of options for the way a system could evolve) than for optimality based on the current or predicted future situation. This article mentions heuristics, biases, and many of the models are related to cue integration and pattern recognition; however, this article is not clearly geared toward any of those and explores DDM in general.
CAN BE USED TO SUPPORT INVESTIGATING: HEURISTICS, BIASES, CUE INTEGRATION, AND/OR PATTERN RECOGNITION
To be used? FOR CONSIDERATION

11. Title: The Accuracy of Intelligence Assessment: Bias, Perception, and Judgement in Analysis and Decision
Author(s): Butterfield, A. P. Jr.
Source: Paper submitted to the Naval War College, Newport, R. I.
Year: 1993
Abstract: This paper examines bias, perception, and judgment in intelligence analysis and decision making. It asks if the accuracy of intelligence assessments can be improved. An answer is sought at fundamental levels of analysis, where biases influence observation, observations are mediated by preconception, and perceptions pass through the filter of critical judgment. Unintentional human errors in observing, perceiving, and judging are the central issues of this paper. Deliberate distortions of intelligence through political calculation or service parochialism are treated peripherally. A survey of literature leads to the conclusion that analytic bias is inevitable; that intelligence concepts are necessary and dangerous; and that uncertainty ensures a margin of error in assessment. Therefore, efforts to eliminate bias and increase the objectivity of intelligence officers are unproductive. Instead, efforts should focus on the suitability and adaptability of concepts. Intelligence officers can be encouraged to use concepts flexibly by exercising several qualities of critical judgment.... Intelligence, Misperception of Adversaries, Bias and Intelligence, Perception and Intelligence, Judgment and intelligence, Ethics and intelligence, Analysis and Decision
Notes: The author examines bias in intelligence analysis. One conclusion is that attempts to remove bias will be unproductive, and so biases must be examined and understood, and attempts made to educate people about them and how they can be appropriate and inappropriate. The author mentions that mistakes in intelligence analysis can be the result of unintentional bias,

but purposeful deception can also play a role.

The author specifies three levels of intelligence assessment:

- Seeing and observing – drawing analytic inferences from raw intelligence reports (problem of bias)
- Observing and believing – mediation of observations by the beliefs and expectations of the analyst (problem of perception and misperception)
- Believing and thinking – filtering perceptions through the screen of reason before making a decision (problem of judgment and ethical thinking)

By organizing intelligence analysis in this way, the author hopes to shed light on types of problems which are often encountered but not made explicit.

Intelligence analysis inevitably contains subjective inferences, but conventionally intelligence analysis is supposed to be objective. It is impossible in intelligence analysis to usefully separate qualitative and quantitative information; e.g., to separate assessments of capabilities from assessments of intention.

Distortions can take many forms, including misunderstanding clear signals, undermining or enhancing the validity of information, and confirmation bias. The author notes that one reason for the fact that there are many examples of misperceptions in wartime is that crisis increases ambiguity, and preconceptions are often used to deal with ambiguity, leading to misperceptions. Intelligence must be structured; facts to be included must be selected for intel reports.

The author notes several attempted methods for dealing with ambiguity and bias. The scientific approach of quantifying analysis and decision making imparts an "artificial order" on an inherently disorderly process. Bureaucratic reforms such as encouraging multiple viewpoints involve tradeoffs such as decreasing preconceptions but increasing ambiguity.

The author suggests that a better approach to dealing with bias is to discuss which biases are best and which concepts are right for a given situation. "Intelligence aims at success, not the truth" (p. viii). Factors that should be considered include tolerance for error, requirements for sensitivity to change, and degree of ambiguity.

Five qualities of critical judgment can be used to improve decision making p. x):

- Full awareness of the inherent limits of intelligence
- Explicitness of assumptions and procedures
- Deliberate analytic self-consciousness
- Intuition supported by knowledge
- Honesty and integrity in analysis and in the relationship between intelligence advisors and decision-makers

This article suggests that, as the use of heuristics and biases are unavoidable, that people who have to make decisions must understand how they affect reasoning and what factors are important when determining which types of reasoning to use. This is more of a discussion than a concrete method of improving performance in DDM.

CAN BE USED TO SUPPORT INVESTIGATING: HEURISTICS and BIASES

To be used? INCLUDE IF RELEVANT

12. Title: Training Decision Makers for Complex Environments: Implications of the Naturalistic Decision Making perspective
Author(s): Canon-Bowers, J. A. & Bell, H.H.
Source: In Naturalistic Decision Making. C.E. Zsambok & G. Klein (Eds.), pp. 99-110. Mahwah NJ: Lawrence Erlbaum Associates.
Year: 1997
Abstract: The purpose of this chapter is to examine Naturalistic Decision Making (NDM)-related theorizing from the standpoint of what it implies for how we train decision makers. It is based largely on the panel discussion (from the Second Naturalistic Decision Making conference held in Dayton OH in June 1994) devoted to this topic. This chapter focuses on generating propositions for training the cognitive aspects of decision making as suggested by the NDM perspective. Suggestions are offered for future research in this area.
Notes: This paper is based on a panel discussion devoted to NDM theories for the purpose of identifying implications for training decision makers. Panellists included: John Schmitt, Hugh Wood, Rannan Lipshitz and Jon Fallesen. The authors identified 1) characteristics of effective decision makers, 2) mechanisms of expert decision making and 3) implications for how to train decision makers. Characteristics of effective decision makers included: • Flexible • Quick • Resilient • Adaptive • Risk taking • Accurate Mechanisms of expert decision making (from which implications for training can be identified) include: • Situation assessment skills – includes cue recognition and pattern recognition • Organized knowledge structures – includes building knowledge templates and matching them to new situation • Mental simulation – simulation of potential solutions for novel situations • Strategy selection – need to continually assess and modulate strategy; requires metacognition • Reasoning skills – includes causal reasoning, hypothesis generation, hypothesis testing, using analogies, critical thinking skills and domain-specific problem-solving skills Implications of NDM theories for training include: • What to train – metacognitive skills, reasoning skills, domain-specific problem-solving skills, mental simulation skills, risk assessment skills, situation assessment skills, knowledge organization

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• How to train – simulations, guided practice and feedback, embedded/organic training, cognitive apprenticeships, multi-media presentation formats Article assessment: Not based on empirical investigations for NDM-based training interventions because very few, if any, exist. Good base for future investigations especially related to the impact of training decision makers in NDM-based strategies/techniques. Primary training challenge is that NDM is inherently not analytical and therefore does not use a structured process so is therefore difficult to train. Training therefore focuses on the skills required to make effective decisions in a DDM environment.
CAN BE USED TO SUPPORT INVESTIGATING PATTERN RECOGNITION, CUE RECOGNITION, CUE INTEGRATION AND ALSO TRAINING IMPLICATIONS FOR NDM/DDM
To be used? INCLUDE IF RELEVANT

13. Title: Training battlefield critical thinking and initiative
Author(s): Cohen, M. S., Thompson, B. B., Adelman, L., & Bresnick, T. A.
Source: Interim report submitted to the U. A. Army Research Institute for the Behavioral and Social Sciences
Year: 1999
Abstract: The first objective of this research was to explore and identify the cognitive skills that individuals need to function effectively in domains that require them to cope with uncertainty, change and conflicting purposes. The second objective was to develop and test methods for training those skills in the context of Army battlefield decision making. The training aimed at improving the ability of Army tactical staff officers to grasp the essential elements of a complex, uncertain, and dynamic situation, visualize those elements in terms of their organizational goals, and take action in a timely and decisive manner. The identification of cognitive skills to be trained and training strategies is based on an original theory of critical thinking skills, the Recognition/Metacognition (R/M) Theory. The theoretical and empirical foundations of the R/M model are described using literature on mental models, expertise, behavioral decision-making, and pattern recognition. The critical thinking skills developed for training include (1) developing and using appropriate mental models of high-order purpose and of time orientation, and (2) applying critical thinking strategies to these models, including the identification and filling of critical information gaps and conflicts in situation understanding, goals and plans, and identifying and evaluating underlying plan assumptions. Training is implemented in a stand-alone Compact Disk (CD).
Notes: Focus on initiative and coordination – importance of both and how to balance them. Coordination (i.e., having multiple people work on a task) has benefits but tends to reduce efficiency unless the task is made less flexible (thereby lessening ability to have/show initiative). Coordination can also result in gains through multiple points of view; however, groups are prone to bias such as

groupthink. The authors propose that decentralization is one way of handling problems with group bias and loss of efficiency. Properly using initiative relies upon using appropriate critical thinking about mental models of the task and team.

The authors argue that optimal performance in DDM contexts rely upon appropriate mental models about organizational purpose, own and others' intent, degrees of initiative, team member reliability, and action sequences. To make the best use of this information, the ability to think critically about these mental models and apply them to novel situations is also required.

Discusses pattern recognition as one type of expertise; however, the ability to purposely create novel solutions is also another characteristic of expertise. An important ability of experts related to pattern recognition is the ability to recognize exceptions.

According to the authors, a fundamental skill is related to separating grounds (what is given) from conclusions (what is inferred). The relationship between grounds and conclusions are not generally 100% certain, so this is a way of identifying assumptions which might have to be tested.

Focus of training is the development of a moderately-sized set of mental model types (e.g., purpose, intent, team member reliability) and critical thinking strategies that should be used to critique and correct those mental models when pattern recognition is inadequate (i.e., novel situations).

This is an interesting article, and presents a way of thinking about decision making in dynamic environments as a mixture of pattern recognition and the use of general mental models and critical thinking. Pattern recognition is used when possible, and general mental models and critical thinking are the best things to use when dealing with novel situations. It isn't quite clear how a decision maker will make the call to use one or the other type of decision making, and real decision making is likely to be a combination of both types. The training information is interesting, and it may result in an improvement in decision making, but it is not clear how useful this method will be in situations with tight timelines (i.e., when people are likely to revert to the most natural method of processing information and have limited time to perform the critical thinking component of the strategy).

CAN BE USED TO SUPPORT INVESTIGATING: HEURISTICS (MENTAL MODELS), PATTERN RECOGNITION

To be used? INCLUDE IF RELEVANT

14. Title: Anchoring-and-adjustment in software project management: An experimental investigation

Author(s): Costello, T. P.

Source: Thesis submitted to the Naval Postgraduate School, Monterey, CA.

Year: 1992

Abstract:

Software project development continues to be characterized by cost overruns, late deliveries, poor reliability and user dissatisfaction. The Systems Dynamics Model of Software Project Management is a quantitative model of software project dynamics that is attempting to gain some valuable insight into the managerial side of developing software systems. The objective of this thesis was to use the Systems Dynamics Model's gaming interface to investigate the cognitive heuristic

anchoring-and-adjustment in dynamic decision environments, and its use in software project management. Specifically, subjects were provided with either a low or a high anchor condition to determine the effect on subject productivity estimation and project performance when confronted with dynamic decision making in software project management. The results show that subjects used anchoring to simplify decision making in the complex dynamic environment. There was evidence of bias introduced by the anchor, thereby causing dysfunctional performance.
Notes: Software project management is described, and appears to be a DDM environment. The Systems Dynamics Model (SDM) is a quantitative simulation of software project dynamics, and has a gaming interface which enables direct interaction with the simulation. Anchoring-and-adjustment (A&A) is described as a heuristic whereby an initial starting point influences the final estimate toward itself. The author discusses the fact that A&A in a dynamic environment could lead to an accurate estimate due to continuous processing, at least if feedback were allowed to play a role in estimating. In the experiment, participants were attempting to manage a software development project; one group was given a low productivity estimate for workers (the low anchor condition) and the other group was given a higher productivity estimate for workers (the high anchor condition). It is interesting to note that, even in the low productivity estimate condition, participants tended to treat the original estimate as optimistic, and the first revision was for lower expected productivity in both anchor conditions. Results indicate that productivity estimates made in the high anchor condition were significantly higher overall than productivity estimates made in the lower anchor condition, indicating that the anchor had an effect on estimates which persisted throughout the experiment. From the data (and the nonsignificant effect of time and time by anchor and time by anchor interactions), it appears as though the size of the effect did not greatly diminish over time, as would be expected from the hypothesis that in a dynamic environment with feedback an anchor's effect would diminish over the course of interacting with the environment. Overall performance (i.e., the completion time for the simulation in days) for the more difficult project was better for the high anchor group, but there was no significant difference between anchor conditions for the easier project. One interesting effect relevant for training is that performance appeared to be better when the easier of the 2 projects was managed first; this supports a training method which increases in difficulty. This experiment is an experiment using an actual DDM context which allows interaction and concrete evaluation of performance. It shows an effect of the A&A heuristic, situations under which it may have a greater effect, and some factors which may influence how A&A affects overall performance. The impact of training order on difficult versus easy simulations is also relevant.
CAN BE USED TO SUPPORT INVESTIGATING: HEURISTICS, BIASES
To be used? INCLUDE IF RELEVANT

15. Title: Impact of diffusion and variability on vendor performance evaluation
Author(s): Doerr, K., Eaton, D.R., & Lewis, I.
Source: Report prepared for the Naval Postgraduate School, Monterey, CA. Report No. NPS LM-

05-016
Year: 2005
Abstract: In this paper we develop a theory of the impact of behavioral decision making factors on the evaluation of logistic service providers under performance-based logistics and provide an analysis of pilot data collected in an attempt to find support for that theory. Based on a review of the logistic measurement, PBL, and behavioral decision making literature, we form four hypotheses about specific impacts of process measures and variance on performance evaluation in PBL. Our first hypothesis is that the difficulty of relating component-level measures to system-level outcomes will lead to an increased use of non-diagnostic or only partially diagnostic process measures. We further propose that these process measures will produce a dilution effect in which system outcomes are undervalued. Our third hypothesis is that absent clear, observable outcome metrics at the component level, decision makers will increasingly rely on measures of inputs as surrogates for outputs. Our fourth hypothesis is that absent a specific guidance on how to value variance, decision makers will tend to overlook this important component of performance. We report results from a pilot test conducted to develop an instrument that will be used to try to find support for hypotheses two and four.
Notes: For weapons systems, logistics are often not considered as part of the evaluation process of the outcome (e.g., an assessment of whether weapons are available does not often have a direct place in the evaluation process of a successful mission). Instead biases ensue and among others, the dilution effect occurs (non-diagnostic information causes diagnostic information to be undervalued). Performance-based logistics investigated in this article is concerned with the measurement of performance data of vendors providing weapons system logistics. The authors seek to explore the role that select biases (e.g. outcome bias, input bias, curse of knowledge, dilution effect) could have in this new process. Hypotheses are made about what effect biases will have and then a study is conducted to explore these hypotheses. Mixed support is found for some of the hypotheses. A short discussion is provided that states how the biases described may be implemented in the PBL. There are strong limitations to this report. The idea that biases and heuristics are used is confirmed through the pilot test. Though the biases are briefly described, there are no details about the origins of the biases or evidence of their use presented. The list of biases chosen seems rather haphazard, with no explanation on what some biases are included or excluded from the discussion. The results are mixed (at best). There is no DDM environment and, no learning opportunities presented.
CAN BE USED TO SUPPORT INVESTIGATING: BIASES
To be used? DO NOT INCLUDE

16. Title: Cognitive adaptation and its consequences: A test of cognitive continuum theory
Author(s): Dunwoody, P. T., Haarbauer, E., Mahan, R. P., Marino, C., & Tang, C.-C.
Source: Journal of Behavioral Decision Making, 13, 35-54
Year: 2000

Abstract:

Cognitive Continuum Theory (CCT) is an adaptive theory of human judgement and posits a continuum of cognitive modes anchored by intuition and analysis. The theory specifies surface and depth task characteristics that are likely to induce cognitive modes at different points along the cognitive continuum. The current study manipulated both the surface (information representation) and depth (task structure) characteristics of a multiple-cue integration threat assessment task. The surface manipulation influenced cognitive mode in the predicted direction with an iconic information display inducing a more intuitive mode than a numeric information display. The depth manipulation influenced cognitive mode in a pattern not predicted by CCT. Results indicate this difference was due to a combination of task complexity and participant satisficing. As predicted, analysis produced a more leptokurtic error distribution than intuition. Task achievement was a function of the extent to which participants demonstrated an analytic cognitive mode index, and not a function of correspondence, as predicted. This difference was likely due to the quantitative nature of the task manipulations. "

Notes:

The authors propose that most decision making is a mix of analytical and intuitive processes; what they call "quasi-rational" decision making. The position the authors take is that neither analytical or intuitive decision making are inherently better; what makes one or the other more appropriate has a lot to do with the nature of the task (e.g., whether rational for decisions will have to be made), the nature of the inputs (e.g., whether cues should be weighted equally; how many cues must be integrated), and other factors. They also indicate that the way information is given can influence where on the "cognitive continuum" decision making will occur.

One interesting point is that analytical decision making does not necessarily provide a ceiling for performance; one reason is that errors made during analytical decision making tend to have more profound effects on the outcome than do errors made during intuitive decision making. In other words, errors may be more frequent in intuitive decision making, but the answer is likely to be closer to the true answer than when errors occur in analytical decision making. Thus, intuitive decision making can be more robust.

The paper describes an experiment which is intended to test the cognitive continuum theory by inducing different types of decision making in participants. They found that an iconic information display induced a more intuitive decision style than a numeric information display. Unlike their predictions, they found a nonlinear relationship between the task characteristics and the actual decision making style selected by participants. One possible reason why this might have occurred is that the same decision had to be made in all conditions. As well, participants may have been driven to reduce cognitive effort, and so been more likely to choose an intuitive strategy no matter the form of the task characteristics. Thus, the authors state that "close correspondence between task characteristics and cognitive characteristics may be less important than the overall functionally adaptive value of quasi-rational cognition when confronting a task with high analytic depth features that includes a high degree of environmental predictability." (p. 50).

This article is relevant for DDM, as it is important for decision makers to apply different decision strategies depending on the task demands, although the task used here is not strictly DDM. Understanding how best to train decision making in DDM should take account the weaknesses inherent in analytical reasoning, including the one pointed out here; that errors can be more profound in analytical reasoning. It is also important to note that the way information is displayed will influence the style of decision making chosen; this may also mean that the way information is displayed during training could skew the decision maker to a particular decision style which may

persevere even when it is no longer suitable, although this hypothesis should be examined. The article does not really address the influence of individual differences, which likely also have a profound impact on the type of decision making strategy used.
CAN BE USED TO SUPPORT INVESTIGATING: HEURISTICS, CUE INTEGRATION
To be used? INCLUDE IF RELEVANT

17. Title: Multiple goals in dynamic decision making: An experimental approach
Author(s): Elser, E. T.
Source: Thesis submitted to the Naval Postgraduate School, Monterey, CA.
Year: 1993
Abstract: Leaders in both the military and civilian sectors make a series of interrelated decisions in real time to achieve goals. These decisions involve the allocation of resources, such as ships and aircraft to influence the situation facing the decision maker. NEWFIRE is a computer-based simulation of a forest fire fighting task that allows the experimenter to control both the goals and the environment in which the decisions are made and thereby explore the effects these variables have on the decision maker. The objective of this thesis was to use the NEWFIRE microworld to determine the effects that multiple goals and system complexity have on decisions. Specifically, subjects were given one, two or three goals, and confronted with three scenarios of varying complexity. The results show that subjects given only one objective outperformed those given two or three objectives. The results also show that the performance of subjects on the most complex scenario was worse than on the less complex scenarios.
Notes: The main goals of this paper was to investigate the role that goal conflict (number of goals) affects the quality of decision making in DDM and how task complexity affects this relationship. The methodology involves using a simulated microworld involving firefighting, which allows a concrete investigation of DDM including concrete goals and measureable objectives which could be useful for training. The hypotheses investigated were that participants will perform better without goal conflict, that participants will perform more poorly as goal conflict increases (i.e., from two to three goals), and that people will perform more poorly as task complexity increases. The justification for this research was that goal conflict has seldom actually been investigated in DDM. Hypotheses were supported in general, although there were some interesting (and unpredicted) interactions between task complexity and goal complexity. There was a suggestion that the three goal (i.e., most complex goal condition) group outperformed the two goal group on the easy and moderately difficult scenarios, but performed the worst in the difficult scenario. The author suggests that the three-goal group might have been more efficient in goal shifting than the two-goal group. The hypotheses investigated in this article are largely very intuitive and so the results are not surprising. The one exception is the interaction between goal and task complexity. It could be an interesting area for research to determine the limits to the benefits of goal shifting, and determine the cons as well (e.g., this might result in more burnout as it requires more resources, so people

could not perform the task for as long as they could with a more simple goal structure). Note that it is not entirely clear whether this paper supports one or more of the four topics of interest, although it could possibly support cue integration and pattern recognition in a broad sense.
CAN BE USED TO SUPPORT INVESTIGATING: CUE INTEGRATION, PATTERN RECOGNITION?
To be used? FOR CONSIDERATION – some interesting ideas but relevance not certain

18. Title: Subjective assessment of uncertainty
Author(s): Fallon, R.
Source: Paper submitted to the Rand Graduate Institute, Santa Monica, CA.
Year: 1976
Abstract: Properly assessing your subjective probabilities is extremely difficult, and is more of an art than a science. One's subjective probability of an uncertain event should truly reflect his proper state of information if it is to be of any value at all for planning purposes. In this study the author points out many of the common cognitive influences, and biases which they lead, that people undergo, either consciously or unconsciously, in the intuitive assessment of probability. These heuristics and biases are not only prevalent in people of a variety of backgrounds but are also common in experienced researchers they think intuitively. A better understanding of these simple heuristics, and the biases to which they lead, by improving the ability for individuals to properly assess their true state of information, could improve judgements and decisions in situations of uncertainty. It is very important, therefore, that advisers and analysts who are involved in planning for uncertain future events be aware of, and consciously try to avoid, these influences.
Notes: This paper reviews several heuristics and the biases which they tend to produce, including anchoring and adjustment, availability, and representativeness. People's experience with statistics and their familiarity with making probabilistic judgments do not seem to significantly affect their use of heuristics and bias that accompanies them. The quality of this paper is in some doubt, as it was prepared for a graduate course and is fairly old. It primarily discusses the use of heuristics, and does not necessarily relate to DDM or how to train people to properly use heuristics and avoid bias.
CAN BE USED TO SUPPORT INVESTIGATING: HEURISTICS, BIASES
To be used? DO NOT INCLUDE

19. Title: Models of Information Aggregation Pertaining to Combat Identification: A Review of the Literature
Author(s): Famewo, J., Matthews, M., & Lamoureux, T.
Source: Report prepared for Defence Research and Development Canada, DRDC-Toronto Report No. CR-2007-062.

Year: 2007
Abstract: This report reviews research literature pertaining to models of human information aggregation in order to apply them, when possible, to combat identification (CID) decisions made by individuals in a land force context. In particular, the review examined social science, science and military literature to identify principles and theories associated with how human decision makers weigh and integrate information. The review identified a variety of heuristics and cognitive biases associated with these processes, along with formal and informal models of combining qualitative and quantitative information. The report presents current conceptualizations of combat identification and places it within the context of cue-based decision making under the intuitive decision framework. By framing this complex decision we were able to evaluate the applicability of the methods of aggregation to the CID task.
Notes: The purpose of the report was to identify plausible human decision making models, approaches and limitations in aggregating information for the purposes of combat identification (CID). Key researchers in the decision making, heuristics and biases area (Amos Tversky at Stanford University, Kahneman at Princeton University; Gerd Gigerenzer and Daniel G. Goldstein at Mac Planck Institute for Human Development) as well as those in Cue-based Decision Making (Gary Klein at Klein and Associates; Raanan Lipshitz at Haifa University; and Eduardo Salas at the University of Central Florida) are briefly included. The authors conclude that research into natural decision making (including Recognition Primed Decision Making and the Brunswickian Lens Model) as well as behavioural decision theory (including classic heuristics and biases, as well as fast and frugal heuristics) are both more useful for describing the CID process than rational decision making models. Each of these models, along with the use of cues, patterns, heuristics and biases are discussed. The role of uncertainty in decision making was also included. Two methods for overcoming uncertainty specifically mentioned were: the Reducing, Assumption, Weighting, Forestalling and Suppressing (RAWFS) heuristic; and, Recognition/Meta-Cognition (R/M) model. Specific cognitive challenges in CID decision making noted were: - improper weighting of cues due to various circumstances - classic limits of working memory (7+-2 units) - decision variability based on the presentation of information (e.g. order effects, salience) - overconfidence, confirmatory, and ignoring of base rates biases - adjustment and anchoring; take-the-best (and other fast and frugal) heuristics - herding behaviour effects
CAN BE USED TO SUPPORT INVESTIGATING CUES, PATTERN RECOGNITION, HEURISTICS, AND BIASES.
To be used? INCLUDE IF RELEVANT

20. Title: When one cue is not enough: Combining fast and frugal heuristics with compound cue processing

Author(s): Garcia-Retamero, R., Hoffrage, U., & Dieckmann, A.
Source: The Quarterly Journal of Experimental Psychology, 60, 1197-1215.
Year: 2006

Abstract:

One-reason decision-making heuristics as proposed by Gigerenzer, Todd, and the ABC Research Group (1999) have been shown to perform accurately. However, such strategies cannot deal with compound cues. We propose the Take The Best Configural Cue (TTB-Configural) as a fast and frugal heuristic that processes compound cues. In a series of three experiments, we analysed whether participants used this heuristic when making cue-based inferences on which of two alternatives had a higher criterion value. In two of the experiments, two cues were amalgamated into a valid compound cue by applying the AND or the OR logical rule, respectively. In the third experiment, there was no valid compound cue. Within each experiment, we also manipulated causal mental models through instructions. In the configural causal model, cues were said to act through the same causal mechanism. In the elemental causal model, cues were said to act through different causal mechanisms. In the neutral causal model, the causal mechanism was not specified. When a highly valid compound existed, and participants had a configural causal model, for the majority of them the strategy that could best account for their choices was TTB-Configural. Otherwise, the strategy that best predicted their choices was the Take The Best (TTB) heuristic.

Notes:

The authors propose a method of processing compound cues termed "Take The Best Configural Cue" (TTB-configural) as a fast and frugal heuristic. The TTB is a heuristic designed to infer which of two alternatives has a higher value on a quantitative criterion. The TTB uses validity (probability that a particular cue will lead to a correct decision). There is no integration of information as the decision is based on the first discriminating cue. The TTB-Configural starts with this theory and integrates the use of compound cues. It starts by searching for a particular set of cues, including both compound and individual cues.

The authors conduct three experiments in which they analyze if participants use this heuristic when making cue-based inferences. This type of heuristic may be used when searching for information in the environment is costly or when decisions have to be made under time pressure.

Previous experiments showed that when participants were instructed to search for highly valid compound cues, and these existed, the TTB-configural strategy was the best fit for the strategies used (based on expected time to use this strategy). When instructed that cues act through different causal mechanism or participants had no info about causal mechanisms TTB was used (a one-reason decision-making heuristic that deals with non-compound cues).

Experiment 1 manipulated participant's "mental models" of the environment. The groups were configural (instruction encouraged participants to search for highly valid compound cues in the environment), elemental (instruction emphasized that cues act through different causal mechanisms when determining the criterion; this was meant to encourage participants to treat cues independently), and neutral (no information about possible causal mechanisms through which cues acted) causal models. Experiment 2 replicated results found in Experiment 1 and used a higher payoff as incentive for participants. Experiment 3 contained no valid compound cue (compound AB = 0.5 corresponding to guessing). All other aspects of the experiment were identical to 1 & 2.

Results showed that when participants were given instruction that cues acted through the same causal mechanism the majority of participants made decisions best modelled by the TTB-Configural heuristic. When instructions suggested cues were acting independently their decisions were best modeled by the elemental TTB. This was also the case for the neutral causal model condition. In an environment with no compound cues, no participants were categorized as using TTB-Configural, but instead were modelled best by the TTB. Those in the configural condition looked up more information during the experiment as they may have been more uncomfortable making the decision due to their original "mental model" that did not prove useful in an environment with no compound cues.

These studies provide evidence that the TTB-Configural heuristic, constructed from building blocks of TTB, can be created as an adaptive tool in decision making. Future research may investigate what happens when imperfect validity relationships occur between the compound cues and the outcome and what results occur when a substantial increase in compound cues are presented in the environment.

The authors demonstrate a number of scenarios in which participants strategies are best reflected by fast and frugal heuristics (take-the-best heuristic, and TTB-configural heuristic). The show that building on a more simplistic heuristic, adaptive decision making tools can be formed when more complex decision making is required.

This study also demonstrates that confidence in decision making, and comfort level with the amount, and quality of the information seems to be an influencing factor in determining whether to search for more information in attempts to use incorporating more analytic strategy, or simply use fast and frugal heuristics with minimal information.

Results from the studies indicate that when information cues are have a more direct, causal relationship to the criterion, strategies used implied a type of "mental model" (what the authors define as a mental representation of the problem solving strategy structure), that gather and process individual pieces of information as well as compound pieces of information (combinations of cues), rather than only individual cues.

Note that within these studies decision tasks were not dynamic.

CAN BE USED TO SUPPORT INVESTIGATING: HEURISTICS, CUE INTEGRATION

To be used? INCLUDE IF RELEVANT

21. Title: The power of causal beliefs and conflicting evidence on causal judgements and decision making

Author(s): Garcia-Retamero, R., Mueller, S. M., Catena, A., & Maldonado, A.

Source: Journal of Learning and Motivation, 40, 284-297.

Year: 2009

Abstract:

In two experiments, we investigated the relative impact of causal beliefs and empirical evidence on both decision making and causal judgments, and whether this relative impact could be altered by previous experience. Participants had to decide which of two alternatives would attain a higher outcome on the basis of four cues. After completing the decision task, they were asked to estimate to what extent each cue was a reliable cause of the outcome. Participants were provided with instructions that causally related two of the cues to the outcome, whereas they received neutral information about the other two cues. Two of the four cues—a causal and a neutral cue—had high validity and were both generative. The remaining two cues had low validity, and were generative in

Experiment 1, but almost not related to the outcome in Experiment 2. Selected groups of participants in both experiments received pre-training with either causal or neutral cues, or no pre-training was provided. Results revealed that the impact of causal beliefs and empirical evidence depends on both the experienced pre-training and cue validity. When all cues were generative and participants received pre-training with causal cues, they mostly relied on their causal beliefs, whereas they relied on empirical evidence when they received pre-training with neutral cues. In contrast, when some of the cues were almost not related to the outcome, participants' responses were primarily influenced by validity and—to a lesser extent—by causal beliefs. In either case, however, the influence of causal beliefs was higher in causal judgments than in decision making. While current theoretical approaches in causal learning focus either on the effect of causal beliefs or empirical evidence, the present research shows that both factors are required to explain the flexibility involved in human inferences.
Notes: Two experiments are conducted that investigate the impact of causal beliefs and empirical evidence on decision making and causal judgements. The studies also examined if previous experience could alter the relative impact between these. Specifically, they looked at rational decision making and decisions related to the capacity to apply inferences about the future drawn from experiences that verify or falsify previous causal beliefs. The first study examines how much individuals rely on previous causal beliefs when interpreting empirical evidence. Results conclude participants' decisions were guided by causal beliefs and by empirical evidence (cue validity). Absence of pre-training and pre-training with causal cues lead to a clear preference for causal cues. Pre-training with valid cues that were not causally linked to the outcome did not have any influence on participants' decisions when presented with causal instruction about the cues (results independent of causal status of cues). The second experiment aimed to replicate findings in Experiment 1 and further investigate if causal judgements and decision making tap into different psychological mechanisms as no correlation was observed between these 2 variables in Experiment 1. Subjecting participants to causal beliefs did impact their causal judgements. Differences in groups showed evidence that decisions and causal judgements tap different psychological processes. Overall, both decision making and causal judgments were primarily influenced by cue validity (the degree to which the cue actually contributes to the outcome), and to a lesser extent by preconceived causal beliefs. Results show participants that were exposed to causal cues (both with and without pre-training) mainly relied on high-validity cues that were causally linked to the outcome and disregarded causal low-validity cues (not related to the outcome). Participants exposed to neutral cues prior to the trials (with and without pre-training) relied preferentially on high-validity cues regardless of whether they were causal or neutral. This proposes that causal beliefs have a great impact on causal judgements. This is in line with research that describes confirmation bias. Future direction: the authors suggest looking at whether there is a way that those exposed to preconceived causal beliefs can become more sensitive to validity information rather than maintaining focus on the causal cues. The authors discuss a Belief Revision Model and a causal belief – reliability equation that examine how causal beliefs and empirical information may impact the interpretation of data and consequently the impact on a decision or judgement. The authors point out that there may be different processes used in making different types of decisions and judgements. This may impact further investigation of DDM and training, in that a each type of process of decision making may need to be investigated individually, if indeed there are large differences.

Cue validity was pointed out as one of the primary influencing factors in making inferences. The validity of cues is subjective within DDM, thus this may be one major challenge in performing DDM tasks. If people are able to have reliable high validity cues, they are less likely to rely on prior causal beliefs. This implies that fewer biases will impact the decision and perhaps even heuristics would be used when there is high validity of cues. The previous Garcia- Retamero et al. paper (2006) indicates that people's confidence in the quality (recency, accuracy) of the cues may impact the use of valid cues. The challenges in this situation may be more environmental rather than cognitive. Pre-established beliefs were found to influence causal judgements more than decision making. However, biases and previous experience, as they may be based on pre-established beliefs (and help to establish beliefs), we understand from other literature, can severely influence decision making. This article does not directly focus on particular biases or heuristics, though we may understand beliefs in a way that may act similarly in decision making.
CAN BE USED TO SUPPORT INVESTIGATING: related to BIASES, HEURISTICS
To be used? FOR CONSIDERATION

22. Title: Does causal knowledge help us be faster and more frugal in our decisions?
Author(s): Garcia-Retamero, R., Wallin, A., & Dieckmann, A.
Source: Memory & Cognition, 35, 1399-1409
Year: 2007
Abstract: One challenge that has to be addressed by the fast and frugal heuristics program is how people manage to select, from the abundance of cues that exist in the environment, those to rely on when making decisions. We hypothesize that causal knowledge helps people target particular cues and estimate their validities. This hypothesis was tested in three experiments. Results show that when causal information about some cues was available (Experiment 1), participants preferred to search for these cues first and to base their decisions on them. When allowed to learn cue validities in addition to causal information (Experiment 2), participants also became more frugal (i.e., they searched fewer of the available cues), made more accurate decisions, and were more precise in estimating cue validities than was a control group that did not receive causal information. These results can be attributed to the causal relation between the cues and the criterion, rather than to greater saliency of the causal cues (Experiment 3). Overall, our results support the hypothesis that causal knowledge aids in the learning of cue validities and is treated as a meta-cue for identifying highly valid cues.
Notes: The authors examine the relationship between causal information and the use of cues to guide decision making. Their hypotheses include the idea that causal information should act as a guide to determine which cues to examine to uncover their validity, and also help to remember the validity of those cues. In effect, causal information acts as a "meta-cue", or a cue about the cues, in determining what is helpful. This is important because in many contexts, including DDM, there is an overabundance of cues, little information (at least at first) about which cues are valid, and decision makers have limited working memory with which to learn the relationships between the

cues and outcomes and which cues are most valid. In fact, without explicit information about cue validity, the authors point out that decision makers don't actually seem to remember information about cue validity. The authors find that the addition of causal information influences the cues which participants choose to examine (the causal ones over noncausal cues), increases the speed with which they make decisions, increases the accuracy of those decisions, increases confidence in decisions, and increases the accuracy of estimations of cue validity. This topic seems very relevant to decision making in DDM, as it is a major question how people select and integrate cues, and how this can be done quickly and accurately. Understanding the role of causal information helps to explain and reduce some of the cognitive complexity inherent in DDM. This may also have a beneficial impact on training, as pointing out causal information could make it easier for people to remember, as well as learn the actual validity of the cues.
CAN BE USED TO SUPPORT INVESTIGATING: HEURISTICS, BIASES, CUE INTEGRATION
To be used? INCLUDE IF RELEVANT

23. Title: A Theoretical model to attack the enemy's decision-making process
Author(s): Gibb, R. W.
Source: Paper submitted to the Naval War College, Newport, R. I.
Year: 2000
Abstract: An operational commander can attack enemy vulnerabilities because of human susceptibilities to biases and limitations when making decisions. This paper proposes a theoretical model to cognitively attack the enemy commander. The model is based on Information Warfare and Command and Control Warfare, as well as psychological human information processing concepts. The Observation-Orientation-Decision-Action loop, a known military decision cycle, is discussed and contrasted with a human information processing model. These concepts are then related to the planning steps of the Commander's Estimate of the Situation. Human decision-making heuristics are recommended to specifically target the enemy's Observation and Orientation stages of the decision cycle. Consequently, affecting the enemy's operational planning of mission analysis and courses of action. The model's objective is to alter enemy knowledge and beliefs, thus affecting situational awareness and mental-model development, which in turn will produce decisions less favourable for the enemy.
Notes: Information Warfare (IW) pertaining to information psychology consists of feeding information to the enemy to have them act as you desire. The goal is to alter their thoughts and decision-making process about the conflict. The ultimate victory would be to convince the enemy that they will be unsuccessful prior to the start of armed conflict. The author relates psychological and physiological process models to decision-making arguing that the same concepts of stress and task saturation are experienced by commanders when establishing informational cues. Understanding the adversary's culture and beliefs is necessary to understand their values and actions. Biases and heuristics can be

utilized to further deceive the enemy into establishing false situation awareness and making false conclusions within the Observation-Orientation-Decision-Action (OODA) cycle. The author discusses how the confirmation bias, availability bias, and as-if heuristics can be exploited in IW. The author proposes a model that incorporates the OODA loop with Commander's Estimate of the Situation (CES) and information processing, emphasizing that attacking stages of the OODA loop will thus indirectly affect later stages of multiple decision-making processes by altering beliefs and mental model development.

The focus if this article is on military decision implies a DDM context. Specific cognitive challenges may be identified through looking at information processing such as is highlighted in this article (Wickens, C.D., Flach, J.M, "Information processing" in aviation psychology, 1998 (19-41).

The author relates the OODA model an Observation-Orientation-Decision-Action loop to the Wicken's and Flach's model :

Observation (gathering info e.g. reconnaissance) = short-term sensory store

Orientation (observing info and converting it into "intelligence". Creating an image of "reality")= pattern recognition

Decision (make decision on "reality" & communicate to others) =decision and response selection

Action (execute decision actions) = response execution

Details of each stage are only briefly described, investigation of this model more in-depth may be useful in understanding pattern recognition.

The OODA model was used to demonstrates some cognitive challenges in decision-making. They include:

- identifying relevant information within the environment is challenging when there are multiple sources of information and a high volume of information
- filtering high volumes of information presents problems because working memory has a limited processing capacity. (7 +/- 2)
- biases influence what information we deem is relevant to the decision at hand. This can then effect the quality of the decision as it may be based on wrongly "weighted" values that have been attributed to each cue.
- People have difficulties forecasting in partially ambiguous situations. Predictions is often inaccurate.
- Attention may be focused on particular area – this may be similar to biases. Good explanation of what is meant is not detailed.

The authors present a theoretical planning model (see figure below) which may be a good place to start in identifying where DDM in operations can be vulnerable; analysis of the mission, factors affecting possible COAs, development of COA, analysis of COA (own and enemy), comparison of COA, may all be influenced by biases (specifically identified are confirmation bias, availability bias, "as-if" heuristic).

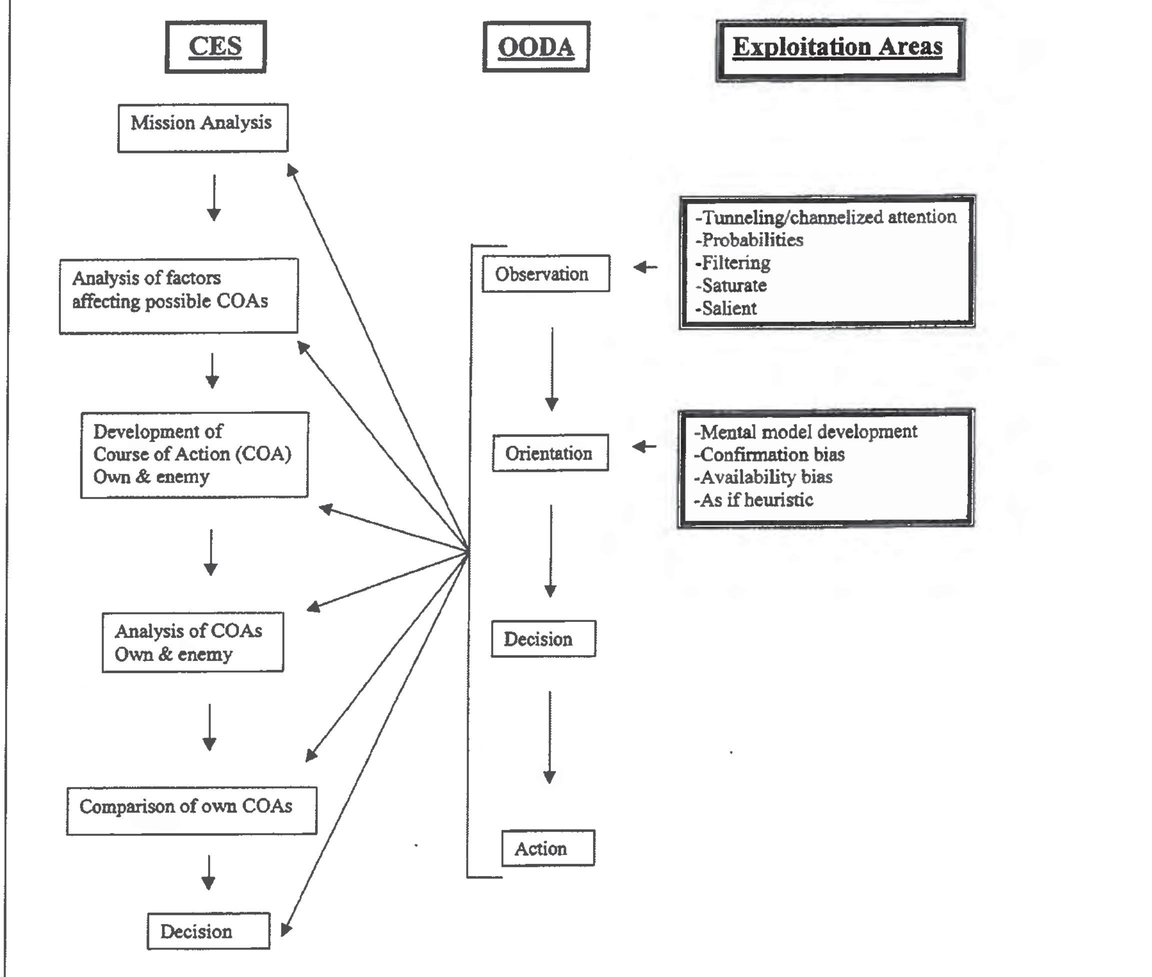

Figure 2. Theoretical planning model.

Figure 5: Planning Model

The authors also identify good decision –making characteristics they include:

1) situational awareness
2) meta-cognition
3) shared mental model
4) resource management.

These may be areas to investigate further for training in DDM.

CAN BE USED TO SUPPORT INVESTIGATING: BIASES, HEURISTICS , general challenges in DDM

To be used? INCUDE IF RELEVANT

24. Title: Why heuristics work
Author(s): Gigerenzer, G.
Source: Perspectives on Psychological Science, 3, 20-29.
Year: 2008

Abstract:

The adaptive toolbox is a Darwinian-inspired theory that conceives of the mind as a modular system that is composed of heuristics, their building blocks, and evolved capacities. The study of the adaptive toolbox is descriptive and analyzes the selection and structure of heuristics in social and physical environments. The study of ecological rationality is prescriptive and identifies the structure of environments in which specific heuristics either succeed or fail. Results have been used for designing heuristics and environments to improve professional decision making in the real world.

Notes:

The author discusses heuristics as an adaptive way of making decisions in complex environments with limited information. One thing stressed is that heuristics are used to make good decisions; in fact, sometimes the decisions are better than "optimal", analytic strategies.

Several relevant and important points made relate to misunderstandings of heuristics and the roles they play, including (from Table 1, p., 21):

- In many situations, optimization is computationally intractable or less accurate because of estimation errors (this means that heuristics are not always second-best to computational optimization, and are sometimes more robust)
- Characteristics of the environment can result in a reliance on heuristics (this means that the use of heuristics is not just the result of cognitive limitations)
- Cognitive capacity appears to be more related to the selection of appropriate heuristics rather than reliance on computational solutions in more complex situations (i.e., reliance on heuristics is not more prevalent in people with lower cognitive capability)
- Good decisions in an uncertain world often require ignoring part of the information (therefore this is another reason why analytic solutions are not always better than heuristics, and more information isn't always better)

In this article, as well as other forecasting articles, the author points out the need to predict the future and not just understand the past. The author indicates that cognitive limitations such as forgetting can actually add to the robustness of decision making, possibly by reducing noise in the system.

The author points out that, just as analytical methods are not always better, heuristics are not always better; one has to assess the "ecological rationality" of the decision-making strategy. Relevant environmental features are ones which predict the performance of the problem domain; some possible examples are the size of learning samples and the amount of uncertainty in the domain.

Table 2 (p. 24) provides a list of possible heuristics that may be contained in the "adaptive toolbox", their definitions, conditions for ecological rationality, and predictions.

This article is an effective argument for the general usefulness and adequacy of heuristics, and seems to be quite useful for this project if heuristics is the topic selected for elaboration. It does

deal with examples from DDM environments (e.g., making investments) and addresses cognitive challenges (from the perspective that they are often strengths of heuristics) and could likely be expanded to the topic of training (e.g., training should focus on understanding environmentally rational strategies, rather than one particular strategy to be generally applied).
CAN BE USED TO SUPPORT INVESTIGATING: HEURISTICS
To be used? INCLUDE IF RELEVANT

25. Title: Challenges supporting cognitive activities in dynamic work environments: Application to policing.
Author(s): Glantz, E. G.
Source: Dissertation Abstracts International Section A: Humanities and Social Sciences, 70 (1-A).
Year: 2009
Abstract: Municipal police officers perform cognitive activities, such as decision making, judgment and problem solving, while facing real world constraints that include large, socially distributed problem spaces with potential for high risk outcomes. As such, the goal of this dissertation is to improve cognitive effectiveness in the policing domain by integrating Cognitive Systems Engineering methodologies to achieve three objectives: 1. Developing an understanding of the police domain and its constraints on the cognitive activities of officers, 2. Analyzing sources of complexity and needs in the cognitive activities of officers, and 3. Exploring technology interventions to reduce officer task complexity and accommodate domain constraints. The results include eight findings with implications for cognitive system design. The findings suggest it is possible to improve the use of technology to enhance cognitive effectiveness, and that there are strengths in combining methodologies to explore the feasibility of cognitive interventions.
Notes: The goals of this dissertation were to 1) develop an understanding of the police domain and the effects domain constrains have on the cognitive activities of officers; 2) analyze cognitive tasks and identify sources of complexity and specific needs of officers; and 3) explore technological interventions to reduce task complexity and accommodate domain constraints. This dissertation describes 3 types of analyses and elements within them. Decision ladders, concept maps, Methodologies include interviews as forms of knowledge elicitation with experts (e.g., 25 years of experience), attending training courses. The report examined the complex socio-technical systems in which officers make dynamic decisions. This is particularly influenced by political and social systems in which they operate. The focus of the data analysis was the development and evaluation of a prototype. The purpose was to provide understanding into cognitive systems and may lead to interventions to support cognitive activities in the field. The prototype examined was a scenario training that provides analytical situation monitoring, planning and control decision opportunities. The outcome of the dissertation was an evaluation of the effectiveness of designed prototype scenario training in a real-world

setting. The author explores aspects of the domain, tasks, and decisions officers make while on duty. The topic of complex decision making is touched upon, though is not the focus of the dissertation. There is discussion of the relevant elements that make a decision complex, and workarounds and potential improvements to these issues. The author touched on aspects of the system in which officers' function that share decision-making. This is mainly focused on the technological systems within their jobs. The author suggests that decision complexities are due to the elements within the nature of the dynamic environment such as: accessing information, quality (timeliness, completeness, accuracy) of information, if information must be shared and/or processed by others, and risks to the worker and the environment. Other general challenges within DDM include that expectations of what will occur are not fully developed in new incidences (mainly due to lack of experience and lack of information about the situation). Training thus may focus on providing more DDM experience, and identifying and searching for more (and higher quality) information. The cognitive challenges are very specific to the situations and tasks of the officers, and mainly focused on the technological systems, not DDM per se. Discussion pertaining to biases, heuristics, cue integration and pattern recognition are not explicit. The majority of this dissertation is focused on how and what tasks officers performed, rather than the issues surrounding complex decision making. The authors present findings, cognitive design implications and research implications. From these a number of cognitive challenges extracted that are relevant to DDM include: - cognitive demands increase as the scope of job responsibilities increases - there can be challenges of information sharing such as coordination and monitoring - interoperability reduces effectiveness and results in unexplored possibilities General challenges in dynamic environments identified include: - accessing information - quality of information (timeliness, completeness, accuracy) - sharing information with others - relying on others to process particular information. This may affect the quality risks to the workers and the environment
CAN BE USED TO: Possible cognitive challenges in DDM.
To be used? FOR CONSIDERATION

26. Title: Does intuition beat fast and frugal heuristics: A systemic empirical analysis
Author(s): Glöckner, A.
Source: In H. Plessner, C. Betsch, and T. Betsch (Eds.), Intuition in judgment and decision making (pp. 309–325). Mahwah, NJ: Lawrence Erlbaum.
Year: 2007

Abstract:

(From introduction):

In numerous recent publications (Betsch, 2005; Damasio, 1994; Dougherty, Gettys, & Ogden, 1999; Haidt, 2001; kahneman & Frederick, 2002) as well as in the previous chapters of this volume (e.g., T. Betsch, chap. 1, this volume; Deutsch & strack, chap. 3, this volume; epstein, chap. 2, this volume; Hogarth, chap. 6, this volume; Weber & lindemann, chap. 12, this volume), the importance of automatic processes and intuitive strategies in decision making has been highlighted. Despite the increased interest in this topic, rigorous empirical tests that measure how many people indeed use such intuitive strategies compared with simplifying fast and frugal heuristics (Gigerenzer, Todd, & the ABc research Group, 1999) and complex-rational serial weighted additive strategies (Payne, Bettman, & Johnson, 1988) are still rare. At least two reasons for this can be identified. First, some of the automatic models make it hard to derive testable and unique predictions (e.g., Damasio, 1994; slovic, Finucane, Peters, & McGregor, 2002). second, classical methods to detect decision strategies like information search analysis (Payne et al., 1988) or analysis of think-aloud protocols (Montgomery & svenson, 1983) are not capable of detecting intuitive decision strategies and might even hamper their application (Glöckner & Betsch, 2006; Hamm, chap. 4, this volume). My aims in this chapter are to outline a method that avoids these problems and to present data from a research program that closes the empirical gap. First, I describe the relevant classes of strategies—namely complex-rational, simplifying, and intuitive strategies—that decision makers might apply. With the consistency-maximizing strategy (cMs; Glöckner, 2006), I introduce one specific intuitive decision strategy that allows for deriving testable and distinguishable predictions. After that, I outline a methodological approach that allows for detecting the intuitive cMs. Finally, I summarize and discuss empirical data from six experiments that shed light on the question of which class of decision strategies accounts for the majority of individuals' decision behavior.

Notes:

The author proposes an intuitive decision-making strategy and a methodological approach. Six empirical experiments are discussed that address the question of which class of decision strategies accounts for the majority of individuals' decision behaviour. The city size paradigm tasks participants with deciding which of two cities has a higher population. Dichotomous cues were used in the majority of the studies reported. Predictors of decision strategies are cues that differ in validity (the degree to which they are correlated to the criterion).

The author argues that one-reason decision strategies (take the best heuristic, TTB, and recognition heuristic, REC) and tallying strategies like equal weight rule (EQW or Dawe's rule) are the most important. However, recent studies show conflicting evidence that the fast and frugal heuristics proposed by Gigerenzer et al (1999) are not always used to adapt in natural environments as proposed. Choice patterns are often congruent with the Weighted Additive Strategies (WADD), but sometimes, it is argued, are best explained by intuitive decision strategies. One process that has gained support as being that which individuals use in decision making is the Parallel Constraint Satisfaction (PCS) network model. In this model, information structures are set in to automatic processes when individuals perceive a decision situation. Information alternatives are weighted against each other. Information is modified and compared/matched with mental representations that might be used in decision making.The author proposes an intuitive Consistency-Maximizing Strategy (CMS) computational algorithm in which different nodes within an informational structure are excited or inhibited and then excite or inhibit others leading to and from different cues and options. This framework serves to form a representation that can be used in the decision. Pieces of information are weighted against each other and the weighting can be modified based on other cues and information nodes being activated. The full time required to complete this process and come up with a decision is the "decision time".

Methods of classification are discussed and limitations are pointed out (i.e., Bayesian strategy which does not allow differentiation between the WADD and CMS methods because the predicted choices are basically equal). The author then proposes a better method of classification based on the analysis of choices and decision times. A study proposes that a 12-second limitation is required to apply a WADD's strategy and decision times below his method would reflect random strategy users. The second step would then classify these random users as TTB, EQW or CMS using the Bayesian strategy classification method. The third step is to compare decision times for different decision tasks that are proposed to verify classification of TTB and EQW.

Memory-based DM may be different than other DM. Fast and frugal heuristics may provide the best fit for this type of DM.

A study proposes the idea that with different time limits (severe and weak) different strategies were used (TTB and CMS respectively).Time dependencies for the use of different strategies could mean that difference in cue dispersion (using the computational algorithm idea) may lead to the application of different heuristic strategies.

The author discusses how to identify different decision strategies. Limitations of the classifications methods are discussed. Actual content of decision strategies are only briefly explained.

This article may be suitable in supporting theories of when different heuristics or DM processing methods may be used. He discusses that fast and frugal heuristics may be used in memory-based decisions, and decision times (e.g., 12 s minimum for use of WADD) may give support to theories that certain types of decisions require particular types of processing.

This article challenges others that put forth the predominant use of fast and frugal heuristic.

All decision making tasks were simple (not dynamic).

CAN BE USED TO SUPPORT INVESTIGATING: the use and categorization of HEURISTICS

To be used? FOR CONSIDERATION

27. Title: Fast and frugal forecasting

Author(s): Goldstein, D. G. & Gigerenzer, G.

Source: International Journal of Forecasting, 25, 760-772.

Year: 2009

Abstract:

Simple statistical forecasting rules, which are usually simplifications of classical models, have been shown to make better predictions than more complex rules, especially when the future values of a criterion are highly uncertain. In this article, we provide evidence that some of the fast and frugal heuristics that people use intuitively are able to make forecasts that are as good as or better than those of knowledge-intensive procedures. We draw from research on the adaptive toolbox and ecological rationality to demonstrate the power of using intuitive heuristics for forecasting in various domains including sport, business, and crime.

Notes:

The authors investigate forecasting, and the possibility that simpler equations might forecast better than more complex ones. They contrast "fitting", or matching the current data available, with "forecasting", or predicting the same information in the future; shown is the fact that using 4 variables will typically fit the data worse than using 25 factors, but when forecasting, the 25-factor model actually has higher error. This is called "overfitting" the data (when fitting current data is better than forecasting). The authors call a model "robust" when it retains accuracy when comparing fitting and forecasting. The authors note that the usefulness of a heuristic is related to features of the information environment, such as low predictability. Information environments cause heuristics to succeed or fail. Their Table 1 lists a number of heuristics (recognition heuristic, fluency heuristic, take-the-best, tallying, hiatus heuristic, persistence of best, 1/N heuristic, center-of-the-circle), conditions favouring their performance, and predictions and results. Simple heuristics have more than just simplicity as an advantage; they are also transparent, which makes learning easier. This article discusses the "cognitive toolbox", as mentioned in other articles (particularly by Gigerenzer). This is a good way for understanding heuristic reasoning and how and when it is useful. Although the articles is not written in a DDM context, it deals with the issue of forecasting (i.e., predicting the future), which is one of the most difficult things about operating in a DDM context. It also discusses fast and frugal reasoning which would be useful in DDM environments.
CAN BE USED TO SUPPORT INVESTIGATING: HEURISTICS, CUE INTEGRATION
To be used? INCLUDE IF RELEVANT

28. Title: Instance-based learning in dynamic decision making.
Author(s): Gonzales, C., Lerch, J. F., & Lebiere, C.
Source: Cognitive Science: A Multidisciplinary Journal, 27, 591-635.
Year: 2003
Abstract: This paper presents a learning theory pertinent to dynamic decision making (DDM) called instance-based learning theory (IBLT). IBLT proposes five learning mechanisms in the context of a decision-making process: instance-based knowledge, recognition-based retrieval, adaptive strategies, necessity-based choice, and feedback updates. IBLT suggests in DDM people learn with the accumulation and refinement of instances, containing the decision-making situation, action, and utility of decisions. As decision makers interact with a dynamic task, they recognize a situation according to its similarity to past instances, adapt their judgment strategies from heuristic-based to instance-based, and refine the accumulated knowledge according to feedback on the result of their actions. The IBLT's learning mechanisms have been implemented in an ACT-R cognitive model. Through a series of experiments, this paper shows how the IBLT's learning mechanisms closely approximate the relative trend magnitude and performance of human data. Although the cognitive model is bounded within the context of a dynamic task, the IBLT is a general theory of decision making applicable to other dynamic environments.
Notes: The goal of this article is to explore different learning theories which are relevant to DDM.

Important aspects of learning include learning the knowledge base (declarative knowledge), recognition (ability to identify familiar versus unfamiliar stimuli), strategies (adaptive production systems), and evaluation functions (ability to assess alternatives). The authors argue that these theories are relevant for DDM even though they may not have been studied in that context.

The authors note the concept of satisficing as a strategy, and also note that the level of satisfaction considered "enough" will depend on the time remaining to make a decision. How the decision maker determines when to intervene is also highly dependent on learning. Feedback is also important, but is often not adequate in DDM.

It appears from this article that the link between heuristics, pattern recognition and cue integration are not clear in the literature – in some cases, it appears as though heuristics rely on pattern recognition and cue integration as the situation must be recognized as relevant for a particular heuristic; in other discussions, it appears as though heuristics are thought of as a strategy if no pattern is recognized.

Simulation experiments are compared to human data to try to uncover the cognitive processes underlying performance in DDM. Learning processes investigated include random choice of strategies, learning instances, recognition-based retrieval, adaptive strategies, necessity level, and feedback updates. Inexperienced decision makers appear to act like the random alternative selection simulation. Over time, expertise develops and humans use task cues to determine relevant strategies and use these to select responses. The model which best fits the learning trend of humans is one which starts random, then incorporates knowledge about time, then retrieves similar instances and blends them to produce an estimate of the best response, and the incorporation of a criterion which will limit the time to make a decision. The model with feedback mechanisms performed better than the humans, so the model without feedback was more accurate at representing human performance.

This article mentions many aspects of learning theories which are relevant for cue integration and pattern recognition including the use of chunks and templates to represent information. The authors also link heuristics and pattern recognition by stating that heuristics are determined by the recognition of familiar patterns of information. The authors also relate cue integration to expertise, saying that experts search for information in the environment much more selectively than novices.

This article contains interesting information about possible patterns of learning and learning types which are applicable to learning in DDM. There is contradictory information provided about the relationship between our four topics of interest. The application of a simulation to learning in DDM is interesting. The focus of this article is more on determining what people do, but it could also be used to infer information about how DDM could be trained.

CAN BE USED TO SUPPORT INVESTIGATING: HEURISTICS, CUE INTEGRATION, AND/OR PATTERN RECOGNITION>

To be used? INCLUDE IF RELEVANT

29. Title: The effects of team leader feedback on situation assessment in distributed anti-air warfare teams
Author(s): Gough, M. J.
Source: Dissertation submitted to the Naval Postgraduate School, Monterey, CA.

Year: 1992
Abstract: Situation assessment is the first step in the Command and Control Process. In naval tactical teams, it has become more critical even as it has become more difficult. Part of the Navy's attempt to address this issue is the Tactical Decision Making Under Stress (TADMUS) program. Under TADMUS, the Situation Assessment In Naval Teams (SAINT) experiment was run at NPS in December, 1991. This thesis describes the SAINT experiment and uses data collected during the experiment to study the effects of team leader feedback on situation assessment in distributed air defense teams. The emphasis of study is on performance, (error rate and pattern), subjective workload, and communication rates. Findings include: feedback of the leader's current assessment lowers explicit coordination; feedback does not affect subjective workload; feedback increases error rates, and may affect error patterns. Evidence of feedback causing confirmatory bias was also found, but more research in this area is recommended.
Notes: The author discusses the problem of anti-air warfare; the navy is now often expected to act in littoral environments which require faster response times and make for more critical errors; the navy is more accustomed to blue-water engagements. This writeup is based on the result of an experiment from the TADMUS (Tactical Decision Making Under Stress) project which examined decision making in the context of anti-air warfare. A participant acting as a Tactical Action Officer (TAO) had to integrate information provided by sensor operators and make a hostility determination about a contact. Feedback about the current assessment of the TAO was given to subordinates in the "feedback" condition; this feedback was produced by the participant playing the role of the TAO and not manipulated in the experiment. An interesting finding related to training was that giving feedback increased perceived workload, instead of lowering it as predicted (although this difference was not statistically significant). There was also no clear relationship between feedback and error rate; in fact, in some conditions there was an increase in errors with feedback. Feedback appears to increase confidence so that people are willing to make faster decisions on less evidence, meaning that error rates increase even as confidence in the decisions increase. In other words, feedback appears to add to confirmatory bias. This article investigates DDM under stress, and provides interesting information about the possible relationships between leader feedback and the effect of some biases such as the confirmation bias. The experiment is also an example of cue integration and pattern recognition, as the TAO has to integrate information from several sources and then make a decision about whether the pattern is more consistent with hostile or not hostile contacts.
CAN BE USED TO SUPPORT INVESTIGATING: HEURISTICS, BIASES, CUE INTEGRATION, AND/OR PATTERN RECOGNITION
To be used? INCLUDE IF RELEVANT

30. Title: Computational cognitive modeling of adaptive choice behavior in a dynamic decision paradigm
Author(s): Gray, W. D.
Source: Report prepared for the Air Force Office of Scientific Research, AFOSR Report number

F49620-03-1-0143.
Year: 2006
Abstract: In this project, we braided together three strands of research to study how interface design and decision strategies interact to affect adaptive choice behavior in a dynamic decision paradigm. In the first strand are computational models of dynamic decision-making built within a well-recognized cognitive architecture, ACT-R. Our second strand is composed of the decades-plus research efforts that show that people adopt decision-making strategies that tradeoff effectiveness for efficiency. Of particular importance is work showing that the way in which information is presented and how decision aids are constructed may unintentionally influence the decision strategies adopted. The third strand is work from our own lab showing the influence of hard and soft constraints on routine interactive behavior. This work suggests that the cognitive system works locally to optimize non-deliberate choices but that the sum of such locally optimized choices may be far from an optimized global outcome. These strands are braided together in Argus Prime: a simulated task environment of a radar operator's task that was designed to study the interaction between the sometimes conflicting top-down and bottom-up demands.
Notes: This is a review of a program of research being carried out – there is not much information here beyond a very brief description of the goals of research and some approaches. There are a few references given that may prove useful.
CAN BE USED TO SUPPORT INVESTIGATING: Nothing
To be used? DO NOT INCLUDE – but examine for references that may prove useful

31. Title: Judgement and Decision making in dynamic tasks
Author(s): Hammond, K.
Source: Report prepared for the United States Army Research Institute for the Behavioral and Social Sciences, ARI Report No. 88-81.
Year: 1988
Abstract: A theory of task conditions is presented on the ground that such a theory is a prerequisite for studying dynamic decision making. The principal features of the theory are (a) a task-cognition inducement principal, (b) a distinction drawn between surface and depth characteristics of tasks, and (c) a task continuum index. Also presented is a theory of cognition in dynamic tasks, the main features of which are (a) a cognitive continuum index set in parallel with the task continuum index, and (b) a description of the role of pattern seeking and functional-relation seeking in dynamic tasks. The practical consequences for both designers and operators are indicated.
Notes: The author describes all features within a theory of task systems and a theory of cognition and relates them to dynamic tasks and cognition. As elements within the task change cognitive conditions change. One change may be the cognitive approach to problem solving between rational, intuition, or the combination.

Pattern seeking is induced by displays of info that provide a high degree of perceptual organization (visual, auditory, etc) or that provide high degrees of conceptual organization (time dependent events), or circumstances that require the subject to produce a coherent explanation of his/her judgement that events will, have, or are occurring. Seeking functional relations are induced with opposite conditions (e.g., not perceptually, conceptually organized, not demanding immediate coherent explanations), that require description and prediction of amounts of variables. The author argues there are different types of templates used in pattern seeking and functional-relation seeking that help to minimize the cognitive workload when making a decision about multiple information cues. Concludes that the theoretical framework shown in the paper argues that the explanation of cognition in dynamic tasks should begin with a detailed examination of task systems. Changes in cognition induced by changes in the properties of task systems – provides some insight as to how the nature of the task affects cognition. This presents the idea that as tasks change, how people cognitively process decisions within that task may change. Thus DDM in different types of tasks may use different approaches. We may need to clarify this, which tasks we want to examine further to understand more about DDM processes. The article may be useful in exploring 2 types of processes suggested to be required in cue integration and how information is processed as required for DDM. A lot of discussion that is not related to DDM or cognitive challenges etc. is in this article. Provides a good theory as to how one should start to examine the cognition as it relates to DDM.
CAN BE USED TO SUPPORT INVESTIGATING: General cognition, pattern recognition.
To be used? INCLUDE IF RELEVANT

32. Title: Exploring the entrepreneurial mindset: Feedback and adaptive decision-making
Author(s): Haynie, J. M. & Shepherd, D. A.
Source: Manuscript prepared at Syracuse University
Year: 2007
Abstract: The ability to sense and adapt to uncertainty may characterize a critical entrepreneurial and organizational resource. We investigate the roles that metacognition and feedback-type play in facilitating cognitive adaptability: the ability to inform and adapt a previously learned decision heuristic given a dynamic task environment. Across four, inter-related conjoint experiments we capture and decompose more than 10,000 "entrepreneurial decisions" nested within 217 individuals, and test hypotheses positioned to assess the concomitant roles of metacognition and feedback-type in the decision-making process. Our findings suggest that metacognitive awareness and cognitive-based feedback are positively related to effective adaptation given a dynamic task environment, and also that metacognitively aware individuals use cognitive-type feedback more effectively than individuals less metacognitively aware.
Notes:

Authors describe an experiment to determine the effects of cognitive (i.e., instruction about the underlying relationships between variables) versus performance (i.e., feedback about overall decision quality only) feedback on performance in a dynamic environment. They hypothesized that cognitive feedback would be more effective in performance than performance feedback; as well, metacognitive awareness would moderate the relationship, with participants with more metacognitive awareness benefitting more from cognitive feedback than participants with less metacognitive awareness. Both hypotheses were supported. Note that although the authors talk about decision making in a dynamic environment, it does not appear as though their experience actually creates one – especially since their own decisions do not appear to affect the decisions they have to make. However, it is likely that the findings are generalizable to DDM. The article does focus on learning; specifically, what kinds of feedback (cognitive versus performance) impact the quality of decision making and how feedback interacts with metacognitive awareness to affect decision making. Interestingly, the authors mention evidence that metacognitive ability can be taught. This indicates that it should be trained, particularly in DDM environments where cognitive feedback is available as people high in metacognition make better use of feedback. Using metacognition may be loosely considered a heuristic during decision making. As well, the article mentions that a major part of decision making in complex environments is understanding how to incorporate information, which is similar to the cue integration problem.
CAN BE USED TO SUPPORT INVESTIGATING: HEURISTICS, CUE INTEGRATION (with broad definitions).
To be used? INCLUDE IF RELEVANT

33. Title: Human Factors Influencing Decision Making
Author(s): Jacobs, P. A. & Gaver, D. P.
Source: Naval Postgraduate School, Monterey, California. NPS-OR-98-003
Year: 1998
Abstract: This report supplies references and comments on literature that identifies human factors influencing decision making, particularly military decision making. The literature has been classified as follows (the classes are not mutually exclusive): features of human information processing; decision making models which are not mathematical models but rather are descriptive; non- personality factors influencing decision making; national characteristics influencing decision making; personality factors influencing decision making; decision making in a military organization. The decision maker is influenced by many factors both internal to the decision maker and external to him/her. The environmental context in which a decision is made makes it difficult to associate personality traits with specific decision making behavior. Internal factors that influence decision making include limited information processing and memory capabilities. These limitations can result in biases in processing information such as anchoring (undue weight for evidence supporting (the initial hypothesis) or recency (undue weight on more recent evidence). The limitations can also result in decision making heuristics. Training and experience can lessen the

effects of limited information processing and memory capabilities. The first part of the report is a summary of the findings of the literature survey. This is followed by detailed endnotes concerning the references.
Notes: Essentially a listing of loosely annotated references, this report draws attention to many pieces of literature about the decision maker and factors that affect decision making. Five specific articles were noted as being relevant in the current project: - Payne, J.W., Bettman, J.R., and Johnson, E.J. (1992). Behavioural decision research: a constructive processing perspective. Annual Review of Psychology, 43, pp 87-131. About task complexity: "A hypothesis is that the more complex a decision problem the more people will use simplifying heuristics". - Shanteau, J., and Stewart, T.R. (1992). Why study expert decision making? Some historical perspectives and comments. Organizational Behaviour and Human Decision Processes, 52, pp 95-106. - Einhorn, H.J., and Hogarth, R.M. (1981). Behavioural decision theory: processes of judgement and choice. Annual Review of Psychology, 32, pp 53-88 - Davies, D.R. and Parasuraman, R. (1982). The Psychology of Vigilance. London: Academic: "High levels of perceived stress, negative affect, or framing-induced anticipated potential losses may have little or marginal effect on simple perceptual tasks performance but appear to have a potentially debilitating effect on developing and using more cognitively complex decision making strategies. Individuals experiencing these influences appear to do more than simply tunnel their focus and disproportionately weight negative information. Framing effects may do more than merely change focus; they can be so disruptive as to be detrimental to the incorporation and adoption of new information into dynamic decision making strategies." - Cohen, M.S. and Freeman, J.T. (1996). Metarecognition in time-stressed decision making: recognizing, critiquing and correcting. Human Factors, 38, pp 206-219. These articles were subsequently reviewed and selected articles were added to the list of articles to be reviewed.
CAN BE USED TO SUPPORT INVESTIGATING NONE OF THE SPECIFIED AREAS.
To be used? DO NOT INCLUDE.

34. Title: Cognitive Biases in Military Decision Making
Author(s): Janser, J.
Source: Paper presented to the U.S. Army War College, PA
Year: 2007
Abstract: This paper examines the applicability of recent findings from behavioral economics to military decision making. Army manuals concerning the Military Decision Making Process mention general biases in decision making but do not mention specific biases or specific mechanisms for mitigating bias. Recent research has shed light on specific biases to include: overconfidence, insensitivity to

sample size, availability, illusionary correlation, retrievability of instances, escalation, break even, snake bite, fear of regret, and the confirmation bias. The Military Decision Making Process has a long and distinguished record of success. However, there are also examples of military failures due to cognitive bias. These failures include Lee at Gettysburg and McClellan in Virginia. Private industry and some elements of the Army have started to account for these deficiencies through various practices including coaching and training. This paper concludes that the Military Decision Making Process as described in FM 5-0 is deficient in not fully recognizing and accounting for cognitive biases. The process can be improved through several steps. These steps include not only research, education, and training, but also procedural and organizational changes.

Notes:

The author identifies a systematic process for complex decision making, Military Decision Making Process (MDMP), trained in the US army; unfortunately time is required to follow through each step, which is not commonly available. This method also requires particular conditions: an accurately defined mission, accurately assessed enemy and friendly situations, all alternatives identified, all criteria identified, all criteria accurately weighted, each COA (course of action) accurately assessed, and a correctly made decision based on a COA comparison. Biases affect all of these conditions. This paper examines a number of different biases and attempts to mitigate biases in military decision making by explicitly identifying the different types and threats they pose.

The conclusions based on these elements include that weaknesses of human decision making are exacerbated at the most critical times such as in combat operations when fatigue, stress, time limitations and incomplete information are high. Psychologist coaching and training has worked in the industrial sector to help improve performance. Suggestions are provided that include incorporating further research, education, procedural changes, training, and organizational changes that may improve the influence of biases when making decisions using the MDMP.

The author provides descriptions of biases such as overconfidence, insensitivity to sample size, availability, illusionary correlation, retrievability of instances, escalation, break even, snakebite, fear of regret, and the confirmation bias.

The author believes that educating decision makers on the nature and type of biases would improve military decision making performance significantly. This idea refuted in more recent studies.

This report is useful for gaining an understanding of the different types of decision making biases though little on their application, or ideas that might be useful for training.

The decision making technique is helpful in understanding the approach military decision makers may use, though clearly the use of this planned strategy is an ideal , and expected to be rarely used in the constraints and limitations of DDM. Training focused on how best to shorten the MDMP process may correspond with the use of heuristics, or other improvements to DDM.

The MDMP include 7 parts:

5) receipt of mission
6) mission analysis
7) course of action (COA) development
8) COA analysis
9) COA comparison
10) COA approval
11) Orders production

CAN BE USED TO SUPPORT INVESTIGATING: BIASES
To be used? FOR CONSIDERATION

35. Title: Patterns of Error: Perceptual and Cognitive Bias in Intelligence Analysis and Decision-Making
Author(s): Jones, L.
Source: Master's thesis presented at the Naval Postgraduate School, Monterey, California.
Year: 2005
Abstract: The history of man is written in choice. Whether simple or complex, on a whim or after labored consideration, inflamed by passion or calculated coolly, the judgments that we form and the choices that we make define who we are and what we want for the future. Yet most of us have little or no conscious awareness of the inner workings of our own minds. We often choose without understanding or accounting for the perceptions, intuitions, and inferences that underlie our decisions. So how do people make decisions? How do we cope with the volume and complexity of information in our environment without being overwhelmed? How do we use our senses to select and process this information, and how do we organize, contextualize, and conceptualize it once it reaches our brains? How do we form judgments about the value of a specific piece of information or about the likelihood of a particular event or outcome? And what are the factors that lead us astray? The search for answers to these questions is more than academic; understanding the fundamentals of perception and cognition is critical to effective analysis and decision-making. For those involved in national security, and particularly for those involved in the collection and analysis of national intelligence, an appreciation of the intricacies of these processes has real-world implications. As evidenced by the dramatic intelligence failures of the last few years, and in particular by the mistaken assessment concerning Iraqi weapons of mass destruction, understanding how we arrive at judgments and decisions can be quite literally a matter of life and death.
Notes: This thesis takes a brief walk from the classic notions of rational decision making into bounded rationality and finally links to the development of theories of heuristics and biases. Attention is paid to the limited knowledge and computational ability of decision makers, the creation of mental models and the existence of sophisticated cognitive processes. Specific aspects of perception are discussed (e.g. perception is unavoidable and it constructs rather that records reality; perception is influenced by expectations and situational context; exposure to blurred/ambiguous stimuli interferes with perception accuracy) as well as three aspects of cognition (a. mental models are unavoidable, b. mental models are quick to form but resistant to change, c. new information is assimilated to existing content). The representative, availability and anchoring heuristics are then introduced. Finally, various intelligence conclusions about Iraq later proven incorrect are discussed and causes of these errors related to perception, decision making, heuristics and biases are postulated. The author provides a well written progress of decision making research linking together the identification of specific cognitive limitations to the development of new theories in decision making. There is no specific discussion about dynamic decision making.

CAN BE USED TO SUPPORT INVESTIGATING CUES, PATTERN RECOGNITION, HEURISTICS, AND BIASES – BUT IS NOT DDM.
To be used? FOR CONSIDERATION

36. Title: The potential for social contextual and group biases in team decision-making: Biases, conditions and psychological mechanisms.
Author(s): Jones, P. E. & Roelofsma, P. H. M. P.
Source: Ergonomics, 43, 1129-1152.
Year: 2000
Abstract:
This paper provides a critical review of social contextual and group biases that are relevant to team decision-making in command and control situations. This paper provides an insight into the potential that these types of biases have to affect the decision-making of such teams. The biases considered are false consensus, groupthink, group polarization, and group escalation of commitment. For each bias, the following questions are addressed: What is the descriptive nature of the bias? What factors induce the bias? What psychological mechanisms underlie the bias? What is the relevance of the bias to command and control teams? The analysis suggests that these biases have a strong potential to affect team decisions. Consistent with the nature of team decision-making in command and control situations, all of the biases tend to be associated with those decisions that are important or novel and are promoted by time pressure and high levels of uncertainty. A concept unifying these biases is that of the shared mental model, but whereas false consensus emanates from social projection tendencies, the rest emanate from social influence factors. The authors also discuss the "tricky" distinction between teams and groups and propose a revised definition for command and control team.
Notes:
Four specific group biases are discussed in detail: false consensus effect, groupthink, group polarization, and group escalation of commitment. These biases are discussed in the context of command and control teams. For each, there is a description of the bias, results of studies of the bias, possible underlying psychological mechanisms, and a discussion about the implications of the bias specifically for command and control teams. False consensus effect is the "tendency to overestimate the degree of similarity between self and others" (p 1134). A strong and well documented bias, possible causes include the availability heuristic and/or a desire for social support. Problems with information estimation, distortion and assumptions about others (e.g. a commander's intentions) are conceivable issues in command and control groups. Groupthink is the ability for poor decisions to come from otherwise capable and well intentioned groups. This effect tends to arise when groups are highly driven by unanimity, a condition relevant to hierarchical military teams with little to no outside help. Group polarization is the intensification of a position on an issue held by the majority and group escalation of commitment is the tendency to support an action path even though it is failing. Though not explicitly discussed, it would be reasonable to assume that DDM could inherently be a part of command and control decision making. Thus, if there is interest in *group* biases this article

would be worthwhile.
CAN BE USED TO SUPPORT INVESTIGATING BIASES.
To be used? INCLUDE IF RELEVANT

37. Title: Exemplar effects in categorization and multiple-cue judgment

Author(s): Juslin, P., Olsson, H., & Olsson, A.-C.

Source: Journal of Experimental Psychology: General, 132, 133-156

Year: 2003

Abstract:

Categorization and multiple-cue judgment are similar tasks, but the influential models in the two areas are different in terms of the computations, processes, and neural substrates that they imply. In categorization, exemplar memory is often emphasized, whereas multiple-cue judgment generally is interpreted in terms of integration of Cues that have been abstracted in training. In 3 experiments the authors investigated whether these conclusions derive from genuine differences in the processes or are accidental to the different research methods. The results revealed large individual differences and a shift from exemplar memory to cue abstraction when the criterion is changed from a binary to a continuous variable, especially for a probabilistic criterion. People appear to switch between qualitatively distinct processes in the 2 tasks.

Notes:

Discusses the similarity and differences between two tasks or research paradigms; categorization and multiple-cue judgment. These appear to basically be the same task, because participants are asked to interpret cues and make inferences based on those cues. The main differences are that in categorization the inference is a determination of which of a small number of categories the stimulus belongs to (usually only 2 categories), whereas the judgment in multiple-cue judgment is a continuous variable (e.g., the probability of precipitation given weather information). Because the two areas of research have arrived at very different conclusions about each of the tasks, the authors have decided to examine whether there is actually evidence that these are different processes, or the same process examined in different ways.

Exemplars are usually incorporated into currently successful models of categorization. Exemplars represent specific examples provided by experience which are then applied to new cases. If the exemplar is similar enough to the new case, then inferences are made about the new case based on the old one. Multiple-cue judgments, on the other hand, are typically represented via multiple-linear regression models, which assume that people integrate information about cues according to a linear additive rule (i.e., information from cues are added, and optimal weights are also remembered and used in making the judgment). These theories would call on different neural processes and make different predictions based on the role of memory.

Based on three experiments, the authors conclude that differences between the categorization and multiple-cue judgment tasks actually produce qualitatively different cognitive processes. Mental cue abstraction is favoured when a continuous criterion is used, whereas a binary criterion tends to be interpreted via exemplar memory. The authors indicate that this might be due to more informative feedback in the continuous judgment paradigm. The authors propose that if feedback is sufficient to infer relations between cues and the criterion used for judgment, then multiple cue abstraction will be favoured. With insufficient feedback rules cannot be inferred, so exemplar memory is the most appropriate guide. The authors did also notice a large individual difference in the preference for exemplar memory or cue abstraction.

In DDM, there are likely many instances of each type of decision; as well, many decisions could probably be imagined as both. For example, a judgment could involve "friend or foe?" – is someone an enemy or not, which would be a categorization judgment. The same type of judgment could be seen as a multiple-cue judgment, if someone were trying to infer the probability of danger.

From the results of this experiment, it seems as though the level of feedback in different important tasks should be examined to determine whether cue abstraction is a viable method of making decisions. Although cue abstraction might be a preferred method of making decisions, there may not be adequate information for it to be used effectively. As well, as there are individual differences in decision-making preference between the two methods, perhaps people should be trained in their natural style, or they may otherwise not perform optimally, especially under stress and time pressure.

CAN BE USED TO SUPPORT INVESTIGATING: CUE INTEGRATION AND PATTERN RECOGNITION

To be used? INCLUDE IF RELEVANT

38. Title: Determinants of linear judgment: A meta-analysis of lens model studies

Author(s): Karelaia, N. & Hogarth, R. M.

Source: Psychological Bulletin, 134, 404-426

Year: 2008

Abstract:

The mathematical representation of E. Brunswik's (1952) lens model has been used extensively to study human judgment and provides a unique opportunity to conduct a meta-analysis of studies that covers roughly 5 decades. Specifically, the authors analyzed statistics of the "lens model equation" (L. R. Tucker, 1964) associated with 249 different task environments obtained from 86 articles. On average, fairly high levels of judgmental achievement were found, and people were seen to be capable of achieving similar levels of cognitive performance in noisy and predictable environments. Further, the effects of task characteristics that influence judgment (numbers and types of cues, inter-cue redundancy, function forms and cue weights in the ecology, laboratory versus field studies, and experience with the task) were identified and estimated. A detailed analysis of learning studies revealed that the most effective form of feedback was information about the task. The authors also analyzed empirically under what conditions the application of bootstrapping— or replacing judges by their linear models—is advantageous. Finally, the authors note shortcomings of the kinds of studies conducted to date, limitations in the lens model methodology, and possibilities for future research.

Notes:

One of the authors' goals is to assess how task characteristics influence judgment, using the lens model as a decision-making strategy. Lens model studies are aggregated and a meta-analysis performed to determine factors that influence decision-making performance.

The lens model, in brief, is a model of judgement which states that human judgment is a linear function of a set of cues. The cues are weighted, and an error term is added which represents an error term. The environmental criterion (i.e., the actual value of what the judgment is about; what the human judgment is aiming to estimate) is represented the same way. The difference between the two values represents the error in judgment. In addition, this is a probabilistic model, as the cues are never perfectly valid or reliable.

The authors cite evidence that environments and judges are generally well modeled by linear functions (such as the lens model).

There is a discussion of bootstrapping; this means replacing a person's judgment with their strategy (i.e., calculating their linear formula and then applying this formula). Some studies show an advantage of bootstrapping in several domains including clinical decision making and employment interviews. Bootstrapping is better when the judge has valid linear knowledge and the environment is predictable.

In their meta-analysis the authors examined different factors which influence judgment performance. Their findings include:

- Number of cues: Judgment accuracy was highest with two cues, and as the number of cues increased accuracy decreased
- Cue redundancy: Judgment accuracy decreased with cue redundancy
- Function form: Judgment accuracy was higher with linear functions between cues than nonlinear functions
- Cue weights: Judgment accuracy was higher with equally weighted cues
- Laboratory vs. field studies: When controlling for other factors (e.g., number of cues), accuracy was equivalent
- Abstract vs. concrete: Performance was better with concrete compared to abstract tasks
- Expertise: expertise was negatively related to judgement accuracy, but positively related to judgmental consistency; however, learning did occur over multiple trials

The authors offer three major conclusions (p. 420):

- People are capable of achieving high levels of judgmental performance
- People learn best from feedback that instructs them about the characteristics of the tasks they face
- The inconsistency that people exhibit in making judgments is sufficient for models of their judgments to be more accurate than they are themselves

This is a useful article which explains the lens model and provides a review of most of the relevant literature related to human judgment. While not explicitly including a DDM context, the findings should be extendable to that domain with a consideration of the impact of DDM characteristics (e.g., time pressure, constantly changing information). A discussion of cognitive and training challenges should address the bootstrapping vs. human judgment issue; that is, when should a statistical model be used instead of a human decision maker? The dichotomy between expertise hurting performance and task training improving performance should also be addressed.

CAN BE USED TO SUPPORT INVESTIGATING: CUE INTEGRATION

To be used? INCLUDE IF RELEVANT

39. Title: Sense Making: Biases and support solutions
Author(s): Kerstholt, J. H.
Source: In Tactical Decision Making and Situation Awareness for Defence Against Terrorism (3-1 – 3-8). Meeting Proceedings RTO-MP-SCI-174. Neuilly-sur-Seine, France: RTO.
Year: 2006
Abstract: Analysts base their hypotheses concerning terrorist groups and terrorist attacks generally on large amounts of information, which may be uncertain, inconsistent and/or incomplete. The present paper addresses the questions of how an analyst constructs a causal scenario, which biases occur and how this intelligence process can be supported. In the first part a model is presented that describes the subsequent steps in the analysis process. Several biases may negatively affect the quality of the analysis process. These are described in the second part of the paper. Subsequently, an experiment is described in which we manipulated the presentation of information: in a time line, a relation scheme or unstructured. In general, the results show that people generate fewer motives in the unstructured task condition and that expectations increase probability assessment of related hypotheses. The last part of the paper presents support concepts which aid analysts to critically think about their own analysis: To what extent is a hypothesis anchored in the data at hand, how to explain data not in line with the hypothesis and which other hypotheses would be possible as well? Supporting analysts in critical thinking not only improves situation awareness and decision making, but allows for better communication with others as well.
Notes: This paper looks at the questions related to how analysts construct causal scenario on which intelligence is based in the context of terrorists groups and terrorist attacks. Biases that occur in this process are discussed. An experiment is then described that manipulates the presentation of information (time line format, relation scheme, or unstructured). General results show that people generate fewer crime motives when required to use unstructured data. The author describes how data can be processed, filtered, and used to build a comprehensive analysis or support for a hypothesis (depending on if you start with data and process bottom-up or start with a story and process top-down). The language used and the experience of the analyst can influence their interpretations in the form of biases, as can analysts' expectations. The author concludes that awareness alone is not sufficient to eliminate biased interpretation. An experiment was conducted that presented information (crime scene /scenario data) in different forms 1) in a timeline fashion; 2) as data related to relationships of the victim; and 3) in an unstructured form. Results showed fewer motives were devised by participants in the unstructured task condition compared with the other two. Possible explanations include that there is an increased workload required to arrange data in the unstructured condition. The author proposes that meta-cognitive strategies enable critical evaluation of data. Discussions focus on the analyst's ability to make judgements and the biases they encounter. This review discusses data processing and potential biases, however not in the context of DDM. Some information, maybe useful in transferring to DDM such as the fact that time is required and cognitive resources are required to make appropriate assessments when data is presented in an unstructured way. A model of the intelligence process is presented (from Pirollo & Card, 2005)

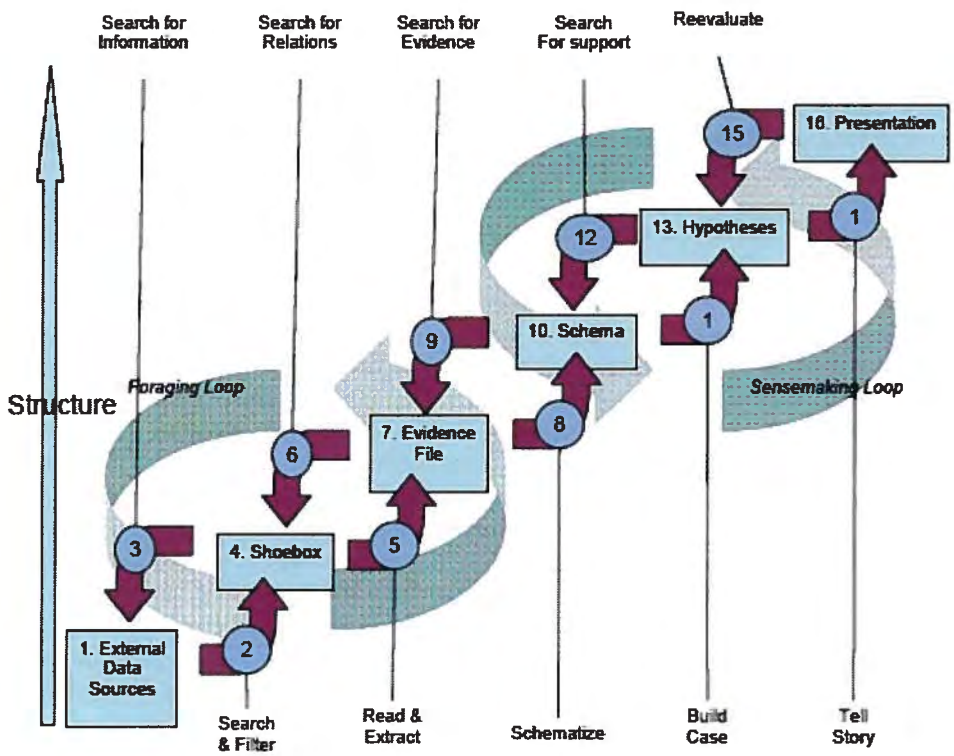

Figure 6: Model of Intelligence Process (Pirollo & Card, 2005)

Understanding how scheme are developed may demonstrate the challenges within the development and use of heuristics and biases. The confirmation bias is the main point of discussion. It is pointed out that when workload increases, confirmation bias is more likely to occur. Similarly, the way the information is presented, the type of language used, and our own past experiences can greatly influence our interpretations in the forms of biases.

The authors state the main threats to biased information processing are the influence of prior beliefs, perspectives, and their mindset. They suggest that increasing the amount of information would help judges make a better assessment of the situation. This however is not agreed upon by all, for example those who advocate "less is more" theory (that people make better decisions with less information). They also suggest that in-depth analysis of critical assumptions underlying their hypothesis may help the to properly evaluate and weight information. This idea is not relevant to DDM as time constraints are an issue.

An important counter argument is to note that they conclude simple awareness of a bias is not enough to eliminate its effects.

CAN BE USED TO SUPPORT INVESTIGATING: BIASES

To be used? FOR CONSIDERATION

40. Title: The effect of the time restrictions on information search and information integration in a dynamic task environment

Author(s): Kerstholt, J. H. & Willems, P.
Source: TNO Defence Research, Report No. IZF 1993 B-8
Year: 1993
Abstract: To date, research has mainly used deadlines in static task environments to investigate the effects of time pressure on decision making behaviour. A dynamic environment, on the other hand, changes over time and time pressure may result when time is not used efficiently and negative consequences are rapidly increasing. An experiment was carried out to investigate the effects of time horizon on decision making behaviour in a dynamic task environment. Subjects were required to monitor the fitness level of a running athlete, depicted graphically on a computer screen, and to apply a proper treatment whenever necessary. Information could be requested on symptoms, which were probabilistically related to underlying causes. The time horizon was manipulated by the speed at which the athlete's fitness level changed over time. Restrictions in time horizon did not affect the amount and type of information that was requested, and the diagnoses became even better. Nevertheless, more athletes collapsed in the more restricted time horizon conditions. In the short time horizon conditions subjects furthermore employed a more cautious decision strategy. As far as the use of time was concerned it was found that information processing was speeded up, but subjects waited relatively the same amount of time before they started to intervene with the system.
Notes: This article details a study looking at the macro effects of time pressure on a dynamic attendant/athlete scenario. Subjects monitored the simulated athlete's fitness level through a graph on a computer screen which ranged from 0 (poor) to 100 (good). When the athlete's performance started to drop, they could request different types of additional information (e.g. tired?) and perform specific actions (e.g. rest) to try to improve the athlete's condition. Three different time horizons (i.e. slopes) for the changing graph were used (long, moderate and short). Results showed that subjects requested the same amount and type of information, no matter the time horizon. Subjects performed fewer actions in the more restricted time horizon and made less errors. This occurred as subjects tended to act more (i.e. apply treatment) when there was more time, and judge more (i.e. ask for more information) when there was less time. This result is based on the fact that in this particular scenario that a wrong action was five times the cost of information request. In other scenarios where actions are less "expensive" the authors anticipate that the subjects will maintain their action-oriented strategy even under high time pressure. Though, realistically, in most DDM environments action errors will be costly. This study provides some interesting evidence about the effects of time constraints on decision making. The study seemed to err on the side of having enough time rather than pushing subjects into real time constraints thus the role of mental underload is suggested as a contributing factor to the poor low time pressure results. In general, the article does not talk specifically about cues or pattern recognition, but their use can be inferred.
CAN BE USED TO SUPPORT INVESTIGATING CUES and PATTERN RECOGNITION.
To be used? FOR CONSIDERATION

41. Title: Supporting perception in the service of dynamic decision making

HUMANSYSTEMS Incorporated

Author(s): Kirlik, A., Walker, N., Fisk, A. D., & Nagel, K.
Source: Human Factors, 38, 288-299
Year: 1996

Abstract:

Skilled performers in complex environments rely heavily on heuristic strategies to cope with the time pressure and complexity of dynamic tasks. We suggest that the use of task simplification strategies based largely on perception and pattern recognition is fundamental to the novice-expert shift in dynamic decision making. We therefore suggest that interface training interventions should support the development of highly effective and robust heuristic strategies, rather than the development of more abstract, cognitively intensive strategies. A pair of empirical studies are presented that investigated the benefits of training interventions aimed at supporting perceptual and pattern-recognitional activities in dynamic environments. Results suggest that the acquisition of skilled performance in dynamic environments can be accelerated by supporting perceptual activities in the service of dynamic decision making. Implications of these results for training, aiding, and interface design are discussed.

Notes:

Kirlik et al. investigate particular coping strategies in dynamic decision making tasks. Using heuristics may be a common coping strategy. The use of these heuristic rely largely on perceptual information and pattern recognition, and less so on abstract, analytic strategies.

Serious errors have been demonstrated when people rely on inappropriate perceptual information.

The authors conduct two studies to look at the use of perceptual information in DDM. The first focuses on comparing participant performance between those who have received training which focuses on their abstract rule learning and visual enhancements as techniques to support DDM. Two factors were examined: rule learning vs. no rule learning and visual enhancement display vs. no enhancement display.

Learning was conducted by having participants read, memorize, and recall all rules. Information on the digital display was enhanced by highlighting the critical information on the screen. The context of this task was a simulated football game where the participants had to identify when the receiver came open.

Results showed that the two groups that received rule-based training were equally accurate; however, the group that received rule-based training and visual enhancement training was superior in response speed. The group that had rule training and no visual enhancement had the slowest response speed. This shows the importance of having training on both the abstract knowledge components and on concrete aspects of the task. The time difference may be due to the heavier reliance on abstract reasoning versus perceptual and pattern-recognition heuristics.

The second study investigated the use of the visual display enhancement in support of DDM behaviour. In this study the information highlighted pertained to the critical properties and relationships in the DDM task. The context of this task was a war where participants commanded a set of UAVs (Unmanned Arial Vehicles) in an offensive attack. This study included a manipulation of the level of workload.

Results showed that two display groups performed equally well under normal conditions; however, in the increased workload conditions participants who had the perceptual enhanced display had better performance, indicating they acquired more robust skills than those using the baseline display.

Conclusions were that perceptual augmentation 1) facilitates decision-making skill acquisition; 2) results in more robust performance in situations with higher workloads; and 3) its removal creates no degradation of skilled performance.

The authors investigate decision making using complex, dynamic environments, though in a laboratory-based setting they are able to control identifying information and highlight valid cues which is not practical nor feasible in real-life DDM.

Challenges in DDM when using heuristics enter at the level of perception and discrimination. Identifying critical information within the environment, and having rule-based training can improve DDM performance, decision times, and robust DDM skills. How this can be done, is through enhancement of valid perceptual information that has direct relationship to the criterion. This may not be feasible in uncertain DDM tasks where there is no overseer who knows what information is relevant to the decisions that need to be made (e.g., military wargaming).

This article shed light on the feasibility of developing training principles to "foster efficient access to, and use of, critical perceptual information in DDM environment".

Training in DDM then may focus on helping participants to gain skills in identifying information, as it is shown in this study after taking away perceptual augmentation (highlighting the information) the performance is not diminished. How transferable this may be to dissimilar situations may be in question.

Using rule-based training, basically to train a particular type of heuristics or "short-cuts", in decision making were shown to improve DDM performance.

CAN BE USED TO SUPPORT INVESTIGATING: HEURISTICS, CUE INTEGRATION

To be used? INCLUDE IF RELEVANT

42. Title: Recognition-Primed Decision Strategies

Author(s): Klein, G. & Crandall, B.

Source: Report prepared for the United States Army Research Institute for the Behavioral and Social Sciences, ARI Report No. 96-36.

Year: 1996

Abstract:

We describe activities conducted during a 3-year basic research contract that has its goal extension and examination of a Recognition-Primed Decision (RPD) model of decision making. The RPD model describes a decision strategy commonly employed by proficient personnel called upon to make decisions in operational settings by high risk, time constraints, and ambiguous or incomplete information. Work was organized around three areas of interest: (1) evaluation of the relative strengths and weaknesses of the RPD strategy, (2) examination of the nature of simulation assessment in C2 environments, and (3) exploration of techniques for supporting decision making in operational environments that are consistent with the RPD framework. The report contains descriptions of nine studies (seven empirical, two analytical) conducted to examine these issues. One important outcome of the research has been to advance understanding of the role of mental simulation in decision making. We have developed a detailed mode of mental simulation, including an account of how mental simulation serves as a source of power for a variety of cognitive functions. Work performed under this contract has helped to establish naturalistic decision making

as an important and unique perspective.
Notes: Klein is a critical player in the natural decision making domain, his major contribution being the Recognition Primed Decision Making (RPDM) model. Detailing the creation process of the RPDM model, this report guides the reader through initial and subsequent phases of RPDM models. This model challenges the application of classic decision making models by experts under complex, ambiguous and time constrained scenarios. This model was developed after observing various expert decision makers in their operational environments (e.g. fire fighters). Many of these environments require dynamic decision making. This report details the development of the RPDM model and expands it from its initial version. Biases due to heuristics (of which experts are just as susceptible as novices) are also discussed in relation to the RPDM model. The RPDM model suggests that experienced decision makers are able "to recognize the essential characteristics of a situation" (p. 2) to identify goals and possible action paths. Possible actions are then evaluated serially until a satisfactory – but not necessarily optimal – course of action is determined. Three cases of RPDM are included, which vary in the level of mental evaluation or simulation that the course of action is subjected to. The mental simulation process is discussed in detail followed by the situation assessment process. Cue integration, pattern recognition and heuristics play distinct roles in these processes. Limitations of the RPD model are included in the report (e.g. mental simulation requires a great deal of attention and can be easily interrupted). Looking at the errors that arise in using this model, the authors found the most common errors were a lack of experience, lack of critical information or faulty mental simulation. No errors due to poor estimation, improper weighting of criteria or confirmation bias were found; though, mental simulation is believed to lead to overconfidence. Training in mental simulation is suggested as a feasible way to improve decision making. Finally, team decision making processes are discussed, and the Advance Team Decision Making model is laid out. Though this article uses the terms "cue integration" and "pattern recognition" rarely, there are clear links to these concepts using more general terms throughout various stages of the RPDM model. This is a highly relevant report to the goals of this project.
CAN BE USED TO SUPPORT INVESTIGATING CUES, PATTERN RECOGNITION, HEURISTICS, AND BIASES.
To be used? INCLUDE IF RELEVANT

43. Title: Fast, frugal, and fit: Simple heuristics for paired comparison
Author(s): Martignon, L. & Hoffrage, U.
Source: Theory and Decision, 52, 29-71.
Year: 2002
Abstract: This article provides an overview of recent results on lexicographic, linear, and Bayesian models for paired comparison from a cognitive psychology perspective. Within each class, the authors distinguish subclasses according to the computational complexity required for parameter setting. They identify the optimal model in each class, where optimality is defined with respect to

performance when fitting known data. Although not optimal when fitting data, simple models can be astonishingly accurate when generalizing to new data. A simple heuristic belonging to the class of lexicographic models is Take The Best (G. Gigerenzer & D. G. Goldstein, 1996). It is more robust than other lexicographic strategies which use complex procedures to establish a cue hierarchy. In fact, it is robust due to its simplicity, not despite it. Similarly, Take The Best looks up only a fraction of the information that linear and Bayesian models require; yet it achieves performance comparable to that of models which integrate information. Due to its simplicity, frugality, and accuracy, Take The Best is a plausible candidate for a psychological model in the tradition of bounded rationality. The authors review empirical evidence showing the descriptive validity of fast and frugal heuristics.
Notes: The authors review models for paired comparison (e.g., choosing 1 of 2 options) from several domains. Computational complexity is one of the key variables examined; the authors report that a simple heuristic, "take the best" (also talked about by Bryant and probably others) is extremely simple yet surprisingly robust, and adequately allows the application of knowledge to new data. The authors cite Gigerenzer, and the idea that the mind has a toolbox of fast, frugal, and accurate heuristics which can be used in different situations. The authors discuss three types of models; lexographic, linear, and Baysian. The lexicographic approach for determining which of a pair of options has a higher criterion value involves examining the cues in a predetermined order. The "take the best" involves examining only the most valid cue; other options are to order cues either optimally or based on some aspect of conditional validity. Note that these models may stop examining cues once a particular level of information has been obtained. Another approach is a linear approach; in this approach, all cues are examined. What sets this approach apart is its emphasis on cue weights, and there are different strategies for determining these weights. Baysian networks compare the cue profiles and determine which option is more likely to exceed the criterion (which has a larger criterion value). This is closest to pattern matching. The authors cite evidence that people tend to make inferences consistent with lexographic models (e.g., take the best) when time is short or it is otherwise costly to examine many cues. Take the best may also be the basis of different heuristics and biases, including the hindsight bias and overconfidence. Note that these decisions are not DDM, but considering the requirements in DDM that decision making be fast and accurate, it is likely that strategies such as take the best would be useful in DDM. Understanding that these strategies are useful, and how they can fall short, would be beneficial in designing training programs for DDM.
CAN BE USED TO SUPPORT INVESTIGATING: HEURISTICS, BIASES, CUE INTEGRATION
To be used? INCLUDE IF RELEVANT

44. Title: On the role of recognition in decision making
Author(s): Newell, B. R. & Shanks, D. R.

Source: Journal of Experimental Psychology: Learning, Memory, and Cognition 30, 923-935
Year: 2004
Abstract: In 2 experiments, the authors sought to distinguish between the claim that recognition of an object is treated simply as a cue among others for the purposes of decision making in a cue-learning task from the claim that recognition is attributed a special status with fundamental, noncompensatory properties. Results of both experiments supported the former interpretation. When recognition had a high predictive validity, it was relied on (solely) by the majority of participants; however, when other cues in the environment had higher validity, recognition was ignored, and these other cues were used. The results provide insight into when, where, and why recognition is used in decision making and also question the elevated status assigned to recognition in some frameworks
Notes: The authors examine the influence of recognition –based information in a simple decision-making task. The focus of Experiment 1 was to investigate if recognition information (in this study a company-name cue) was used similarly to other cue information. Experiment 2 tested the notion (based on a statement by Goldstein and Gigerenzer, 2002) that recognition information, when presented, was used as a sole information source and people do not seek further information. Experiment 1: Used an investment scenario to investigate how recognition information was used in a decision-making task. Participants were presented with two companies in which they could invest. Some participants were able to see company names as information and buy advice from advisors. Three conditions were used. In all conditions participants received advice from 3 advisors on whether to invest in a particular company or not. The two conditions were: Recognition High (RH) where the company name had the highest validity (degree to which the cue predicts the outcome) and highest discrimination rate (proportion of occasions on which a cue has a different values for each alternative) making it the best source of information; Recognition-Low (RL) condition where the company name cue was the lease valid and had low discrimination; no recognition condition where the company name cue was replaced by advice from a advisor. Equations were presented that could be used to determine which strategies were used based on the payoff (results) achieved. The usefulness of each cue was rated and it was seen that within the RH condition the company name was recognized as being more useful than any of the advice. There were large individual differences in the amount of extra advice purchased. Results support the idea that recognition cues are treated in a similar way as other cues. The validity of the cues was the primary factor in determining if it would be used as the main information in the decision-making process. Experiment 2: The RL condition was used in Experiment 2 in order to answer the question: will participants learn to use advice cues, or does the use of recognition information have a :special status" that will override the temptation to search for and use additional information? Results indicate that the majority of participants still did purchase and followed additional information even when recognition information could be relied on solely. Participants may have regarded the recognition information as somewhat special as they tended to overestimate the

usefulness of recognizing the company name for making accurate decisions. The overall discussion reiterates the findings that recognition-information is treated similarly to other cue information, and that it may not be treated as uniquely as suggested, though participants often overestimated its usefulness. The authors discuss the findings and claims of the *noncompensatory* use of recognition information (simple recognition overrides alternatives to search for more information about there recognized object) as proposed by Goldstein & Gigerenzer, 2002. An idea is discussed in which one process gives rise to an automatic generation of familiarity when an object is recognized, and another process assesses the basis for the feeling of familiarity (Kahneman & Frederick, 2002). Not dynamic decision making, only simple decision-making tasks discussed and used in the experimentation. Within an investment type scenario, recognition cues may not be used in the same way as within other decision-making scenarios because it may be considered a domain in which multiple sources of information should be consulted prior to making a decision. This may be reflected in the large individual differences in the amount of extra advice purchased Recognition here is discussed as recognizing objects, not patterns or multiple pieces of information as we have defined it. The discussion about different theories of recognition may transfer to our definition of pattern recognition and could be useful to the current project, though keeping in mind that all approaches were discussed using simple decision tasks. Results would not be expected to transfer well to DDM.
CAN BE USED TO SUPPORT INVESTIGATING: PATTERN RECOGNITION, CUE INTEGRATION (some heuristics)
To be used? DO NOT USE.

45. Title: On the psychology of the recognition heuristic: Retrieval primacy as a key determinant of its use
Author(s): Pachur, T. & Hertwig, R.
Source: Journal of Experimental Psychology: Learning, Memory, and Cognition, 32, 983-1002.
Year: 2006
Abstract: The recognition heuristic is a prime example of a boundedly rational mind tool that rests on an evolved capacity, recognition, and exploits environmental structures. When originally proposed, it was conjectured that no other probabilistic cue reverses the recognition-based inference (D. G. Goldstein & G. Gigerenzer, 2002). More recent studies challenged this view and gave rise to the argument that recognition enters inferences just like any other probabilistic cue. By linking research on the heuristic with research on recognition memory, the authors argue that the retrieval of recognition information is not tantamount to the retrieval of other probabilistic cues. Specifically, the retrieval of subjective recognition precedes that of an objective probabilistic cue and occurs at little to no cognitive cost. This retrieval primacy gives rise to 2 predictions, both of which have been empirically supported: Inferences in line with the recognition heuristic (a) are made faster than inferences inconsistent with it and (b) are more prevalent under time pressure.

Suspension of the heuristic, in contrast, requires additional time, and direct knowledge of the criterion variable, if available, can trigger such suspension.
Notes: The recognition heuristic refers to the strategy of assuming that if one of two objects is recognized and the other is not, then the recognized object has the higher value with respect to the criterion (e.g., is more frequent, more famous, etc.). The authors attempt to address the question of why humans have so many resources allocated to lower-level tasks such as perception and so many more limitations on higher-level cognitive functions. The authors argue that complex and effective cognition can arise from co-opting more simple functions, and that appropriate behaviour is the result of selecting the right tools for the right situation, rather than having a single, large-capacity cognitive processor. The authors review the debate about whether the recognition heuristic is compensatory or noncompensatory – that is, whether recognition information is integrated with other information when making a judgment (compensatory), or whether it overrides other information and drives the judgment (noncompensatory). The authors review and critique arguments for each view, and argue that recognition information is special. The authors review previous research and provide evidence that there are situations in which the recognition heuristic is not used: when recognition knowledge did not evolve naturally (e.g., it was derived through an experiment) or when recognition is traced to a source that is not relevant for the criterion variable, and recognition is used as a heuristic only when a direct solution fails. This is an important indication that people are not insensitive to conditions in which the heuristic may not be appropriate, and do not use it if they have other options which would be more accurate. The authors clarify the difference between the recognition and availability heuristics: the availability heuristic involves retrieving instances of the target event, whereas the recognition heuristic involves merely recognizing the name of the event category. This appears to be an article with well-performed experiments, although some of their data representation seems peculiar (e.g., they divided RTs into percentiles and compared differences within those percentiles, which I haven't seen done before and is not justified within the method). This article is very useful in exploring how heuristics may be used, how they might rest upon more "basic" perceptual or cognitive processes, and how they may be "turned off" when they are not appropriate. Note is also made of the strong individual differences in heuristic use. This article provides a useful example for exploring heuristic use, and could be broadened to the DDM context (e.g., they examine the use of the heuristic with increased time pressure).
CAN BE USED TO SUPPORT INVESTIGATING: HEURISTICS, BIASES, (some CUE INTEGRATION)
To be used? INCLUDE IF RELEVANT

46. Title: Behavioural Decision Research: A constructive processing perspective
Author(s): Payne, J. W., Bettman, J. R., & Johnson, E. J.
Source: Annual Review of Psychology, 43, 87-131
Year: 1992

Abstract: n/a
Notes: Behavioural Decision Research is an interdisciplinary approach that explores cognitive mechanisms involved in decision making in economics and other complex fields. One axiom of it is that preferences and beliefs are often constructed, and are dependent not just on the task, but also the decision maker and the context. These factors lead to a great deal of variance in responses, going against common sense which would suggest that good decisions are consistent. When decision makers face problems where one choice is transparently dominant, consistent responses are found; however, dominance can be easily masked. Framing effects, information presentation, time pressure, scenario complexity, number of alternatives, incentives, uncertainty or ambiguity, experience and affect decision outcomes. These and other factors are discussed. Additional cognitive challenges discussed include: evaluating the utilities of future consequences, the neglect of potentially relevant problem information, ignoring values when they are difficult to estimate, "general tendency to accept problems as given and the segregation of the decision problem at hand from its broader context" (p 116). Attributes and their cognitive structure are discussed, providing potential insights into cue integration. For example, "people actively restructure decision problems until one alternative is seen to be dominant… The restructuring may involve such operations as collapsing two or more attributes into a more comprehensive one, emphasizing an attribute or adding new attributes to the problem representation that will bolster one alternative" (p 101). Congruence between the format of the information and judgement required is also suggested to affect cue integration. Though how this congruence is determined was not clearly described. Briefly, a continuum of decision making from intuitive to rational is detailed. Interestingly, the authors suggest that errors will be fewer but larger after rational analysis compared to intuitive judgments. Some of the studies discussed do not relate directly to DDM scenarios, but in general the article is looking at decision making under complex and uncertain circumstances.
CAN BE USED TO SUPPORT INVESTIGATING CUES, HEURISTICS, and BIASES.
To be used? INCLUDE IF RELEVANT

47. Title: A model of human decision making in complex systems and its use for design of system control strategies
Author(s): Rasmussen, J. & Lind, M.
Source: Paper presented at the American Control Conference, June 14-16, Arlington, Virginia, U.S.A.
Year: 1982
Abstract: The paper describes a model of operators' decision making in complex system control, based on studies of event reports and performance in control rooms. This study shows how operators base their decisions on knowledge of system properties at different levels of abstraction depending on

their perception of the system's immediate control requirements. These levels correspond to the abstraction hierarchy including system purpose, functions, and physical details, which is generally used to describe a formal design process. In emergency situations the task of the operator is to design a suitable control strategy for systems recovery, and the control systems designer should provide a man-machine interface, supporting the operator in identification of his task and in communication with the system at the level of abstraction corresponding to the immediate control requirement. A formalized representation of system properties in a multilevel flow model is described to provide a basis for an integrated control system design.
Notes: It is pointed out that there are many subjective aspects to a decision (e.g., information known, preferences, and circumstances) within an unfamiliar situation. It may not be realistic to model the detail flow of information processes within this type of decision. Rasmussen & Lind identify the states of knowledge within a generic decision. Decision Ladder structures are formulated. Shortcuts can be used to skip steps within the DL to make quicker decisions. Skill-based, rule-based, and knowledge-based human performance is examined and how they demonstrate different levels of automated or analysis-based action. The authors propose that system control requires systematic state identification (identification of any changes or deviations from a specified norm) by means of "logical inferences based on measurable variables." [*comment: not possible in military DDM*] Decision tasks to operators and computers are considered. Overall control structure and task allocations are developed in terms of an abstract-flow typology. The decision ladder structure identifies knowledge states and stages within a decision. Relating these to cognitive tasks within each state/stage could be a method to identify types of challenges. Dynamic decisions would need to be the focus- this may require some additional interpretation and inferences. The "leaps" and "shunts" that act as bypasses from one rung on the ladder to another use heuristics to skip stages in the decision making process. The authors identify the difficulty in identifying information flow within new, unfamiliar situations in a decision making task. Control of a situation is derived from the relationships between the actual state, desired state (or changes of states) and required actions. In addition if we include, external factors that influence changes within a state, or changes to information this can be representative of DDM. The background of the decision maker may influence the conceptual framework of the decisions. The authors further propose that experts are able to identify required information in analyzing the situation, and ignore irrelevant information, or determine if information is relevant after it is examined, and switch to an effective strategy of information searching when required. To do this one must have a high capacity for remembering required information. This could be a challenge – particularly under high stress.
CAN BE USED TO SUPPORT INVESTIGATING: general DM structure, HEURISTICS
To be used? INCLUDE IF RELEVANT

48. Title: Improving Analysis: Dealing with Information Processing Errors

Author(s): Rodgers, R. S.
Source: Report prepared for the Air Force Research Laboratory, Report No. AFB OH 45433-7604.
Year: 2006
Abstract: Intelligence analysts and mental health clinicians have some aspects of their respective crafts in common. In many cases both have to make predictions about future behavior. Findings from the clinical literature were used to make the point that humans, in general, are not particularly skilled at combining various pieces of information in order to make predictions, and by extension, intelligence analysts suffer the same fate. Understanding the problems involved in information processing can help us develop methods and tools to assist in mitigating three broad cognitive errors: (a) the tendency to see patterns where none exist, (b) the tendency to seek confirmatory evidence, and (c) the use of preconceived biases.
Notes: Focusing on similarities between the tasks of clinicians and intelligence analysts, the author looks at tasks with poor performance and potential underlying causes. For example, neither group appears to perform prediction tasks effectively, they also have limited perception abilities, seek confirmatory evidence and show preconceived biases. It is noted that although decision maker may strive for accurate results, 100% correctness is not a realistic goal in either workspace. The body of the report looks at classic heuristics (availability, overconfidence, representativeness, anchoring and adjustment, and hindsight) and details scenarios where these biases can manifest themselves. Finally, decision making recommendations are included. This article provides a succinct review of various classical heuristics and how they impact the work of both clinicians and intelligence analysts. The extent to which either of these environments involve dynamic decision making is subjective. This article does not offer much in terms of insights into biases or DDM.
CAN BE USED TO SUPPORT INVESTIGATING HEURISTICS AND BIASES.
To be used? FOR CONSIDERATION

49. Title: Bias in planning and explanation-based learning
Author(s): Rosenbloom, P. S., Lee, S., & Unruh, A.
Source: Report prepared for the Defense Advanced Research Projects Agency, Arlington, VA, ARPA Report No. AD-A269 608.
Year: 1993
Abstract: Biases enable systems to make decisions in realms where all legitimate sources of knowledge have been exhausted. This article investigates the application of biases to the problem of planning, and how this can indirectly induce effective biases in a learning process that is based on planner's experiences. Experimental results from six biased planners, plus several more complex multimethod planners, indicate complex tradeoffs among planner completeness, planning efficiency, and length. Learning also varies in complex ways among these planners, with one notable result being the ease with which some planners learn rules that can generalize from one

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object to many; a phenomenon known in machine learning as generalization to N.
Notes: The authors are interested in how bias is used to make planning decisions when there is inadequate information, and how these biases affect learning. According to the authors, bias determines the answer, but search control is what determines the efficiency with which the answer is found. Biases are beneficial in several ways, including: • Biases can help organize and understand concepts • Can reduce computational effort (reduce number of COAs to be examined) • Can create effective bias on learning Absolute biases are biases which reduce the problem space; these biases must be used properly or they will result in faulty answers. Relative biases simply create preferences in solutions, they don't eliminate solutions (part of the problem space). Experiments were performed using a software program (SOAR) to investigate these benefits. It is unknown whether people actually use these biases, as no human data was provided, and there is not enough discussion of how people would or could actually use these biases. However, the discussion of how biases can be useful in creating plans and learning the planning process could add to this project.
CAN BE USED TO SUPPORT INVESTIGATING: BIASES
To be used? FOR CONSIDERATION

50. Title: Inferring rule-based strategies in dynamic judgment tasks: Towards a noncompensatory formulation of the lens model
Author(s): Rothrock, L. & Kirlik, A.
Source: Report prepared for the Naval Training Systems Center, Orlando, FL. Report No. AHFD-03-5/NTSC-03-1.
Year: 2003
Abstract: Performers in time-stressed, information-rich tasks develop rule-based, simplification strategies to cope with the severe cognitive demands imposed by judgment and decision making. Linear regression modeling, proven useful for describing judgment in a wide range of static tasks, may provide misleading accounts of these heuristics. That approach assumes cue-weighting and cue-integration are well described by compensatory strategies. In contrast, evidence suggests that heuristic strategies in dynamic tasks may instead reflect rule-based, noncompensatory cue usage. We therefore present a technique, called Genetics-Based Policy Capturing (GBPC), for inferring noncompensatory, rule-based heuristics from judgment data, as an alternative to regression. In GBPC, rule-base representation and search uses a genetic algorithm, and fitting the model to data uses multi-objective optimization to maximize fit on three dimensions: a) completeness (all human judgments are represented); b) specificity (maximal concreteness); and c) parsimony (no unnecessary rules are used). GBPC is illustrated using data from the highest and lowest scoring participants in a simulated dynamic, combat information center (CIC) task. GBPC inferred rule-

bases for these two performers that shed light on both skill and error. We compare the GBPC results with regression-based Lens Modeling of the same data set, and discuss how the GBPC results allowed us to interpret the high scoring performer's highly significant use of unmodeled knowledge (C=1) revealed by Lens Model analysis. The GBPC findings also allow us to now interpret a similarly high use of unmodeled knowledge (C=1) in a previously published Lens Model analysis of a different data set collected in the same experimental task.

Notes:

The authors attempted to provide feedback to participants by gathering behavioural data and inferring what heuristics people were using to make decisions. Thus, feedback can be tailored to the individual. The authors argue that experienced decision makers deal with time pressure, uncertainty, and large amounts of information by developing heuristics which they use to oversimplify the information. Like most heuristics, these will sometimes be appropriate and sometimes lead to bias.

The lens model is a way of determining how someone is making decisions (i.e., what criteria they are using and how the criteria are weighted); however, applying this model requires that the judgment environment is adequately modeled (appropriate judgment criteria can either be objectively measured or estimated by SMEs).

The authors discuss compensatory and noncompensatory strategies. Compensatory strategies are strategies which weigh information and opposite values can cancel each other out. As well, the presence of a cue with high value (weight) can compensate for an absence of cues with low weight (e.g., evidence for the decision can still be considered strong). Noncompensatory strategies are strategies where this does not happen (the "trading off" property doesn't apply; e.g., every cue must have a high value for evidence for the decision to be considered strong). The authors note that many heuristics are noncompensatory strategies. The authors note that noncompensatory strategies often yield very good results compared to more cognitively demanding compensatory strategies. The authors discuss a strategy for inferring the noncompensatory heuristics which are actually used.

Note that the authors attempt to provide empirical evidence for their theory; however, the participants used were nonexperts. As the theory is supposed to apply to experts who develop their own heuristics, this is probably not appropriate (although it says they were trained on 15 30-minute scenarios, it is unclear whether they reached expert level).

One proposed heuristic is to actively search for diagnostic information. This implies the ability to learn what information is diagnostic, and that it is available.

This is an article that is somewhat relevant to DDM; based on the amount of information available, the constantly changing nature of that information, and the time pressure that is often on people to act in the DDM environment, it is reasonable to suggest that heuristics are used to manage performance in DDM. To use this method to understand behaviour in the DDM, performance would have to be monitored in realistic situations, but the "ground truth" would have to be known in order to interpret the results. As well, it is uncertain the benefit that can be gained from providing people feedback about their own heuristics, as this was not examined in this paper.

CAN BE USED TO SUPPORT INVESTIGATING: HEURISTICS, BIASES, AND CUE INTEGRATION

To be used? FOR CONSIDERATION

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51. Title: Using prospect theory to investigate decision-making bias within an information security context.	
Author(s): Schroeder, N. J.	
Source: Master's thesis submitted to the Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio.	
Year: 2005	

Abstract:

Information security is an issue that has increased in importance over the past decade. In this time both practitioner and academic circles have researched and developed practices and process to more effectively handle information security. Even with growth in these areas there has been little research conducted into how decision makers actually behave. This is problematic because decision makers in the Department of Defense have been observed exhibiting risk seeking behavior when making information security decisions that seemingly violate accepted norms. There are presently no models in the literature that provide sufficient insight into this phenomenon. This study used Prospect Theory as a framework to develop a survey in an effort to obtain insight into how decision makers actually behave while making information security decisions. The survey was distributed to Majors in the Air Force who represented likely future information security decision makers. The results of the study were mixed, showing that prospect theory had only limited explanatory power in this context. The most significant finding showed that negatively connotated decision frames result in significantly more risk seeking behavior. These results provide insight into decision maker behavior and highlight the fact that there are biases in information security decision making.

Notes:

This thesis concerns itself with the security of information and how decision makers are handling it. Prospect Theory developed by Kahneman and Tversky is used as a framework to obtain insight into this behaviour using a survey based data collection. Note that a limitation to using survey-based data gathers insight only to the intentional behaviour rather than actual behaviour.

The first step in the research agenda is to better understand the gap between CA's (Certification Authority) and DAA's (Designated Approving Authority) in the DITSCAP (Department of Defence Information Technology Security Certification and Accreditation Process). Following this the research will investigate if there are biases in DM that influence a decision maker in such an information-security context.

A literature review was conducted to gather background on information security processes in businesses. The review showed that research has lead to the development of a prescriptive approach for managing information security and provided evidence that demonstrates how to make decisions in this area. Research efforts have also explored end-user issues (e.g., implementation of technology and security behaviour).

Previous research on decision making is also explored in attempts to identify a method, or combination of methods that may best suit the context of information security. Research looking into decision making under risk also within this scope (usually pertaining to a business context) is examined. It is concluded that there is minimal prior research into managerial decision making in the information-security context.

Based on the literature, Prospect theory was chosen as a model that meets the criteria for DM under risk and DM made independent of dispositional and organizational factors.

The survey study conducted assessed 11 hypotheses that investigated the use of Prospect Theory to model decision making behaviour in information security. The results were mixed. Some hypothesis were supported, others were not.

A summary of the results shows that negatively-connotated decision frames result in significantly more risk-seeking behaviour.

*H1: supported: DM are significantly risk averse in general information-security gain domains.

H2: not supported: conclusions are that DM are indifferent in risk behaviour in general information-security loss domains.

H3: not supported: conclusions are that risk seeking behaviour is similar between decision makers in operationally- and security-framed loss domains.

*H4: supported: decision makers are more risk seeking in negatively-framed information-security outcomes than in the similar positively-framed outcomes.

H5a: not supported: conclusions are that decision makers did not behave in a more risk-averse way when there was a shift in the reference point into a loss domain.

H5b: not supported: conclusions are similar to above, decision makers did not behave more averse to risk for significant gains when there was a shift in the reference point into a loss domain.

*H6: supported: decision makers tend to give a greater decision weight to operations outcome when the situation presents both security and operations.

*H7a: supported: Compared with operational decision makers, non-operational decision makers are significantly more averse to risk in information security gain domains.

H7b: not supported: conclusions explore an issue similar to the above, though in a loss domain; Compared with operational decision makers, non-operational decision makers are significantly more averse to risk in information security loss domains.

H7c: not supported: the hypothesis explored investigates if in an information security context operational decision makers prefer operational outcomes to security outcomes compared with non-operational decision makers.

*H7d: supported: When the reference point is shifted negatively, operational decision makers are significantly more risk avers in information security related gain domains compared with non-operational decision makers.

H7e: not supported: Similar to H7d within a loss domain; When the reference point is shifted negatively, operational decision makers are significantly more risk avers in information security related loss domains compared with non-operational decision makers.

(all * hypothesis were supported).

Conclusions from these results imply that external factors (those outside the control of the decision maker) can influence a bias in decision makers' risk behaviour (based on H4). It is also suggested that, in general (based on H6), decision makers tend to lace a greater weight on particular pieces of the situation (or pieces of information, e.g., operational versus security). The authors showed evidence that Prospect Theory provided insight that can be used as a starting point for future research, though does not provide a perfect model for describing decision making under risk in information security contexts.

Limitations to this study include:

- Minimal time allotted during class time for participants to complete.

- The study measures intentions rather than actual behaviour. - Scenarios used were at the researcher's discretion and wording may not adequately represent the domain. This may explain some reasons why some Ho were not confirmed. - Questions were general, and more specific situations may provide better insight. Situations explored in this review and study were not dynamic. The author focuses on the description of background information and of Prospect Theory and how it can be implemented to DM in an information security context. Literature on DM is reviewed and the findings are shared. The literature review presented a few helpful insights into challenges in normative reasoning examples: - Older people take more risk to avoid loss and less risk for gains. - Bias: A "fads and fashion" effect- the more excitement around a particular industry, the more likely managers were to underestimate risk. - Expectations interfere with risk in DM. When people expect their choices to be reviewed by others decision makers become more unwilling to take risks. - People in a higher position of authority take more risk. Societal pressure to "make things happen" and take good risks to do so. - People are often unaware of the influence of priming to risk related issues affect their level of risk seeking behaviour. Overall conclusions show that people can be biased to external factors that are out of their control, and that DMs may give preference, or over weighting, to some information rather than others influencing their final decision.
CAN BE USED TO SUPPORT INVESTIGATING: BIASES
To be used? FOR CONSIDERATION

52. Title: A framework for military decision making under risks
Author(s): Schultz, J. V.
Source: Thesis presented at the School of Advanced Airpower Studies, Air University, Maxwell Air Force Base, Alabama.
Year: 1996
Abstract: This is a study of the applicability of prospect theory to military decision making. Prospect theory posits that the decision maker's reference point determines the domain in which he makes a decision. If the domain is one of losses, the decision maker will tend to be risk seeking, if gains, then he will be risk averse. The author proposes that if prospect theory's propositions are correct, then it may be possible for the decision maker, by assessing his own domain, to make better informed decisions. One implication of this study is that if he can do the same for a subordinate or for an enemy, he may be better able to predict their responses in a given situation. The project's goal is to develop a framework for assessing risk propensity. It does this by first describing the military decision making process and concluding that it is a rational decision making process. Next,

the paper describes prospect theory and matches the key aspects of the theory with the military decision making process. Next, it proposes a framework for assessing risk propensity. The theory is tested in a case study of General Dwight D. Eisenhower's 1944 decision to launch Operation Market Garden. This decision is analyzed in terms of Graham Allison's three models for decision making and prospect theory to determine which model or theory seems to provide the best explanations for Eisenhower's decision. The last chapter applies the risk propensity framework to the case study to test if it can predict risk propensity and its impact on decision making. The author concludes that prospect theory's propositions are valid and that this theory provides a prescriptive way to consider decision making under risk. Although prospect theory does not predict the choice a decision maker will select, it should reveal his bias toward a risky or over cautious solution.

Notes:

The author is interested in understanding how military commanders make decisions about risk. Prospect theory is used, and this theory indicates that the perspective of the decision maker influences risk decisions; that is, is the decision maker thinking about possible gains or losses?

The author discusses the expected utility model, which assumes that preference ordering is constant, whereas actual behaviour contradicts this assumption. Prospect theory allows for differences in preferences depending on the loss or gain focus of the decision maker. An example of this is when people are more likely to engage in risky behaviour in a game if they are losing than if they are winning (e.g., pulling the goalie in hockey).

Outcomes are thought of as changes from a reference point – the reference point is itself changed by how the decision maker evaluates and edits the decision problem – editing and framing the problem are dynamic processes, which can change the assessment of a particular outcome from a gain to a loss, and vice versa. Thinking of an outcome as a gain or a loss will influence the assessment of risk, which will in turn influence decisions.

Prospect theory does not allow for the evaluation of a decision as good or bad; however, it does allow a decision maker to assess whether they are likely to make a risk averse or risk seeking decision by determining the reference point and domain for the decision which are based on framing effects. This can be used in a metacognitive fashion to mitigate overly risk´seeking or risk adverse behaviours and possibly mitigate this bias.

Several limitations of prospect theory are noted, including the possibility of individual differences, influences of other variables such as uncertainty can influence judgments, and the fact that reference points can change during decision making, making it difficult to determine whether a risk assessment will be stable.

Prospect theory, and therefore this paper, is relevant to DDM in several ways. It highlights the need to think of decision making outside of the rational "box", but demonstrates in a relatively concrete way a specific method for applying to particular situations. How risk influences decision making can be thought of as a heuristic, a bias, and also a way in which cues are integrated. Investigating prospect theory has the potential for providing ways of mitigating the tendency to inappropriately make risky and risk adverse decisions.

CAN BE USED TO SUPPORT INVESTIGATING: HEURISTICS, BIASES, CUE INTEGRATION

To be used? INCLUDE IF RELEVANT

53. Title: Affect, risk, and decision making
Author(s): Slovic, P., Peters, E., Finucane, M. L., & MacGregor, D. G.
Source: Health Psychology, 24, S35-S40.
Year: 2005
Abstract: Risk is perceived and acted on in 2 fundamental ways. Risk as feelings refers to individuals' fast, instinctive, and intuitive reactions to danger. Risk as analysis brings logic, reason, and scientific deliberation to bear on risk management. Reliance on risk as feelings is described with ""the affect heuristic."" The authors trace the development of this heuristic across a variety of research paths. The authors also discuss some of the important practical implications resulting from ways that this heuristic impacts how people perceive and evaluate risk, and, more generally, how it influences all human decision making. Finally, some important implications of the affect heuristic for communication and decision making pertaining to cancer prevention and treatment are briefly discussed.
Notes: The authors compare and contrast the assessment of risk based on emotions or logic. They portray the use of emotional assessments of risk as the "affect heuristic". The emotional assessment of risk is assumed to be much older in terms of human evolution, and the use of logic a relatively recent means of "boosting" risk assessment. Affective risk assessment is quick and occurs outside of consciousness, and seems to heavily influence further information processing and judgment. The authors note the finding that risk and benefit tend to be positively correlated in the world, but people perceive them as negatively correlated. This inverse perceived relationship tends to be linked to the strength of positive or negative affect associated with that activity. If affect is positive toward an activity, the risk is judged as low and benefit as high; the opposite occurs if affect is negative (risk is judged as high and benefit as low). If the risk or benefit is manipulated in someone's perception, the other is affected as well. The authors note that the framing of information also influences decisions – probabilities tend to be assessed as less probable when discussed in terms of percentages rather than absolute numbers (e.g., 20% is judged as less likely than 20 out of 100). This can profoundly affect decision making with respect to probabilistic judgment. This article is relevant to the use of heuristics and subsequent biases, both in risk assessment and other decision making contexts. There is no explicit link to DDM contexts, but the heuristic would likely be at play in any type of situation.
CAN BE USED TO SUPPORT INVESTIGATING: HEURISTICS, BIASES
To be used? INCLUDE IF RELEVANT

54. Title: Validation of the recognition-primed decision model and the roles of common-sense strategies in an adversarial environment
Author(s): Soh, B. K.
Source: Dissertation submitted to Virginia Polytechnic Institute and State University, Blacksburg, VA.

Year: 2007
Abstract: This dissertation set out to understand the decision processes used by decision makers in adversarial environment by setting up an adversarial decision making microworld, as an experimental platform, using a Real Time Strategy (RTS) game called Rise of Nations (RON). The specific objectives of this dissertation were: (1) Contribute to the validation of Recognition-Primed Decision (RPD) model in a simulated adversarial environment; (2) Explore the roles of common-sense strategies in decision making in the adversarial environment; and (3) Test the effectiveness of training recommendations based on the RPD model. Three related experimental studies were setup to investigate each of the objectives. Study 1 found that RPD model was partly valid where RPD processes were prevalently used but other decision processes were also important in an adversarial environment. A new decision model (ConPAD model) was proposed to capture the nature of decision making in the adversarial environment. It was also found that cognitive abilities might have some effects on the types of decision processes used by the decision makers. Study 2 found that common-sense strategies were prevalent in the adversarial environment where the participants were able to use all but one of the warfare related strategies extracted from literature without teaching them. The strategy familiarization training was not found to significantly improve decision making but showed that common-sense strategies were prevalent and simple familiarization training was not sufficient to produce differences in strategy usage and performances from the novice participants. Study 3 also found that RPD based training (cue-recognition and decision skill training) were not significant in producing better performance although subjective feedback found such training to be useful. However, the participants with RPD based training conditions were able to perform on the same level as the expert participants bridging the gap between novices and experts. Based on the findings, it was recommended that decision training should involve not just RPD based training, but comparisons of attributes as well. A more interactive training combining common-sense strategies, cue-recognition and decision skill training might be more useful. More theoretical experimentation would be required to validate the new decision model proposed in this dissertation.
Notes: RPD is characteristic of experts, and involves choosing one most likely alternative and COA. In contrast, novices tend to concurrently assess several options and not necessarily know which critical factors are most useful in making decisions. The author also notes that individual differences in attention and working memory relates to the RPD model. The article relates schemas to RPD – schemas are how expert knowledge may be structured. Strategies are considered to be the sequence of actions taken when a schema is instantiated, and these strategies may be thought of as heuristics. "Commonsense strategies" are described as heuristics which are extended to day-to-day reasoning and decision making; another way of describing them is as rules of thumb in daily reasoning (e.g., "divide and conquer"). What makes a good decision maker is the ability to identify the right strategy for the situation. Discusses the importance of experience for pattern recognition, and the practical reasons for using simulation (compressed time frame). Discusses training for decision making in natural tasks (p. 25) from previous work, and variables which should be considered when choosing training methods (e.g., workload, time stress). Goals for training should also be considered, including recognizing patterns, making perceptual discriminations, detecting anomalies (p. 30). Note that research validating these methods was only subjective in nature, as it was considered impossible to actually

judge the appropriateness of decisions.

The author of this dissertation chose a laboratory approach to provide greater control over the task and participants, and (presumably) to allow more empirical evaluation of decisions made. Participants were gathered from the community, and people with real-time strategy game experience were considered experts, rather than people with experience with military decision making.

Evidence suggests that people use multiple decision-making strategies, and experts often don't use RPD. There was also not a straightforward link between cognitive abilities and decision processes. It is an open question whether any participants actually reached the status of experts in the game, which could significantly affect the validity of the results.

Training participants in commonsense strategies did not improve performance. The actual strategies used tended to differ between groups, but there were a large number of strategies considered and family-wise error was not controlled for. One trend was that people familiarized with different strategies used more strategies; making people aware of strategies may provide some benefit as participants may see more options. It is also possible that large effects were not observed because the "common sense" strategies were just that; people were already aware of them and used them, and were at ceiling for strategy knowledge.

Two options for using the RPD model for training is to either train cue recognition or train decision-makers to critique their decisions and improve their decision making. No significant differences in level or type of training was found.

This dissertation provides an interesting discussion of types of training that could be useful in developing training to help decision makers, but evidence was inconclusive about which methods would be most useful. Understanding how "common sense" reasoning is applied in new domains is a useful one, but it is uncertain whether this is used in addition to heuristics developed by experts or more often by novices who have not created expert schemas.

CAN BE USED TO SUPPORT INVESTIGATING: HEURISTICS, BIASES, AND PATTERN RECOGNITION

To be used? INCLUDE IF RELEVANT

55. Title: Misperceptions of Feedback in Dynamic Decision Making

Author(s): Sterman, J. D.

Source: Organizational Behavior and Human Decision Processes, 43, 301-335.

Year: 1989

Abstract:

In recent years laboratory experiments have shed significant light on the behavior of economic agents in a variety of microeconomic and decision-theoretic contexts such as auction markets, portfolio choice, and preference elicitation. Despite the success of experimental techniques in the micro domain, there has been relatively little work linking the behavior of decision makers to the dynamics of larger organizations such as corporations, industries, or the macroeconomy. This paper presents a laboratory experiment in which subjects manage a simulated economy. Subjects must invest sufficient capital plant and equipment to satisfy demand. Subjects were given complete and perfect information regarding the structure of the simulated economy, the values of all variables,

and the past history of the system. Nevertheless, the overwhelming majority of the subjects generate significant and costly oscillations. A simple decision rule based on the anchoring and adjustment heuristic is shown to simulate the subjects' decisions quite well. Several distinct sources of the subjects' poor performance are identified and termed "misperceptions of feedback." The decision rule is related to various models of economic fluctuations; implications for experimental investigation of dynamic decision making in aggregate systems are explored.

Notes:

The author conducted a study that ran participants through a DDM experiment and then modeled their responses to determine what (if any) heuristics they seemed to be following. The system chosen for the experiment was called the multiplier-accelerator model of capital investment. Participants in this study included both students and economic professionals knowledgeable about economic and control theory. Despite only a single simple system input change, only 8% of the participants were able to re-establish equilibrium before the end of the simulation. Follow-on articles about this study have suggested the anchoring and adjustment heuristic is a good description of the rule modeled by the subjects.

One implication of the suggested response rule is a lack of consideration of feedback. Removing the multiplier feedback from the system, the response rule becomes locally rational. Thus, a number of specific causal factors that appear to be ignored by the subjects are discussed (misperception of time delays, misperceptions of feedbacks from decisions to the environment and a tendency to think in causal single strand series). Arguably, this shows a lack of pattern recognition on the part of the subjects.

No where in this study is there an exploration of the cues/information actually taken into account by the subjects or the salience of the different information categories. Thus, it would be interesting to see what (if any) effects a different, perhaps optimized, interface would have on the results.

CAN BE USED TO SUPPORT INVESTIGATING: CUE INTEGRATION, PATTERN RECOGNITION, HEURISTICS, and BIASES.

To be used? INCLUDE IF RELEVANT

56. Title: My Intuition Works, so Why Mess with this Decision Analysis Stuff

Author(s): Stonebraker, J. S.

Source: Report prepared for the Department of Mathematical Sciences, US Air Force Academy.

Year: 1990

Abstract:

This report describes possible shortcomings of unaided decision making and benefits of decision analysis. The premise of this report is that unaided decision making only works for simple decisions, but rarely suffices for complicated decision problems. Unaided decision making is a holistic approach using the decision maker's intuition and heuristics. Unaided decision making can result in biases and systematic errors. Decision analysis is a systematic process with the objective to provide insight and aid a decision maker in making better decisions by being consistent and logical. Decision analysis is a modelling process that quantifies uncertain information using probability theory and risk using utility theory. Decision analysis involves decomposing the decision problem into manageable pieces and then recombining the information as the expectation

of probabilities and utilities.
Notes: This report staunchly supports rational decision making and is critical of decision makers who follow their intuition. Referring to intuition as "holistic", common sense and heuristic decision making, the author prefers to decompose problems into smaller parts and analyse those subcomponents instead – calling this process Decision Analysis (DA). The four steps to this process are: formulate, evaluate, refine and decide. Citing many studies supporting the sub-optimal decision making that humans perform, little recommendation is given for decision making under scenarios with ambiguous and uncertain information. Further, though time is listed as a disadvantage of DA, optimal decision strategy solutions during time sensitive scenarios are not discussed. In general, the author is presenting a perspective with little supporting evidence against intuition. This viewpoint seems out of date given more recent research (e.g. Klein).
CANNOT BE USED TO SUPPORT INVESTIGATING ANY OF THE RELVANT TOPICS.
To be used? DO NOT INCLUDE

57. Title: The Decision Dilemma- Cognitive Bias
Author(s): Stormer, W. P.
Source: Paper presented to the U.S. Army War College, Carlisle Barracks, PA.
Year: 1991
Abstract: Military decision-making at the national level is a formidable task. The environment is ambiguous and constantly changing. Intelligence systems, as good as they are, will never provide perfect information. The stakes involved range from the loss of thousands of lives to the sovereignty of the nation. Faced with this difficult task, the military decision-maker often has to rely on intuitive processes to arrive at a final decision. One of the magnificent qualities of human beings is the ability to integrate a vast array of factors weighing on a situation and come up with a viable solution. This process involves a great degree of intuitive judgment. While there are many examples of great military decisions made substantially on the basis of intuition, there is also a down side to this phenomenon. Research has shown that there are cognitive biases which can adversely affect the decision-making process. This paper provides an analysis of these biases and offers practical suggestions on how to reduce their effects.
Notes: Some points made in this document include: The environment in which military decisions need to be made is very dynamic; Assessing different aspects of a situation/ environment are necessarily subjective; Decisions are often made using intuitive processes; Cognitive biases inevitably come into play within such a decision-making process; Decision makers are often unaware of biases and their effects on the decision process. The goal of the report is to provide military decision makers fundamental awareness of cognitive biases in the efforts to improve decision-making effectiveness. Decision makers operate within "bounded rationality" limited by time constraints, available funds,

imperfect information, memory limitations, etc. People also "satisfice" in decision-making processes, meaning that they seek a satisfactory solution rather than an optimum solution. The author suggests that understanding the biases, their root causes, and learning ways to reduce their influence will improve decision making, and thus this is the purpose of the report. Examples of biases are presented and it is argued that they are a result of using heuristics. The author argues just being aware of cognitive biases can help avoid them. Improvements in the quality of decision making can be made thorough studying the decision-making process. Studying previous events in which biases are prevalent may provide good examples that help people to avoid biases in their own decision making. Similar to Jansen (2007), the author believes that simply identifying biases and making them explicit can change their influence in decision making. This is not necessarily in agreement with more resent research. The author identifies intuitive decision making processes as helpful but impacted by biases due to the use of heuristics in intuitive processing. The author suggests ways of improving the negative impact of biases: - awareness of biases can help avoid them - increase the amount of time spent studying and understanding the decision making process at a training level (in school). - Using historical examples to understand biases. Knowing detailed accounts of history when negative outcomes occur can help to understand and qualify the importance of good decision making. - The decision-maker should take time to reflect on the courses of action being considered and determine if there are dominant themes. - Decisions should consider all alternatives as much as possible. These suggestions would not fare well in a DDM context where time constraints and cognitive workload are severely limited.
CAN BE USED TO SUPPORT INVESTIGATING: HEURISTICS, BIASES
To be used? FOR CONSIDERATION

58. Title: Pattern recognition training for combat leaders: Sample training package
Author(s): Thronesbery, C., Sullivan, B. D., & Rhoads, R.
Source: Report prepared for the United States Army Research Institute for the Behavioral and Social Sciences, ARI Report No. 96-17.
Year: 1996
Abstract: Lesson plans were developed to facilitate and increase pattern recognition for combat leaders. Following an overview of the pattern recognition approach to training, this report contains a demonstration package that illustrates implementation of the pattern recognition approach to training. An extensive set of storyboards offers instructional material covering enemy situation understanding from an elementary to an advanced level. It incorporates the development of key

pattern concepts that are used in threat evaluation during Intelligence Preparation of the Battlefield. The demonstration materials additionally provide training for Soviet tactical considerations of a motorized rifle regiment during two tactical scenarios.
Notes: This article contains a brief description of the goals and contents of a training package to support pattern recognition; the majority of the report contains storyboards to be used for training. The goal is to show development of key concepts (patterns) necessary for threat evaluation during intel preparation of the battlefield. The authors stress the importance of overlearning in training (i.e., training to the point of automaticity), as well as the importance of hierarchical training (teaching basic skills and then more advance skills) in pattern recognition. Also stressed is the importance of mental models in pattern recognition; understanding the deeper principles which make patterns similar. Types of training exercises include identifying stimuli which are similar to a prototype, identifying variations of a prototype (including which components might be missing), and assigning examples to prototypes. Feedback is provided, including information about whether the response was correct or incorrect, and reason for error when it occurred (i.e., why an error is an error). Although this article contains specific examples of training materials for pattern recognition, it contains only minimal information about the justification for choices made and strategies for training. More detail is needed to understand the rationale for decisions and how to understand the applicability of the methods detailed here.
CAN BE USED TO SUPPORT INVESTIGATING: PATTERN RECOGNITION
To be used? FOR CONSIDERATION– probably need to find the justification research rather than using this reference

59. Title: Précis of *Simple heuristics that make us smart*
Author(s): Todd, P. M. & Gigerenzer, G.
Source: Behavioral and Brain Sciences, 23, 727-741.
Year: 1999
Abstract: How can anyone be rational in a world where knowledge is limited, time is pressing, and deep thought is often an unattainable luxury? Traditional models of unbounded rationality and optimization in cognitive science, economics, and animal behavior have tended to view decision-makers as possessing supernatural powers of reason, limitless knowledge, and endless time. But understanding decisions in the real world requires a more psychologically plausible notion of bounded rationality. In Simple heuristics that make us smart, we explore fast and frugal heuristics—simple rules in the mind's adaptive toolbox for making decisions with realistic mental resources. These heuristics can enable both living organisms and artificial systems to make smart choices quickly and with a minimum of information by exploiting the way that information is structured in particular environments. In this precis, we show how simple building blocks that control information search, stop search, and make decisions can be put together to form classes of heuristics, including: ignorance-based and one-reason decision making for choice, elimination models for categorization, and satisficing heuristics for sequential search. These simple heuristics

perform comparably to more complex algorithms, particularly when generalizing to new data—that is, simplicity leads to robustness. We present evidence regarding when people use simple heuristics and describe the challenges to be addressed by this research program.
Notes: The first chapter of this book was read. The authors discuss the use of heuristics in decision making. They investigate different types of heuristics, performance when using heuristics, and methodologies to investigate and study heuristics. The challenges of decision making are due to the uncertainty and time limitations within the decision-making environment. They discuss the differences between *unbounded rationality*, described as knowing everything about the situation that is required (as God might); *optimization under constraints*, describing how our decisions are grounded in uncertainty; and *bounded rationality,* described as "satisficing", which is when there may be no optimal method for making a decision, thus a few options are explored and one is chosen often as a result the structure of the information determines much of our behaviour. *Bounded rationalit,* often focuses on the use of heuristics such as "one-reason decision making". The authors then discuss heuristic principles for guiding research and decision making. How heuristics may be used in real world environments is also discussed, as is the use of "fast and frugal" heuristics. Summaries and introductions to different chapters of the book focus on these topics. The environments explored are all related to simple decision making tasks. The authors discuss the challenges within decision making (DM) are based on the uncertainty of situational and temporal factors. Working memory capacities are one limitation thus is the reason heuristics are used. This helps to limit the analytic processing that people have to do. The environment and structure of the information largely determines how we behave. This may mean that much of our behaviour within these constrained environments is beyond our control. Coping strategies in dealing with such situations are identified as heuristics. Ideas of using heuristics is to avoid and compensate for the environmental challenges Our cognitive capacities and abilities are limited because of the lack of information.
CAN BE USED TO SUPPORT INVESTIGATING: HEURISTICS
To be used? FOR CONSIDERATION Particular chapters of this book may be useful if relevant

60. Title: Situation Assessment and Hypothesis Testing in an Evolving Situation
Author(s): Tolcott, M. A., Marvin, F. F., & Bresnick, T. A.
Source: Report prepared for the United States Army Research Institute for the Behavioural and Social Sciences, ARI Report No. 96-34.
Year: 1996

Abstract:
This research investigated the effects of early judgment on (1) the handling of new information, some of which confirmed and some of which contradicted the early judgment, and (2) the selection of hypothesis-testing indicators. The context was situation assessment by Army intelligence analysts during an evolving battlefield scenario. Unaided analysts typically ignored or underweighted contradictory evidence; their confidence in their early judgment tended to rise. A second group was given a brief tutorial on common decision biases and graphic displays that fostered awareness of uncertainty; in this group the tendencies were reduced (but not eliminated), and one-half of the group reversed their judgment at least once. A third group selected indicators; however, in the face of balanced feedback, their confidence remained constant rather than rising. The findings support the extension of confirmation bias theories to trained personnel performing realistic tasks. In addition, the results suggest that when decision makes the indicators they believe to be important, they pay more attention to contradictory evidence than when they are the passive recipients of new information.
Notes:
Focused on confirmation and overconfidence bias, this report summarizes two previous studies and details a third study involving intelligence analysts (IA). Findings suggest that confirmation and overconfidence bias occurs in natural settings, as the IAs taking a part in the study repeatedly focused on areas they believed the enemy would attack and were overconfident in their assessments. The authors suggest a number of cognitive skills that should be addressed. This report was very focused on these two specific biases, and provides little in the way of training suggestions for DDM.
CAN BE USED TO SUPPORT INVESTIGATING BIASES.
To be used? DO NOT INCLUDE

Annex B

This section contains a summary of each of the four areas reviewed. Below are definitions that we used as guidelines in our review. Note that there are many different definitions in the literature and so these definitions are not to be taken as consistently held by other authors.

- Cue integration is the process by which information is selected from the environment, weighted, and combined to serve as the input to a decision.
- Pattern Recognition is the process of applying knowledge about the relationships between aspects of the environment (e.g., patterns). Pattern recognition is usually thought to be a function of the similarity between the state of the environment and the patterns stored in memory, which are usually learned through experience.
- Heuristics are shortcuts in decision making, generally designed to find a decision that is "good enough" (i.e., satisficing). Heuristics are often contrasted with analytical methods which systematically examine all possibilities and are intended to arrive at an optimal decision (definition adapted from Adams, Rehak, Brown, & Hall, 2009).
- Biases are systematic (i.e., non-random) errors in decision making (Adams et al., 2009).

Cue integration

Drawing from our understanding of the term "cue integration", a number of general themes, challenges and training related issues can be pulled from the literature. These are discussed below.

General Themes

Cue integration involves the use of cues, hints or data in decision making. These cues are used to determine which decision, action or judgement is most appropriate. In any given situation a decision maker must learn what cues to pay attention to, how valid those cues are and the how to integrate the cues together. One issue not discussed in detail in the literature is determining what a cue is. For our purposes, a cue can be considered any piece of data used in decision making. This includes data pertaining to the task at hand (e.g., the location of enemy groups), data internal to the decision maker (e.g., affect), and data from the environment (e.g., time constraints). Each of these categories of cues affects the decision maker differently, potentially changing the resulting decision (Kerstholt & Willems, 1993; Schroeder, 2005; Famewo et al., 2005).

Arguably, cues – especially task cues – must be perceived before they can be incorporated into the decision making process. The process of perception is unavoidable; however, cue perception is not a straightforward recording of reality. Instead, our perceptions are believed to be constructed (Jones, 2005), and that construction process is affected by internal cues and environmental cues. This makes determining what cues are being used, and whether or not those cues are being used in a decision correctly and/or effectively a challenge. This is especially the case in DDM scenarios where the quantity of task cues is large, and the interrelationship between cues can be complicated and changes over time.

Taking a closer look at the actual cue integration process, a number of cognitive strategies and procedures are discussed in the literature concerning how cues are integrated. Hammond (1988) outlines two distinct cognitive strategies based on the way information is presented: 1) Pattern seeking: induced by displays of information of a high degree of perceptual or conceptual organization; and 2) Functional-relation seeking: induced by displays that demand description and prediction on the variables. Cue integration logically occurs in both of these strategies, though different cue integration strategies would be applied.

There have been some studies suggesting that the cognitive processes involved in cue integration vary based on the type of output required. For example, Juslin, Olsson and Olsson (2003) suggest that different cognitive processes are used to determine categorization (i.e. allocating between 2 or more categories) versus multiple cue judgements of a continuous variable (e.g., probability of precipitation given weather information).

Finally, the use of cues is heavily discussed in comparisons of compensatory and non-compensatory decision strategies. Compensatory strategies involve integrating all information together to be used in the decision, whereas non-compensatory strategies involve disregarding certain information (e.g., in the "choose the best" heuristic only the most valid cue is considered) (Pachur & Hertwig, 2006). Non-compensatory cue usage strategies seem to be prevalent in dynamic tasks, which are reasonable given that non-compensatory strategies often yield very good results compared to the more cognitively demanding compensatory strategies (Rothrock & Kirlik, 2003).

While each of these examples could be considered micro-decisions in the broader DDM process, the evidence for different cognitive processes implies that cues are not only used to make decisions, but also used to determine which strategy to use to make the decision (Gonzales, Lerch, & Lebiere, 2003) as different cues are used to determine which cognitive process to use. This could be especially applicable to DDM training.

Cue Integration-based challenges

The effects of information presentation (e.g., framing) of cues on decisions have been extensively researched. The order, format, salience, context, affect, etc. of cues impact how and if a cue is incorporated into decision making (Adelman & Bresnick, 1995; Bois, 2002; Dunwoody, Haarbauer, Mahan, Marino, & Tang, 2000; Famewo et al., 2005; Jones, 2005; Payne, Bettman, & Johnson, 1992; Tolcott, Marvin, & Bresnick, 1996). Some of these studies conclude that the effects occur outside of consciousness (e.g., Slovic et al., 2005) while other effects are more accessible (Schulz, 1996). Collectively, these effects lead to: neglecting potentially relevant problem information, ignoring values when they are difficult to estimate, inaccurately weighting cue validity, and the "general tendency to accept problems as given and the segregation of the decision problem at hand from its broader context" (p. 116, Payne, Bettman, & Johnson, 1992).

Defining "cue validity" as "the probability that a cue will lead to the correct decision given that it discriminates between the alternatives" (p. 1399), Garcia-Retamero, Wallin, and Dieckmann (2007) looked at how decision makers select cues, and how estimations of cue validity is performed. Cues can be present or not present, but they can also be associated with uncertainty. A cue may be ambiguous, inaccurate, or probabilistic. Thus, determining cue validity can also be seen as a cognitive challenge.

Additional challenges alluded to above include the sheer quantity of cues which can exceed the cognitive limitations of the decision maker (Adelman & Bresnick, 1995; Jones, 2005), and the use of cues to select decision strategies. The limitations of working memory restrict the ability to process, and integrate multiple sources of information resulting in poor decision making performance (Famewo, Matthews, & Lamoureux, 2007; Gibb, 2000; Jacobs & Graver, 1998). These restrictions also impact the ability to identify relationships between cues (Garcia-Retamero, Wallin, & Dieckman, 2007). Jacobs and Graver (1998) argue that training and experience can lessen the effects of limited information processing and memory capabilities.

Training Cue Integration in a DDM context

Providing subjects with perfect information does not mean that subjects understand or perceive all the cues. This is the case for general data as well as feedback. Logically, feedback could be considered a cue in DDM, or information about cue validity given the cyclical and continuous nature of DDM scenarios. However, Sterman (1989) found that in DDM scenarios, subjects show a general lack of consideration of feedback, including misperceptions of time delays, misperceptions of feedbacks from decision to the environment and a tendency to think in causal single strand series. Further, Gonzales, Lerch, and Lebiere (2003) found that when modelling behaviour, models without feedback were more accurate at representing human performance that those with feedback. Collectively, these studies suggest that feedback is not readily incorporated as a cue in dynamic decision making.

If feedback is not used, how do decision makers learn appropriate relations between cues? Juslin, Olsson, and Olsson (2003) suggest that exemplar memory is used as a guide to determine which cues should be selected. Other studies have tried to impress rules upon participants in order to increase the usage of appropriate cues. Bois (2002) found that if you provide participants with a decision rule that focuses their attention on proper cues and how to weigh their importance, subject performance was improved. Costello (1992) further found that subject performance in a DDM environment was better when the easier of two projects was managed first – showing that training with increased difficulty could be effective in DDM environments.

Further (as alluded to above), training on the use of cues to select a decision strategy could be effective. Butterfield (1993) found with intelligence officers that efforts focusing on the adaptability of concepts and how to apply critical judgements were a more effective training approach than explicitly training participants to increase their objectivity.

In general, DDM decision makers should be trained in a way that increases robustness (i.e. in strategies that are suitable across a wide variety of options due to variability in the way the system could evolve) rather than for optimality given the current or predicted situation (Busemeyer & Pleskak, 2008).

Pattern Recognition

Drawing from our understanding of the term "pattern recognition", a number of general themes, challenges and training related issues can be pulled from the literature. Pattern Recognition is the process of applying knowledge about the relationships between aspects of the environment (e.g., patterns) and knowledge of what decisions are appropriate and what the effects of those decisions are likely to be. It is a complicated process that involves selecting, combining, categorizing, and understanding information. Interest in this area of decision making has grown with recent interest in intuitive and naturalistic decision making, including Recognition Primed Decision Making (RPDM; Klein and Crandall, 1996). These approaches often treat pattern recognition as a "black box", whose input is data and whose output is categorization and/or a deeper understanding. However, a closer look at pattern recognition is warranted.

General Themes

Pattern recognition can take place at either a conscious (e.g., deliberately manipulating mental models) or subconscious (e.g., affective response) level. Logically, pattern recognition is a skill that increases with familiarity and experience. Experts who are effective at pattern recognition are able to also recognize novel situations and exceptions (Cohen et al., 1999). As decision makers become more experienced – and presumably better at pattern recognition – there is a shift away from analytical and toward intuitive decision making processes (Bois, 2002). Thus, a key defining characteristic of decision-making expertise is recognizing when NOT to trust your intuition and when to apply more rigorous analytical processes (Bakken, 2008). This could be seen as performing a higher level of pattern recognition or simply identifying a pattern (in this case the pattern "unmatched" or "unpredictable").

The relationship between pattern recognition and heuristics is still under debate in the literature. Some literature suggests that heuristics rely on pattern recognition in order to identify which heuristic to apply, other literature suggests that heuristics are applied when no pattern emerges (Gonzales, Lerch, & Lebiere, 2003). All this builds on a similar idea from cue integration: that important cognitive processes are not only used to make a decision but may also be used to determine which decision strategy or methods to apply at any given time. This is iterated by Soh (2007) as well as Gigerenzer (2008) who states that what makes a good decision maker is the ability to recognize the right strategy for the situation.

Pattern Recognition-based challenges

As with cue integration, internal and environmental variables affect pattern recognition. With satisficing, for example, Gonzales, Lerch, and Lebiere (2003) noted that the level of satisfaction felt by the decision maker considered "enough" will depend on the time remaining to make a decision. This implies that a decision maker's pattern recognition judgements are heavily dependent on time constraints (Kerstholt & Willems, 1993).

Various other factors also affect the pattern recognition process. Prospect theory shows another example. In prospect theory, recognizing an outcome as a gain or loss will influence the assessment of risk, which will in turn influence the decision (Schulz, 1996). Interestingly risk and benefit tend to be positively correlated in reality, but people perceive them as negatively correlated (Slovic et al., 2005) further complicating decision makers pattern recognition abilities.

DDM requires decision makers to create mental models, think critically about those mental models and apply them to novel situations (Cohen et al., 1999). Pattern recognition can be assumed to play a role in mental models, both in their identification and manipulation. Thus faulty mental simulation errors which are commonly made by decision makers in recognition primed decision making (Klein & Crandall, 1996) could also be seen as errors in pattern recognition.

Building on the lack of use of feedback by decision makers in DDM scenarios (see Cue Integration Section above), feedback to decision makers has been found to increase the error rate. Despite this, subject confidence was increased as people made faster decisions on less evidence (Gough, 1992). Thus DDM decision makers are not incorporating feedback into their pattern recognition strategies. This could be due to many reasons, perhaps a lack of understanding of the implications of the feedback, low motivation (Bois, 2002) or overconfidence. More exploration of this is required.

Training pattern recognition in a DDM context

Over learning, to the point of automaticity, is important in training. For pattern recognition, this means teaching basic skills and then more advanced skills, as well as learning the importance of mental models in pattern recognition and understanding the deeper principles which make patterns similar (Thronesbery, Sullivan, Rhoads, 1996). Effective decision makers should be flexible, quick, resilient, adaptive, risk taking and accurate (Canon-Bowers & Bell, 1997) – all of which should improve with more effective pattern recognition abilities.

Heuristics

General Themes

Much of the reason decision makers use heuristics is due to the limited amount of time, cognitive resources, and information constraints within the environment (Janser, 2007). As defined earlier, DDM contexts are highly time constrained and uncertain. Heuristics have been described as "short-cuts" or coping strategies as a method of dealing with time pressures, uncertainties, and large amounts of information (Janser, 2007; Rothrock, & Kirlik, 2003; Todd & Gigerenzer, 1999).The ability to use heuristics to cut down the time and mental resources required to produce a decision is not a surprise. This implies that within a DDM context, which is defined by these factors, heuristics are inevitably required.

From the literature reviewed, several contrasting perspectives were identified. They are:

- Heuristics are negative (nonoptimal) (e.g., Stormer, 1991) or heuristics are useful and accurate decision-making methods (e.g., Soh, 2007; Costello, 1992; Goldenstein & Gigerenzer, 2009); and,
- Heuristics are avoidable (e.g., Stormer, 1991; Parchur & Hertwig, 2006) or heuristics are unavoidable due to either human cognitive processing, environmental characteristics, task characteristics, or a combination of these or other factors (Butterfield, 1993).

Heuristic-based challenges

It has been noted in a number of studies that as people gain experience, there is a shift from analytical towards intuitive decision making processes (Bakken, 2008) and decision making is often a combination of both (Dunwoody, Haarbauer, Mahan, Marino, & Tang, 2000; Payne, Bettman, & Johnson, 1992; Rasmussen & Lind, 1982). Errors are introduced as people become more reliant on intuitive decision making. It seems people are not able to accurately assess the limitations of their own intuitive processes; thus, there are challenges when attempting to understand when intuitive processes should not be trusted (Bakken, 2008).

Another challenge is the high amounts of cognitive resources and experience required to develop heuristics (Cohen, Thompson, Adleman & Bresnick, 1999; Rasmussen & Lind, 1982). Gigerenzer and Goldstein's idea of a toolbox of fast, frugal, and accurate heuristics supports this idea that people must form different heuristics for different decision making problems (Martignon & Hoffrage, 2002). Challenges in using heuristics then in DDM environments, are both in their development and the implementation.

Training and heuristics in a DDM context

The disagreements of the usefulness and avoidable or unavoidable heuristics significantly impact the direction that further research and training may take. With the idea that heuristics are negative and avoidable, one may attempt to educate the decision maker by explicitly identifying detriments of using heuristics (Butterfield, 1993; Janser, 2007; Stormer, 1991). With the perspective that heuristics are useful and unavoidable, one may take a stance to monopolize positive effects. For example, Haynie and Shepherd (2007) provide evidence that meta-cognitive feedback can lead to improved decision making. In this instance, meta-cognition is idealized as a type of heuristic that can be trained. Rule-based training which similarly focuses on cognitive aspects was also shown to result in more robust performance in dynamic decision making (Kirklik, Walker, Fisk, & Nagel, 1996). Heuristic training based on this perspective may alternatively focus on critical thinking strategies (Cohen et al., 1999) and rule-based training (Kirklik et al., 1996; Rasmussen & Link, 1982) as they relate to contributing to positive problem solving outcomes.

Biases

General Themes

Biases can become evident at multiple stages within the decision making process (Adams et al., 2009). Researchers refer to biases as affecting the process of decision making by mediating the identification, gathering, and interpretation of relevant information (Bakken, 2008; Garcia-Retamero, Mueller, Catena, & Maldonado, 2009; Janser, 2007) and as an outcome of the decision making processes (e.g., result of using heuristics) (Adelman & Bresnick, 1995; Janser, 2007; Rothrock & Kirlik, 2003). This makes general findings within bias literature difficult to identify, rather general statements may be best summarised for particular biases, or for a type or category of biases.

Confusion between biases and heuristics can also contribute to this difficulty. For example, "assessment of risk" has been reviewed as an affect heuristic (Slovic, Peters, Funucane, MacGregor, 2005) as well as an emotional-based bias, i.e. "fads and fashion" effect (Schroeder, 2005).

The general consensus in the literature seems to be that biases are associated with highly uncertain and time-constrained decision environments (Butterfield, 1993). Increased situational uncertainty and time pressure requires decision makers to make faster decisions which are more prone to biases (Bakken, 2008). This suggests that the number of biases in DDM contexts will be increased compared to more simplistic decision making. Other themes within the literature demonstrate divided perspectives concerning whether biases contribute positively or negatively to decision making. Rosenbloom, Lee, and Unruh (1993) suggest that biases can help organize and understand concepts, and reduce computational effort. Others argue that biases can only have negative effects on decision making (Brewer, 2005). Even for those who do support that biases are useful, there is high agreement that biases often lead to faulty decision outcomes (Rosenbloom, Lee, & Unruh, 1993). It has been generally accepted that biases are most often applied unconsciously (Butterfield, 1993; Janser, 2007; Stormer, 1991).

Bias-based challenges

As biases may be incorporated into multiple stages within the decision making process, cognitive challenges may result as the effect of both internal and external influences. Research has shown that assigning value weightings to pieces of information can produce biases (Broder & Eichler, 2006; Butterfield, 1993; Gibb, 2000; Schroeder, 2005). It has also been proposed that when values are difficult to estimate, those values may be ignored entirely (Payne, Bettman, & Johnson, 1992), resulting in a different form of bias. This challenge may be partly due to cognitive abilities, but also situational factors such as uncertainty.

Influence from other people within the situation can also dramatically affect biases. For example, the attention and affect within a context can change people's willingness to take risks. The "fads and fashion" effect suggests managers are more likely to underestimate risks with increased excitement around a particular industry (Schroeder, 2005). Challenges presented within this context may be more social in nature as individual biases are affected by not only the situational information, but also surrounding relationships.

In DDM contexts it is assumed that information overload is generally high. Attempting to prevent, or analyze biases and their effects on decision making would require cognitive resources that are often unavailable. Thus, limitations of working memory produce challenges related to biases. Also within a DDM context, decisions are interdependent. Biases that affect a source of information or decision early on in the situation may result in confounding errors as the DDM situation progresses.

Training and biases in a DDM context

Continuing from the idea that biases are unconsciously applied, several researchers advocate that creating awareness about biases, that is to educate the decision maker about common biases, will help to minimize their negative impact in decision making (Butterfield, 1993; Janser, 2007; Stormer, 1991). Thus far this type of education paradigm has not been shown to provide consistent performance increases, thus it does not rid decision makers of their biases and has not lead to any particular type of training methodology for changing (increasing or decreasing) biases in decision making outcomes.

Similar to the discussion about heuristics, it may be important to identify if the foundation of training will be the presumption that biases can be avoided or not. Butterfield (2005) argues that biases (and heuristics) are unavoidable and training someone to keep biases out of decision making is futile. Much of the literature recommends focusing training on analytic type processes to teach people to exercise qualities of critical judgement (Butterfield, 2005; Cohen, Thompson, Adelman, & Bresnick, 1999). Other methodologies focus on improving heuristics, from which biases are produced, in order to minimize their effects (Brewer, 2005). In both cases, the goal is to rid the decision making process of biases. Those who, as discussed earlier, are of the perspective that biases can be helpful may focus on a different training type approach.

Though training using highly analytical processes may be useful in transferring DDM skills, we should be careful not to apply such a process to training in DDM situations as DDM contexts may not facilitate the time, nor environment (e.g., certainty) required. For this reason, some suggestions of overcoming biases may not be appropriate for a DDM context. For example, Stormer (1991) suggests that the decision maker should take more time to reflect on COAs being considered and pick out dominant themes. Unfortunately, with the nature of DDM, especially the time constraints and constantly changing information, this is not likely to be a useful strategy.

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(U) Defence Research and Development Canada (DRDC) Toronto is interested in researching training techniques to prepare Canadian Forces (CF) commanders and staff for decision making in complex and dynamic environments. The complex and dynamic nature of various types of operations (e.g., effects–based operations, stability operations, counter–IED, counter–insurgency) pose specific cognitive challenges on the decision–making process that the current training regimen of military commanders does not directly address. This project serves to provide understanding of underlying cognitive mechanisms within DDM as a contribution to determining how best to improve the DDM process and training. A brief review of four recognition processes, namely pattern recognition, cue integration, heuristics, and biases, was conducted as Phase I of a two phase process. Based on this review, cue integration was selected as an area of key interest and was the focus of a more comprehensive review (Phase II). Results from this review indicated that the cue integration literature within DDM is sparse. A significant amount literature concerning more simplistic decision making thus was used to infer the role of cue integration within DDM. Particular aspects of cue integration, namely perception, working memory, long term memory, and feedback were considered to play an important role in DDM. Training implications including recommendations of what and how to train are considered. Concluding remarks and future recommendations are also discussed.

(U) Recherche et développement pour la défense Canada (RDDC) Toronto s'intéresse à la recherche sur les techniques de formation destinées à préparer les commandants et le personnel des états–majors des Forces canadiennes (FC) à prendre des décisions dans des environnements complexes et dynamiques. La nature complexe et dynamique de différents types d'opérations (p. ex., les opérations basées sur les effets, les opérations de stabilité, la lutte aux IED, les mesures anti–insurrectionnelles) pose des défis particuliers au niveau cognitif dans le processus de prise de décisions qui ne sont pas abordés directement dans le cadre de l'actuel régime d'instruction des commandants militaires. Le présent projet sert à comprendre les mécanismes cognitifs sous–jacents de la prise de décisions dynamique (PDD) en tant qu'éléments contribuant à déterminer quelle est la meilleure façon d'améliorer le processus de PDD et la formation. La première des deux phases de ce processus était une étude brève de quatre processus de reconnaissance, à savoir la reconnaissance des tendances, l'intégration des indices, les heuristiques et les biais. En fonction des résultats de cette étude, l'intégration des indices a été choisie comme domaine d'intérêt clé et a fait l'objet d'une étude plus détaillée dans la Phase II. Les résultats de cette étude indiquaient qu'il y avait peu de documentation sur l'intégration des indices dans le domaine de la PDD. Une quantité importante de documentation relative aux contextes de prise de décisions plus simples a donc ainsi été utilisée pour induire le rôle de l'intégration des indices dans la PDD. On estime que des aspects particuliers de l'intégration des indices, c'est–à–dire la perception, la mémoire de travail, la mémoire à long terme et la rétroaction, jouent un rôle important dans la PDD. Les implications au niveau de la formation sont abordées. Des recommandations sont faites sur ce qui devrait faire l'objet de la formation et la façon de former les gens. Le présent document se termine par un commentaire de conclusion et des recommandations sur les recherches à venir.

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(U) cue integration; dynamic decision making; microworlds; recognition processes; heuristics; biases; pattern recognition; training; cognition; working memory; long term memory; feedback

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