Decision Support for Dismounted Soldiers (ARP 04dq)

Project Summary and Closeout Report

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Abstract

The purpose of this report is to summarize the work conducted within Project 04dq "Decision Support for Dismounted Soldiers." The report begins with a review of the project objectives and provides some background concerning the need for this work. The project achievements are summarized with descriptions of the major research accomplished. Among the major outcomes are: a) a model of the human cognitive processes of CID, b) preliminary experimentation to validate this model and provide insight into the likely effects of blue-force tracking and rifle-mounted combat identification assist systems on human decision making, and c) a proof of concept prototype mobile ad hoc network field BFT test bed. A complete list of lessons learned from the project is provided. The report ends with discussion of potential avenues for exploitation of the project results and suggestions of future research and development directions.

Significance to Defence and Security

This project was begun with the goal of better understanding the cognitive processes underlying combat identification and, hence, providing useful design guidance for dismounted soldier systems. Specification of the types of decision support that are effective and the performance characteristics (e.g., accuracy, timeliness of information) needed for effective decision support will ensure quicker and more efficient adoption of soldier decision support. Such decision aids can be more effective if predicated on a comprehensive model of how the human soldier perceives, recognizes, and decides.

This applied research project examined the impact of temporal and spatial uncertainty on the effectiveness of blue force tracking support tools. A model of soldier situation awareness and decision making was developed; and laboratory, and field based experimentation was designed to evaluate handheld and rifle-mounted systems. Year 1 focused on model development and validation, definition of soldier information needs, and review of support tools. In Years 2 and 3, we developed blue force tracking test beds, including handheld and rifle-mounted variants, and performed empirical studies to examine the impact of these systems on soldier situation awareness and performance. In addition, we compared the relative effectiveness of different system configurations and commercially available technologies.

Significant budget cuts in Years 2 and 3 necessitated the scaling back of the scope of research activities. In addition, in Year 3, the project faced severe personnel resource limitations which forced the cancellation of some planned experimentation.

Among the major outcomes of this project are: a) a model of the human cognitive processes of CID, b) preliminary experimentation to validate this model and provide insight into the likely effects of blue-force tracking and rifle-mounted combat identification assist systems on human decision making, and c) a proof of concept prototype mobile ad hoc network field blue force tracking test bed. A complete list of lessons learned from the project is provided.

Major deliverables for this project included reports examining the underlying decision processed of target identification and the factors that govern decision strategy selection. The Sequential

Evidence Accumulation for Combat IDentification model was developed to provide a framework for understanding the interaction of situation awareness and evidence accumulation target identification processes. A review of technologies indicated that numerous systems exist to support the combat identification process but few have been rigorously evaluated for effectiveness. Experimental results indicated that blue force tracking systems can substantially improve combat identification performance in terms of reducing the risk of fratricide but even small lag in the update of positional information can eliminate the benefit of such systems. Further, blue force tracking seems to provide less benefit when used in an environment containing civilians.

Résumé

Le présent rapport résume les travaux réalisés dans le cadre du projet 04dq intitulé « Aide à la décision à l'intention des soldats débarqués ». Il débute par un rappel des objectifs du projet et justifie, dans une certaine mesure, sa raison d'être. Les résultats obtenus y sont résumés, assortis de la description des principales recherches effectuées. On compte parmi les principales réalisations dans le cadre de ce projet a) un modèle des processus cognitifs humains se rapportant à l'identification au combat (IDCbt); b) l'expérience préliminaire servant à valider le modèle, de même qu'à saisir les effets possibles des systèmes montés sur arme pour le suivi de la force bleue et l'aide à l'identification au combat dans les processus décisionnels humains; c) un prototype de validation de principe d'un banc d'essai du réseau mobile ad hoc pour le suivi de la force bleue sur le terrain. La liste complète des leçons retenues en cours de projet est jointe. Le rapport se termine par une discussion des moyens possibles d'exploiter les résultats et des suggestions d'orientations pour la recherche et le développement à venir.

Importance pour la défense et la sécurité

Le présent projet a été entrepris pour que nous puissions mieux comprendre les processus cognitifs sous-jacents dans l'identification au combat. Il visait à fournir une orientation utile pour la conception de systèmes de soldats débarqués. Les types efficaces d'aide à la décision et les caractéristiques de rendement (exactitude, actualité des renseignements) nécessaires à une aide véritable à la décision feront en sorte que nous pourrons adopter plus rapidement et plus avantageusement des aides à la décision qui seront mises à la disposition des soldats. Ces aides décisionnelles pourront gagner en efficacité si elles reposent sur un modèle exhaustif du cheminement de perception, de reconnaissance et de décision du soldat.

Ce projet de recherche appliquée a permis d'examiner comment l'incertitude temporelle et spatiale peut influer sur l'efficacité des outils d'aide au suivi de la force bleue. Un modèle de connaissance de la situation et de prise de décision du soldat a été élaboré, de même qu'un programme d'expérimentation en laboratoire et sur le terrain pour évaluer les systèmes portatifs et montés sur fusil. Au cours de l'an 1, l'équipe du projet s'est concentrée sur l'élaboration et la validation du modèle, sur la définition des besoins d'information des soldats et sur l'examen des outils d'aide. Au cours des ans 2 et 3, l'équipe a élaboré des bancs d'essai pour le suivi de la force bleue, y compris des variantes portatives et montées sur fusil, et a mené des études empiriques permettant d'examiner l'incidence de ces systèmes sur la conscience qu'a le soldat de la situation et sur son rendement. L'équipe a d'autre part comparé l'efficacité relative des diverses configurations de systèmes et des technologies disponibles dans le commerce.

Les dures compressions budgétaires subies pendant les ans 2 et 3 ont forcé l'équipe à réduire la portée de ses activités de recherche. Par surcroît, au cours de l'an 3, l'équipe a été confrontée à d'importantes restrictions des ressources humaines qui l'ont obligée à annuler une partie de l'expérimentation prévue.

On compte parmi les grands produits obtenus dans le cadre du projet a) un modèle des processus cognitifs humains se rapportant à l'identification au combat b) l'expérience préliminaire servant à valider le modèle, de même qu'à saisir les effets possibles des systèmes montés sur arme pour le suivi de la force bleue et l'aide à l'identification au combat dans les processus décisionnels humains; c) un prototype de validation de principe d'un banc d'essai du réseau mobile ad hoc pour le suivi de la force bleue sur le terrain. La liste complète des leçons retenues en cours de projet est jointe.

Les principaux résultats attendus de ce projet comprenaient des rapports d'examen des processus décisionnels sous-jacents d'identification des cibles et d'examen des facteurs régissant le choix de la stratégie décisionnelle. Le modèle nommé Accumulation séquentielle de preuves pour l'identification au combat (ASPIC) a été élaboré pour donner un cadre à la compréhension de l'interaction de la connaissance de la situation et des processus d'identification des cibles par accumulation de preuves. Un examen des technologies a permis de constater qu'il existe de nombreux systèmes de soutien du processus d'identification au combat mais que peu d'entre eux ont été soumis à l'évaluation rigoureuse de leur efficacité. Les résultats des expériences ont mené à la conclusion que les systèmes de suivi de la force bleue peuvent très nettement améliorer l'identification au combat au chapitre de la réduction du risque de tir fratricide mais qu'un retard, même léger, de mise à jour de l'information positionnelle peut en annuler les avantages. Qui plus est, le suivi de la force bleue semble perdre en efficacité quand il est employé dans un milieu où se trouvent des civils.

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Introduction

Background

This project was begun with the goal of better understanding the cognitive processes underlying Combat Identification (CID) and, hence, providing useful design guidance for dismounted soldier systems. The Canadian Armed Forces (CAF) will acquire technologies for Blue Force Tracking (BFT) devices, target designation capability, and soldier Situation Awareness (SA) support in the future. Specification of the types of decision support that are effective and the performance characteristics (e.g., accuracy, timeliness of information) needed for effective decision support will ensure quicker and more efficient adoption of soldier decision support. Such decision aids can be more effective if predicated on a comprehensive and detailed model of how the human soldier perceives, recognizes, and decides.

Current Project

Rationale

Failure of the CID process can lead to fratricide, the inappropriate engagement and potential wounding or killing of a friendly soldier or unit, neutricide (identifying a neutral contact as hostile) and injury or death to oneself caused by failing to identify an enemy contact [1]. Fratricide and neutricide are fundamentally issues of human judgment [2] and most instances can be related to either the loss of SA, misidentification of the target, or both [1, 3]. Consequently, efforts are underway to enhance CID decision making by supporting SA and target identification [4, 5]. In particular, BFT and target designation systems are under investigation as SA support tools. Significant work has been done on developing these systems but significant questions remain regarding the performance characteristics (accuracy, timeliness) needed to make these systems effective decision support.

Overview

This Applied Research Project (ARP) examined the impact of temporal and spatial uncertainty on the effectiveness of BFT and target designation support tools. A model of soldier SA and decision making was developed and laboratory, and-field based experimentation was designed to evaluate handheld and rifle-mounted systems. The results of this project are intended to improve understanding of human decision-making under conditions of uncertainty and guide the development of future decision aids.

Year 1 focused on model development and validation, definition of soldier SA-related information needs, and review of support tools. In Years 2 and 3, we developed BFT test beds, including handheld and rifle-mounted variants, and performed empirical studies to examine the impact of these systems on soldier SA and performance. In addition, we compared the relative effectiveness of different system configurations and commercially available technologies.

Potential for Exploitation

BFT and soldier SA systems have the potential to greatly enhance combat effectiveness and reduce risk. Integration of SA and target designation capabilities in C2 systems could enhance command capabilities at the section and platoon levels. By defining the requirements for dismounted soldier decision support and testing various available systems we can have dramatic impact on the further development and procurement of these technologies. Studies conducted under this ARP contribute to our understanding and modeling of human decision-making under conditions of spatial and temporal uncertainty, which supports development of decision aids for other applications.

Personnel/Contractors

DRDC Toronto

Dr. David J. Bryant - Project Manager
Dr. Geoffrey Ho - Scientist
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Achievement of the Project Objectives

Impact of Budget Cuts

The project budget was cut in both Years 2 and 3. Funding in Year 2 was only 50% of the planned level, whereas funding in Year 3 was only 80% of the planned level. These cuts necessitated the reduction of work that could be accomplished. In addition, in Year 3, the project faced severe personnel resource limitations due to the large amount of work being done at DRDC – Toronto Research Centre. This forced the cancellation of some experimentation planned under Milestones 7 and 10.

Milestones and Deliverables

Table 1 lists the major milestones for this project. As discussed above, the project budget was cut in Years 2 and 3, requiring the termination of some work elements. As a result, not all milestones were met.

Table 1: Milestone Completion Report.

No.	Milestones	Planned Completion Date	Actual Completion Date	Status
1	Report: Review of soldier support systems	31-Mar-12	31-Mar-12	Completed
2	Report: Model of soldier decision making	31-Mar-12	31-Mar-12	Completed
3	Report: Decision support & information requirements	31-Mar-12	N/A	Terminated
4	Synthetic 3D immersive platform for experimentation	31-Jul-13	31-Jul-13	Completed
5	Report: Documentation of synthetic platform	31-Jul-13	N/A	Terminated
6	Experimental methodology	31-Jul-13	31-Jul-13	Completed
7	Report: Experimental results	31-Mar-14	31-Mar-14	Partial
8	Report: User interface requirements	31-Mar-14	N/A	Terminated
9	Field test bed and methodology	31-Mar-13	31-Mar-14	Completed
10	Report: Results of field experimentation	31-Mar-14	31-Mar-07	Partial
11	Validated list of user requirements & technical specifications	31-Mar-14	N/A	Terminated
12	Report: Summary of user & interface requirements validation	31-Mar-14	31-Mar-14	Partial

Milestone 3 was not completed in the first year and, with the budget reduction in Year 2, this milestone was abandoned. Although a synthetic 3D immersive platform for experimentation was developed, the effort to document this platform was deemed secondary and Milestone 5 terminated. Milestone 7 was only partially completed as some experimentation was terminated. Milestones 8 and 11 could not be completed due to budget cuts. Milestone 10 was only partially completed as a demonstration rather than a field experiment, with the results contributing to, but not fully completing, Milestone 12.

All deliverables other than software and hardware from these milestones are listed in Annex A.

Cue-Based Target Identification Strategies

Combat Identification

CID is a basic military task in which one attempts to rapidly and accurately identify friendly, enemy and neutral forces. Formally, CID can be viewed as a cue-based classification task in which a soldier categorizes one or more entities in the environment using whatever human perceptual and mechanical sensor cues are available. This can be a difficult task when no cue provides certain classification. Uncertainty results from flawed human perception and ambiguous sensor data, as well as inherent uncertainty as to which characteristics are important, or diagnostic, to the identity of targets that can impair assessment [6, 7]. In light of the importance of CID and the potential difficulty of the task, a precise understanding of the cognitive processes involved is needed to determine appropriate policies and procedures and to develop decision support systems.

Analytic and Heuristic Models

Looking at CID as a cue-based classification task, an important question arises as to the nature of the cognitive processes used to classify objects. A great deal of research has examined cue-based decision tasks and identified numerous specific procedures that can be applied successfully. These procedures can be broadly divided into analytic and heuristic strategies.

Analytic strategies are based on the premise that people apply compensatory algorithms that consider all available cues and their relative degrees of association to each alternative [8]. Heuristic models, in contrast, assume that people apply simple rules that often rely on a subset of available information [9–11]. These different kinds of decision strategies vary widely in terms of the amount of information used, the cognitive effort required, and the probability of a satisfactory outcome[13].

Analytic decision procedures require some kind of formal comparison among decision alternatives using procedural rules that quantify those alternatives. Numerous specific procedures for comparing alternatives are known, most of which can be computationally modeled. Many, for example, are based on Bayesian statistics and evaluate options in terms of base rates for different hypotheses and probabilities of the accuracy of different observations [14]. Others are based on additive procedures in which target dimensions are weighted and integrated to produce a numeric score for each decision alternative [15–17].

Heuristic models of decision making are based on the recognition that decision making mechanisms must work within the limits of time, knowledge, and computational power imposed by the situation and the decision maker him/herself [11, 12]. Heuristics are informal, intuitive strategies that specify simple steps, which are often based on probabilistic data, and are designed to work under a few general assumptions. The Take-the-Best (TTB) heuristic, for example, performs two-alternative choice tasks by determining the single cue dimension that both discriminates options and has the highest validity (i.e., the cue offers the greatest conditional probability of indicating the correct choice given the cue's presence) [18]. Heuristics such as TTB can also provide plausible models of human decision making in tasks in which subjects are required to use probabilistically predictive cues to select an alternative (e.g., [19, 20]).

Strategy Selection

Given the variety of potential decision strategies available, it is not surprising that researchers have observed that people will use different strategies to perform the same multiple-cue judgment task (e.g., [21–23]). It is not clear, however, how people choose a decision strategy for a given task [24]. Some (e.g., [25]) have argued that peoples' strategy selections are based on an implicit tradeoff between the benefits and costs of strategies within the context of the specific decision task. Indeed, decision makers have been found to be sensitive to factors that increase the cost of decision strategies [20–22, 26]. Others have suggested that people learn to apply certain strategies for particular problems through reinforcement learning [27].

If accuracy and cognitive effort are key factors in the selection of a decision strategy, it follows that any factor that changes the relative costs and/or benefits of a decision task can alter peoples' preferences for strategies. When the amount of cognitive effort required to make a decision is increased, people should choose a simpler, less demanding strategy.

Despite some evidence that increased cognitive effort induces people to show a preference for an heuristic decision strategy [20–22, 26], others have suggested that increased cognitive effort can produce greater reliance on compensatory strategies under certain circumstances. Glöckner and Betsch [28] have proposed that automatic processes enable people to use compensatory decision rules to quickly integrate multiple reasons in decisions. This suggestion is in line with research conducted by Ashby and colleagues [29–31], which suggests that people possess two distinct systems for categorization—an explicit system that is deliberate and suited to learning rule-based class distinctions and an implicit system that is automatic and suited to learning how to integrate probabilistic cues to form categories.

To examine the possible use of heuristic and analytic strategies in target identification decision making, we conducted experiments investigating the impact of cognitive demand on strategy selection in a simulated combat identification task [32]. The research was also intended to shed light on the nature of heuristics and analytic decision processes. The traditional view holds that both are based largely on deliberate processing and hence sensitive to cognitive demands of the task. In light of Glöckner and Betsch's [28] research, it may be that at least some compensatory strategies are based on automatic processes, which would indicate a qualitative difference between compensatory and heuristic strategies.

The first experiment of Bryant [32] employed a dual task methodology to investigate the impact of cognitive load on peoples' classification decision making and strategy selection. If heuristic and compensatory strategies are based on different (deliberate, rule-based versus automatic, information integration) systems or processes, a secondary task will have different effects on the performance of each kind of strategy. Thus, the impact of a competing cognitive demand can illuminate underlying differences in the natures of these strategies.

The experiment made use of a numerical Stroop task [33] developed by Waldron and Ashby [29]. The Stroop task required participants to hold a representation of the stimulus in working memory during the categorization process, thus competing for cognitive resources. All participants in the first experiment learned to classify friends versus foes through trial-and-error learning then performed a test phase in one of two conditions. In the control condition, participants performed only the judgment task, whereas in the secondary task condition, participants performed the concurrent secondary task.

Predictions for subjects' strategy selection followed from the following line of reasoning. If a simple heuristic such as TTB is based on deliberate processing [28], a secondary task should impair the target classification performance of participants who use TTB. Likewise, if compensatory strategies are based on automatic processing, participants using those strategies should exhibit little negative effect of a secondary task.

The experiment, however, produced no evidence that a secondary task increased the use of an heuristic decision strategy, contrary to the view that people should shift to a simpler decision strategy as a way of coping with increased cognitive demands. But neither did the secondary task shift participants' strategy preference toward an analytic, compensatory strategy.

Although the external cognitive demands did not affect participants' choices of decision strategy, they did differentially affect participants' performance of heuristic and compensatory strategies. The secondary task slowed participants' responses to some degree in all cases but the effect was much more pronounced for those using TTB than a compensatory strategy. This result is consistent with Glöckner and Betsch [28] and suggests that TTB is a deliberate, effortful strategy in which cue search and/or processing consumes some appreciable amount of cognitive resources even when cues are visually available as opposed to retrieved from memory (cf. [34]). In contrast, the Bayesian and additive rules take advantage, to some degree, of automatic processing.

The results of the first experiment did not support the view that the cognitive demand alone was the determinant of strategy selection. An unexpected set effect was observed in Bryant's [32] first experiment suggested that a different factor was determining strategy selection. In one set, the most predictive cue was also highly salient, whereas in the other the most predictive cue was not salient. It may be that when a perceptually salient cue, or a cue with a pre-existing association to the target identification task, is the most predictive, participants are able to quickly notice its relation to classification and use TTB. In other words the salient, high validity cue suggests TTB as a decision rule. In contrast, when a non-salient cue is most predictive, participants do not have one cue that immediately stands out as a key predictor and so they tend to consider all cues to identify targets. This suggests a compensatory decision rule, either because participants explicitly weigh all cues or because they acquire richer instances of targets in memory, which supports a recognition-based decision rule that conforms to Bayesian predictions.

The set effect was consistent with findings by Platzer and Bröder [35]. In an experiment, they positively and negatively correlated cue validity and salience and observed that participants tended to employ the TTB heuristic when high validity cues were also highly salient. In contrast, participants preferred to use compensatory strategies when cue validity and salience did not correspond to one another. Platzer and Bröder [35] suggest that the congruence of cue validity and cue salience favor the use of a heuristic strategy over a compensatory strategy.

A second experiment was performed to test whether the conjunction of high cue salience with high cue validity induces a preference for the TTB heuristic among participants [32]. In this experiment, participants learned to make friend-foe classification judgments in the same manner as the first experiment. To examine the impact of cue salience, some changes were made to the stimuli set. Conceivably, both perceptual and semantic salience could affect how participants interpret the cues as well as their selection of a decision strategy. To distinguish perceptual and semantic salience, a coloured dot was placed on the chest of the targets to create a perceptually salient but meaningless cue with no pre-existing association to the friend-foe classification.

The results of the second experiment indicated that when a perceptually and/or semantically salient cue was also the most valid, the majority of participants preferred a single-cue heuristic strategy. Overall, the results contradict the view that heuristics are more likely to be adopted when a task is made more cognitively demanding.

Strategy Selection Experiments

The results of the two experiments by Bryant [32] can be understood in terms of two competitive learning processes occurring during the training phase. The first is an associative learning process in which the participant samples multiple cues simultaneously and develops cue-outcome associations [36]. Thus, the participant builds a progressively accurate representation of individual cue validity that can be used in a compensatory decision strategy.

The other learning process involves the sequential examination of single cues to serve as a basis for a single-cue heuristic [37]. During training, the participant is presumed to select a single cue to test as a potential predictor. The process could reflect explicit hypothesis testing or passive observation of cue-outcome relationship. For participants to adopt TTB, they must notice that one cue is highly predictive (e.g., it leads to a correct outcome 90% of the time) and decide to use it as the sole basis for judgment. If the selected cue is not sufficiently predictive, the participant moves on to consider another cue. As each cue is considered, it is evaluated for its usefulness in distinguishing category members and non-members. Perceptually salient cues are most likely to be noticed early in the learning process [37], and, if also predictive, more likely to be incorporated in the representation of the category than predictive but non-salient cues.

Assuming the associative and cue-testing learning processes proceed in competition to discover a viable decision strategy, there is the potential for one or the other process to succeed before the other. Both would require some minimal number of trials to identify a strategy but the most predictive cue can sometimes be identified early in training in which case the participant can then adopt a single-cue decision strategy which supports accurate performance. If, however, the most predictive cue is not identified early on, the associative learning process builds progressively more accurate cue-outcome associations that can support a compensatory strategy. The more trials a participant completes without identifying the most predictive cue, the more attractive the compensatory strategy becomes, as the necessary cue-outcome associations are built up.

Heuristic and Analytic Judgment

The more traditional view has been that heuristics correspond to intuitive, simpler processes whereas compensatory strategies, especially complex ones such as the Bayesian strategy, correspond to deliberate, effortful processes [8, 10, 13]. This has led to the expectation that any factor that increased the complexity or cognitive demand of a decision task would induce people to adopt a heuristic strategy (e.g., [38]). More recent work has modified this understanding, suggesting that, in fact, heuristics equate to rule-based, deliberate processes and compensatory strategies can be automatic (e.g., [39]).

The results of Bryant's [32] experiments contribute to the growing empirical evidence that increased cognitive demands do not necessarily lead to reliance on heuristic decision strategies [28, 40]. With sufficient training or practice, compensatory strategies can be used even under high cognitive demand, as long as automatic processing can be accessed.

Heuristics have been linked to so-called "intuitive" thinking because they tend to be simple procedures and emphasize effort reduction and selective information processing as key features of intuitive thought. Intuitive thinking, however, rests on more than simplicity. Intuitive thinking may now be thought of more as fast, effortless, unconscious, and based on large amounts of prior experience—as automatic processes [39]. Automatic processes offer a more natural contrast to analytic processes, which are slow, effortful, generally available to consciousness, and generalizable beyond one's prior experience [9].

Heuristics, rather than being intuitive processes, seem to be more closely aligned with deliberate rule-based processes. Heuristics can reduce the cognitive effort needed to make a decision by reducing the amount of information considered and, potentially, the complexity of computations performed. However, heuristics do not appear to circumvent deliberate processing and so are subject to interference by competing cognitive demands [40]. Instead, analytic processes can, at least in some situations, make use of automatic processes that are distinct from conscious, deliberate processing.

The Combat Identification Decision Making Process

CID is a cognitive task that entails classification of targets on the basis of their perceptual features. As noted previously, CID can be viewed as multi-attribute classification based on uncertain cues. The task can be difficult because soldiers cannot rely on the presence of cues that provide certain evidence for classification. All of this occurs in complex, dynamic operational environments and soldiers often work under extreme time pressure and stress.

This section describes the Sequential Evidence Accumulation for Combat IDentification (SEACID) model [41]. The model of CID was based in part on Dean et al.'s [42] Integrative Combat Identification Entity Relationship (INCIDER) model. Their model describes the information flow from an observed entity, or target, to an observer and the internal decision making process of the decision maker. A key premise of INCIDER is that a soldier interacts with the battlespace through both sensing channels, which can be organic human senses or external sensors, and SA. Separate SA and sensory models are combined by a mixture of fusion processes to determine the identity of the target and assign a level of confidence to that outcome.

The SEACID model is illustrated in Figure 1. It is a framework for understanding the human decision making processes underlying CID and to serve as a basis for future experimentation. The SEACID model describes the cognitive processes by which a soldier detects and classifies an encountered entity. Interaction with the external environment begins through a Detection Module. The Detection Module takes in sensory information to perform the initial analysis aimed at detecting objects of interest in the environment.

Like the INCIDER model [42, 43], the SEACID model assumes both top-down and bottom-up processes in detection. The top-down process begins with the development of SA prior to a mission. Within the operational context of the infantry soldier, SA is a spatial and temporal model of the local battlespace, including locations and types of potential hostile entities as well as friends [44, 45].

The Situation Awareness Module (SA Module) corresponds to all cognitive processes by which a soldier builds and maintains an understanding of the battlespace. A soldier initially gains SA through briefings and other preparatory materials that help define the kinds of features the soldier should search for to detect and identify potentially hostile targets. SA continues to develop during a mission as the soldier engages in surveillance, which contributes to the constant updating of the SA Module.

The Detection Module performs both active and passive searches of the environment. Active search comprises the small area of conscious attention in which the observer can take in detailed information. In vision, this area (often called the functional field of view) consists of the part of the field of view (FOV) covered by the fovea, which covers an area of only a few degrees [46]. Because this area is a small portion of the total FOV, it can be likened to a "focal spotlight" that can be directed to any part of the FOV, either by conscious choice or by automatic processes in the periphery that solicit attention.

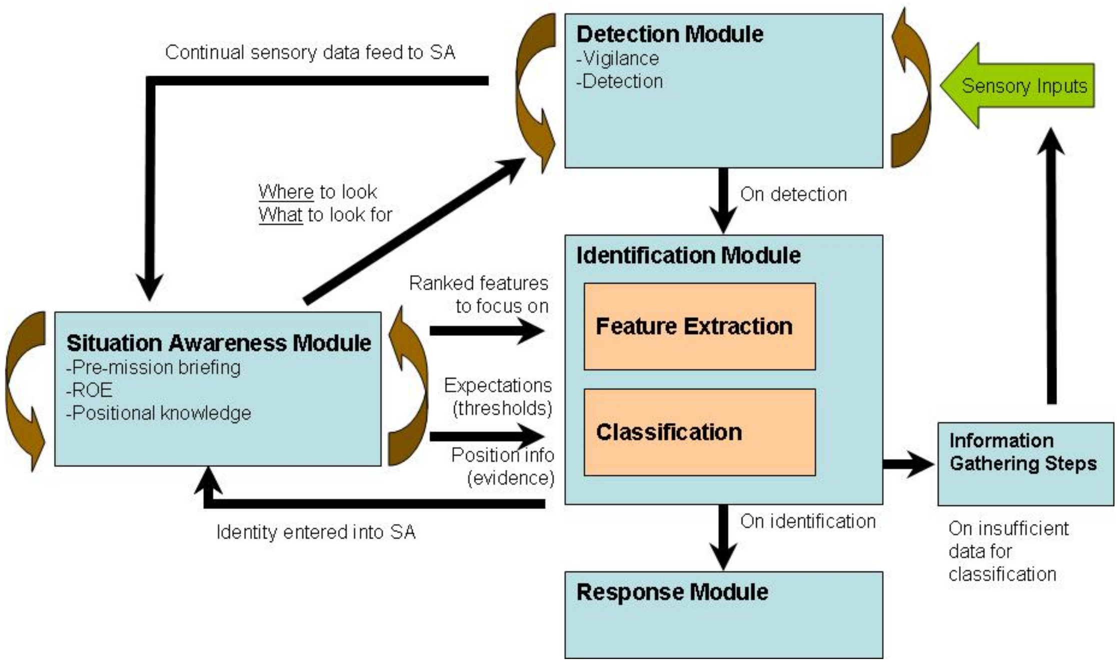

Figure 1: The Sequential Evidence Accumulation for Combat Identification (SEACID) Model.

In addition to the focal spotlight, some visual processing is performed in the peripheral FOV. For the most part, this processing is not consciously controlled by the observer and offers only low-detail resolution. When an object of interest is detected, the focal spotlight can be directed to it for further verification of its status.

Once an object of interest is detected, processing moves to the Identification Module where an assessment is made to determine its specific identity (Friend, Hostile, Non-Hostile). The SEACID model assumes that identification is an additive evidence accumulation process based on distinct features of the object of interest. The evidence accumulation process is a generalized additive model based on the compensatory decision strategies described by Bryant [32]. Simple heuristics can be performed by such a process by limiting information search and imposing a stricter stopping rule.

The first stage of identification is the extraction of the object's features. This refers to the process of determining specific characteristics of the object that have diagnostic value in determining its identity. Extracted features can be sequentially sampled by a classification process in which each feature is assigned a value, weighted by the degree to which that feature is known to provide reliable evidence for a given class of targets. Each weighted value is added to running totals for Friend, Hostile, and Non-Hostile categories until one total exceeds a pre-set threshold value and that category becomes the identification of the object of interest. A time limit can be placed on this process so that if no evidence total exceeds its threshold after a certain period the classification process can be terminated and the observer can initiate actions to gain additional information, such as moving to a better vantage point, deploying additional sensors, or using communications to request additional information from others.

Once a target has been identified, the response taken by the soldier depends on the ROEs and mission orders under which he/she operates. The decision facing a soldier centers on choosing a course of action (COA) to prevent or stop a threat identified based on information gathered during the identification process. This decision can be cognitively demanding because it involves making trade-offs, considering uncertainty and large amounts of information [47].

Blue Force Tracking Experiments

Given that CID is based, in part, on an SA-driven contextual process, a great deal of interest has been devoted to the development of BFT devices. Systems to aid the feature extraction process, such as Interrogate Friend Foe (IFF) and automated target cuing systems, are being developed but their implementation likely will lag somewhat behind that of BFT. A series of experiments were planned to examine the impact of temporal and spatial uncertainty on human CID judgments when using BFT devices. Budget cuts in the second and third years of this project substantially reduced the amount of experimentation completed. Initially, the plan had been to conduct a series of laboratory-based and one field-based experiments but this was not feasible. Several laboratory-based experiments were completed but these did not address all the issues initially identified.

Review of Combat Identification Support Systems

CAE Professional Services (Canada) produced a report reviewing currently available Combat Identification technologies of potential use to the dismounted soldier [48]. To understand the potential operational impact of potential technologies, CAE evaluated technologies against physical and cognitive effects on the dismounted soldier.

Six categories of CID technology were reviewed based on a taxonomy developed by Boyd, Collyer, Skinner, Smeaton, Wilson, Krause, Dexter, Perry and Godfrey [49]:

1. **Passive signalling devices:** Devices that enable CID of friendly units without any action or response by the person or platform carrying the device.
2. **Active signalling devices:** Devices that emit electromagnetic energy to facilitate SA.
3. **Interrogation/response systems:** Devices that enable positive identification through the process of query and response.

4. **Situation Awareness (SA) systems:** Devices that ensure timely dissemination of the 'operating picture,' including combat identification systems of systems using a variety of information, across the combat force.
5. **Recognition training systems:** Systems designed to increase the ability of soldiers to recognise potential targets through training of personnel before battle and in the field.
6. **Emerging technologies:** Technologies that are still emerging from the laboratory could eventually play a role in supporting CID.

For each category, CAE evaluated the most suitable product (or products) for the dismounted soldier and recommended research and development work that could address limitations with products in the category. The report concluded by summarizing the likely impacts on the soldier and making recommendations regarding the most fruitful areas for research and development for CID:

1. **Passive signalling devices:** These devices have limited implications for the dismounted soldier with respect to mobility or task execution. However, they typically require others have line-of-sight and an appropriate viewing device (e.g., a flashlight, NVGs) to be useful. Passive signalling devices can also be detected and mimicked by a suitably-equipped adversary. Frequency-coding passive signalling devices are more difficult to mimic but still require equipment that can detect the specific frequency of light reflected by the passive signalling device.
2. **Active signalling devices:** Active signalling devices require line-of-sight to be detected and are observable to adversaries. Uncoordinated flashing can also be disruptive when there are many such devices in the field of view [50]. To mitigate, somewhat, the problems associated with active signalling devices, they can be designed to use specific sequences of flashes to clearly identify a friend. Research should focus on systems that control the sequence, wavelength and frequency of the emissions.
3. **Interrogation/response systems:** These systems require targets to be equipped with a transponder to make a response. Because only friendly forces will be equipped, the user of this kind of system will only be able to distinguish friendlies from non-friendlies (i.e., enemies and neutrals). The act of interrogation is time consuming since the soldier must somehow direct the interrogator onto the target and wait for a response (which, although transmit and receive times are almost imperceptible, may take in excess of a second to process and display a response to the soldier). Finally, the act of interrogation may also impose additional tasks on the soldier, reducing their combat effectiveness briefly. Interrogation/response systems may impose weight penalties on the soldier.
4. **Situation Awareness (SA) systems:** The integration of GPS and digital radio allows extensive positional information to be transmitted and collated through BFT devices. Questions remain concerning the precise information requirements of soldiers using a BFT device, in particular those requirements pertaining to spatial accuracy, update lag, and spatial frame of reference. Research is also needed to better understand how information should be presented to soldiers. Standards for the amount of information and the speed of information transfer could be used as benchmarks for effective CID technology.

5. **Recognition training systems:** Since recognition training systems are used to develop long-term skill and knowledge prior to deployment, there are few implications for the dismounted soldier in the field. However, training is only one component of effective CID and recognition training systems can be, at most, an effective adjunct to other forms of CID support.
6. **Emerging technologies:** New technologies are present many opportunities and potential issues for use by soldiers, depending on the specific types of technologies considered.

Experimental Studies

Bryant and Smith [51] performed an experiment to contrast CID performance under real-time and lagged BFT. Subjects again played the role of a dismounted infantry soldier in a dynamic, first-person perspective gaming environment as friendly and enemy troops moved through the subject's area of responsibility. In some conditions, subjects could access a real-time BFT device whereas in two other conditions, subjects had access to a BFT device which provided data that was 10 seconds old. In one case, subjects were unaware of this lag whereas in the other, subjects were alerted to the lag. Providing a real-time BFT device led subjects to exhibit greater hit rate and lower false alarm rate than observed when subjects had no decision support. Adding a 10 second delay to the updating of position information in the BFT significantly impaired subjects' ability to identify enemies relative to real-time BFT. Subjects were as likely to commit fratricide when using a lagged BFT as when they had no decision support, whether they were warned of the lag or not. In addition, subjects exhibited a strong response bias toward engaging targets in conditions with a lagged BFT device compared to essentially zero or small negative bias in real-time BFT conditions.

Use of BFT in Civilian-Occupied Areas

Bryant and Smith [51, 52] demonstrated the potential benefit of providing soldiers with BFT devices, as well as the negative impact that update lag is likely to have on the effectiveness of such decision aids. Those studies, however, employed simulated environments containing only friendly and enemy soldiers. This is problematic in that Canada and her coalition partners find themselves participating in high tempo, non-linear operations with enemies who eschew traditional uniforms and employ diverse equipment. The so-called "three-block war" is likely to remain a strategic reality, with soldiers being called on to perform missions ranging from support to an indigenous population, to restoring stability/security, to fighting an armed opponent in force-on-force combat, often simultaneously and in close proximity [53].

The presence of civilians in the battlespace could affect the utility of BFT. BFT facilitates CID by enhancing a soldier's SA by providing certain positional information. It remains for the user of a BFT device, however, to correlate that positional information with the locations of actual entities in the environment [41]. When only blue forces are present, this mapping is self-evident but when the environment contains civilians who are not indicated on the BFT device, the mapping is made more complex. Large civilian populations in urban areas contribute to loss of soldier SA and BFT devices are not designed to mitigate this problem [54]. This requires transformation of spatial frames of reference, which involves matching objects in the field of view to objects in the map display. In the transformation process, civilians are "distracters" because they are not displayed in the BFT map. Thus, civilians seen by a soldier have no corresponding object in the

BFT display to which they can be matched. Instead, civilians act as potential matches to friends shown in the BFT and must be eliminated as candidates in order to correctly match friends in the field of view to friends indicated on the map. The greater the number of civilian distracters in the environment, the more difficult and cognitively demanding is this process.

Bryant [55] performed an experiment to examine the effectiveness of BFT for dismounted soldiers operating in an urban environment containing civilians. Twenty-four subjects performed five conditions: a baseline with no decision support, a condition with BFT providing real-time positional information, a 10 second delay condition with no warning that the BFT data would lag actual movement, a 10 second delay condition in which subjects were told of the delay, and a final end baseline with real-time update of the BFT.

Providing a real-time BFT device led subjects to exhibit greater hit rate and lower false alarm (FA) rate than observed when subjects had no decision support. Adding a 10 second delay to the updating of position information in the BFT resulted in subjects being significantly more likely to mistakenly engage a friend but did not affect the likelihood of mistakenly engaging a civilian. Subjects' civilian FA rates were not affected by BFT condition and mean civilian FA rates were roughly equivalent when subjects had real-time or lagged BFT, or no decision support at all. Overall, a delay in BFT updating made subjects significantly more likely to mistakenly engage a friend but did not affect the likelihood of mistakenly engaging a civilian. This pattern of results replicated Bryant and Smith's [51] finding that perfect, real-time BFT improved subjects' performance but a 10 second lag in the BFT display completely eliminated that benefit.

Although the pattern of results was the same as that of Bryant and Smith [51], the degree to which real-time BFT improved subjects' performance was substantially smaller. An analysis of effect sizes [56] indicated that subjects' improvement in friend FA rate was in fact smaller. The effect sizes observed in Bryant and Smith's [51] experiment exceeded those observed in the current experiment. Thus, it appears that including civilians in the simulated environment led to a reduction in the beneficial effect of real-time BFT on subjects' FA rates. Providing real-time BFT to dismounted soldiers can enhance combat effectiveness, in particular a reduction in the risk of fratricide, even in environments containing civilians. However, the presence of civilians has the potential to reduce the usefulness of BFT to dismounted soldiers.

Impact of Spatial Error

A lack of accuracy in tracking blue forces is a potential problem for any BFT system. The spatial accuracy of BFT is dependent on multiple factors, including the quality of the GPS receiver, satellite positions, atmospheric conditions, nearby structures, the potential for multipath signals, and the velocity of the target [57].

An experiment was performed to examine the impact of random spatial error as opposed to the systematic error created by update lag. When a BFT device lags by 10 seconds, the user is presented data that is in error relative to the current situation. The error, however, preserves the actual spatial relations among displayed friendly forces that had existed 10 seconds ago. This systematicity could prove beneficial to the user's SA if the user is able to create a mental model of the environment and predict movements of friendly forces. On the other hand, it could prove harmful to the user's SA if the systematicity disguises the error associated with the BFT display (i.e., the discrepancy between the 10 second old displayed data and the current situation) and leads the user to accept the lagged data as current ground truth.

We performed an experiment that followed the general procedure used by Bryant [55] but included a random spatial error condition. Twenty-four subjects performed five conditions: a baseline with no decision support, a condition with BFT providing real-time positional information, a condition in which each location of a friendly in the BFT display was displaced in a random direction to a distance of 5 to 10 metres (in game distance), a 10 second delay condition with no warning that the BFT data would lag actual movement, a 10 second delay condition in which subjects were told of the delay, and a final end baseline with real-time update of the BFT.

Subjects exhibited a higher hit rate in the no BFT condition than any other, a finding contrary to what was observed by Bryant & Smith [51]. Subjects' hit rates, however, were very similar across all other conditions, as expected since the BFT device provided no information pertaining to enemy identity or location. In contrast to Bryant and Smith [51], BFT condition did not affect friend FA rates. Although no significant differences were observed between conditions in which BFT was provided, subjects did exhibit a significantly higher friend FA rate in the No BFT condition. Thus, providing BFT did seem to reduce the risk of fratricide but, unlike the results of Bryant and Smith [51], the temporal and spatial accuracy of the BFT did not affect the degree to which the friend FA rate was reduced. Looking at mean friend FA rates across conditions, it appeared that friend FA rates in the 10s Delay (No Warning) and 10s Delay (Warning) conditions tended to be somewhat higher than those in the initial and end BFT conditions. It may be that a more sensitive analysis or experiment with greater power would reveal significant differences among these conditions. Interestingly, there was no indication that friend FA rate would be greater in the Spatial Error (No Delay) condition than the initial and end BFT conditions. Random spatial error may be less disruptive to subjects' CID performance than systematic error caused by system lag. Subjects' mean sensitivity and bias were both somewhat greater in the No BFT condition than all others but no other conditions exhibited significant differences.

In a related study, Ho, Hollands, Tombu, Ueno, and Lamb [57] examined the impact of BFT on a broader range of performance indicators, including navigation, communication, and workload. Participants in their experiment lead a simulated infantry section on a patrol mission in a simulated environment. During the patrol the section was fired upon and the participant had to identify the shooter and respond appropriately. In half of the missions, the shooter was an enemy sentry which the section would then engage, whereas in the other half the shooter was a friendly soldier. In the latter case, the participant was to communicate with higher command to get the friendly soldier to stop shooting. After dealing with the first encounter, the participant led the section to another area in which friendly and enemy forces were engage in a firefight and the participant was asked to identify the friendly force.

Ho et al. [57] compared the effects of three conditions— a "no BFT" control condition in which the participant had access to an electronic map of the area but no friendly positional data, a reliable BFT condition in which the electronic map provided completely accurate real-time positional information on all friendlies, and an unreliable BFT condition in which the electronic map provided inaccurate positional information on all friendlies. Their results indicated that participants using BFT engaged enemy forces more quickly, used their BFT to gain a wider scope of their environment, and had lower workload. For most measures, there were no significant differences between reliable and unreliable BFT conditions, suggesting that even an unreliable BFT can provide benefits to soldier performance.

Field Mobile BFT

Background

Establishing and maintaining SA in the battlespace is an integral part to the success of military operations. Safety in the battlespace is a difficult and a non-intuitive task. A lack of de-confliction of the military battlespace in the decision making process may strain the relationship between team members, a situation which may, in turn, jeopardize mission success and undermine the military's ability to provide critical decisions in combat scenarios. It is critical that improvements be made to the coalition interoperability and safety by improving battlespace de-confliction. The integration of systems of systems is an area that requires improvement to reduce latency in transmission, encryption for secure data transmission and visual analytics of the battle space (e.g., Command View).

As part of this project a prototype rifle-mounted BFT was developed to serve as a test bed for experimentation. The prototype was developed through the integration of Commercial Off-The-Shelf (COTS) and Government Off The Shelf (GOTS) systems. It was initially planned to evaluate the prototype in a battlespace scenario between dismounted soldiers in garrison, sensor assets, command post and command and control headquarter. Budget cuts necessitated the scaling back of this plan and the prototype was developed as a working system for demonstration purposes only.

Results

DRDC Toronto partnered with the tactical edge cyber command and control Technology Demonstration Project to put together a proof of concept prototype mobile ad hoc network field BFT test bed. A review of previous research done on the current/future solider tracking system as well as current implementation from allied partners was completed. The field test bed BFT was demonstrated with a mobile ad hoc encrypted mesh network outdoors connected to a simulated command post and command center to demonstrate and test the design of the network and the associated advanced human computer interface tools displaying the information to the individuals in the field.

Future Work and Exploitation

This work will continue/transition (Experimentation with CAF subjects) potential enhancements of the test bed within the tactical edge command and control project as well as potentially in the Battle Space De-confliction project. The results of future experimentation and current test bed development plan will be exploited through the Cyber Task Force and Integrated Soldier System Program (ISSP).

Further work on the proof of concept will demonstrate:

- network and security SA in a tactical Mobile Ad hoc Network (MANET);
- selected attack detection tools in a MANET;
- policy-guided network transformation and C2 to mitigate attack in a tactical MANET;
- C2 tools for conducting full-spectrum cyber operations on peer-level adversaries
- advance human computer interaction media (head mounted displays, mobile phones, etc.) in a field test bed of an ad hoc mobile BFT application; and
- de-confliction of the battle space through the chain of command, from HQ to command post to solider.

Lessons Learned

There are three major outcomes of the ARP 04dq ("Decision Support for Dismounted Soldiers"). These are a) a model of the human cognitive processes of CID, b) preliminary experimentation to validate this model and provide insight into the likely effects of blue-force tracking and rifle-mounted combat identification assist systems on human decision making, and c) a proof of concept prototype mobile ad hoc network field BFT test bed.

These outcomes are documented in a series of reports published by DRDC Toronto or in the open scientific literature (see Annex A).

The following are the major lessons learned during the course of this project.

1. Target identification can be modelled as a multi-attribute classification task for which people can use both heuristic and analytic decision strategies. There is individual variability in preference for heuristic and analytic strategies but strategy selection is guided by an interaction of factors, including the rational such as cue validity, and the extraneous such as cue salience. The effectiveness of a decision strategy depends on the stochastic properties of the target set but generally compensatory strategies will perform better across a wider range of conditions than a heuristic.
2. Learning categorical distinctions of the kind embodied in target identification relies on two competitive learning processes. One is an associative learning process in which the participant samples multiple cues simultaneously and develops cue-outcome associations. The other learning process involves the sequential examination of single cues to serve as a basis for a single-cue heuristic.
3. The SEACID model provides a framework for understanding the interaction of SA and evidence accumulation processes. Although an evidence accumulation process is used to identify targets, situation awareness plays a key role in target identification. SA is used to identify features/cues to focus on, to set evidence thresholds, and to form expectations that "bias" judgments. Position can also be a form of evidence.

4. Numerous systems exist to support CID decision making but few have been rigorously evaluated for effectiveness. Interrogation/response and SA systems offer the most promise as support to dismounted soldiers in the field. Both kinds of systems enhance key aspects of the CID decision making process (target identification and SA, respectively).
5. BFT can substantially improve CID performance in terms of reducing the risk of fratricide. Even a small lag in the update of positional information, however, can eliminate the benefit of BFT. BFT also seems to provide less benefit when used in environments containing civilians. The effects of temporal and spatial error in system performance should be distinguished as they may not have the same impact on human judgment.
6. A mobile ad hoc network field BFT can be created using COTS and GOTS technologies to serve as a test bed for further development of dismounted soldier systems.

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References

[1] Harris, M. J. & Syms, P. R. (2002). Land fratricide and IFF OA review. Farnborough, Hampshire, Defence Science and Technology Laboratory UK.

[2] Regan, G. (1995). Blue on blue: A history of friendly fire. New York: Avon Books.

[3] Wilson, K. A., Salas, E., Priest, H. A., & Andrews, D. (2007). Errors in the heat of battle: Taking a closer look at shared cognition breakdowns through teamwork. *Human Factors*, 49, 243–256.

[4] Hart, R. G. (2007). Combat identification: It's all about combat effectiveness. *The Canadian Army Journal*, 10, 6–11.

[5] Sherman, K. B. (2002). Combat ID coming for individual soldiers. *Journal of Electronic Defense*, 25(3), 34–35.

[6] Defense Science Board (1996). Defense Science Board Task Force on combat identification. Report Number: 20301–3140.

[7] Dean, D. F., & Handley, A. (2006). Representing the human decision maker in combat identification. Proceedings of the 2006 Command and Control Research and Technology Symposium.

[8] Payne, J. W., & Bettman, J. R. (2001). Preferential choice and adaptive strategy use. In G. Gigerenzer & R. Selten (Eds.), Bounded rationality: The adaptive toolbox (pp 124–145). Cambridge, MA: The MIT Press.

[9] Betsch, T., & Glöckner, A. (2010). Intuition in judgment and decision making: Extensive thinking without effort. *Psychological Inquiry*, 21, 279–294.

[10] Tietz, R. (1992). Semi-normative theories based on bounded rationality. *Journal of Economic Psychology*, 13, 297–314.

[11] Todd, P. M., & Gigerenzer, G. (2000). Precis of Simple heuristics that make us smart. *Behavioral and Brain Sciences*, 23, 727–780.

[12] Todd, P. M. (2001). Fast and frugal heuristics for environmentally bound minds. In G. Gigerenzer & R. Selten (Eds.), Bounded rationality: The adaptive toolbox (pp. 51–70). Cambridge, MA: The MIT Press.

[13] Payne, J. W., Bettman, J. R., & Johnson, E. J. (1993). The adaptive decision maker. New York, NY, US: Cambridge University Press.

[14] Klein, G. (1992). Decision Making in Complex Military Environments. Final Contract Summary Report, prepared for Naval Command, Control and Ocean Surveillance Center, Klein Associates, Fairborn, OH.

[15] Ben-Zur, H. (1998). Dimensions and patterns in decision making models and the controlled/automatic distinction in human information processing. *European Journal of Cognitive Psychology*, 10, 171–189.

[16] Hogarth, R. M. (1980). Judgment and choice: The psychology of decision. New York, NY: John Wiley.

[17] Hunt, E. (1994). Problem solving. In R. J. Sternberg (Ed.), Thinking and problem solving (pp. 215–232). San Diego, CA: Academic Press.

[18] Gigerenzer, G., & Goldstein, D. G. (1996). Reasoning the fast and frugal way: Models of bounded rationality. *Psychological Review*, 103, 650–669.

[19] Bröder, A., & Schiffer, S. (2003). Bayesian strategy assessment in multi-attribute decision research. *Journal of Behavioral Decision Making*, 16, 193–213.

[20] Newell, B. R., & Shanks, D. R. (2003). Take the best or look at the rest? Factors influencing "one-reason" decision making. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 29, 53–65.

[21] Bröder, A. (2000). Assessing the empirical validity of the "take the best" heuristic as a model of human probabilistic inference. Journal of Experimental *Psychology: Learning, Memory, and Cognition*, 26, 1332–1346.

[22] Bröder, A., & Schiffer, S. (2003). Take the best versus simultaneous feature matching: Probabilistic inferences from memory and effects of representation format. *Journal of Experimental Psychology: General*, 132, 277–293.

[23] Newell, B. R., Weston, N. J., & Shanks, D. R. (2003). Empirical tests of a fast-and-frugal heuristic: Not everyone "takes-the-best". *Organizational Behavior and Human Decision Processes*, 91, 82–96.

[24] Marewski, J. N., & Schooler, L. J. (2011). Cognitive Niches: An Ecological Model of Strategy Selection. *Psychological Review*, 118, 393–437.

[25] Beach, L. R., & Mitchell, T. R. (1978). A Contingency Model for the Selection of Decision Strategies. *The Academy of Management Review*, 3, 439–449.

[26] Rieskamp, J., & Hoffrage, U. (1999). When do people use simple heuristics, and how can we tell? In G. Gigerenzer, P. M. Todd, & the ABC Research Group (Eds.), Simple heuristics that make us smart (pp. 141–167). Oxford, UK: Oxford University Press.

[27] Rieskamp, J., & Otto, P. E. (2006). SSL: A Theory of How People Learn to Select Strategies. *Journal of Experimental Psychology: General*, 135, 207–236.

[28] Glöckner, A., & Betsch, T. (2008). Multiple-reason decision making based on automatic processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 34, 1055–1075.

[29] Waldron, E. M., & Ashby, F. G. (2001). The effects of concurrent task interference on category learning: Evidence for multiple category learning systems. *Psychonomic Bulletin & Review*, 8, 168–176.

[30] Ashby, F. G., Maddox, W. T., & Bohil, C. J. (2002). Observational versus feedback training in rule-based and information-integration category learning. *Memory & Cognition*, 30, 666–677.

[31] Maddox, W. T., Ashby, F. G., Ing, A. D., & Pickering, A. D. (2004). Disrupting feedback processing interferes with rule-based but not information-integration category learning. *Memory & Cognition*, 32, 582–591.

[32] Bryant, D. J. (2014). Strategy selection in cue-based decision making. *Canadian Journal of Experimental Psychology*, 68, 97–110.

[33] McLeod, C. M. (1991). Half a century of research on the Stroop Effect: An integrative review. *Psychological Bulletin*, 109, 163–203.

[34] Waldron, E. M., & Ashby, F. G. (2001). The effects of concurrent task interference on category learning: Evidence for multiple category learning systems. *Psychonomic Bulletin & Review*, 8, 168–176.

[35] Bröder, A., & Newell, B. R. (2008). Challenging some common beliefs about cognitive costs: Empirical work within the adaptive toolbox metaphor. *Judgment and Decision Making*, 3, 195–204.

[36] Platzer, C., & Bröder, A. (2012). Most people do not ignore salient invalid cues in memory-based decisions. *Psychonomic Bulletin and Review*, 19, 654–661.

[37] Gluck, M. A., & Bower, G. H. (1988). From conditioning to category learning: An adaptive network model. *Journal of Experimental Psychology: General*, 117, 225–244.

[38] Martin, R. C., & Caramazza, A. (1980). Classification in well-defined and ill-defined categories: Evidence for common processing strategies. *Journal of Experimental Psychology: General*, 109, 320–353.

[39] Rieskamp, J., & Hoffrage, U. (2008). Inferences under time pressure: How opportunity costs affect strategy selection. *Acta psychologica*, 127, 258–276.

[40] Hilbig, B. E., Scholl, S. G., & Pohl, R. F. (2010). Think or blink – is the recognition heuristic an "intuitive" strategy? *Judgment and Decision Making*, 5, 300–309.

[41] Glöckner, A., & Betsch, T. (2012). Decisions beyond boundaries: When more information is processed faster than less. *Acta Psychologica*, 139, 532–542.

[42] Dean, D., Vincent, A., Mistry, B., Hynd, K., & Syms P. R. (2005) The Integrative Combat Identification Entity Relationship (INCIDER) conceptual model. Technical Working Paper. Fareham, Hants. Ministry of Defence.

[43] Dean, D., Vincent, A., Mistry, B., Hossain, A., Spaans, M., & Petiet, P. (2008). Representing human decision making in constructive simulations for analysis. *The International C2 Journal*, 2, 1–32.

[44] Endsley, M. R., Holder, L. D., Leibrecht, B. C., Garland, D. J., Wampler, R. L., & Matthews, M. D. (2000). Modeling and measuring situation awareness in the infantry operational environment. Research Report 1753, U.S. Army Research Institute for the Behavioral and Social Sciences: Alexandria, VA.

[45] Looney, C. G., & Liang, L. R. (2003). Cognitive situation and threat assessments of ground battlespaces. *Information Fusion*, 4, 297–308.

[46] Nelson, W. W., & Loftus, G. R. (1980). The functional visual field during picture viewing. *Journal of Experimental Psychology: Human Learning and Memory*, 6, 391–399.

[47] Famewo, J. J., Bruyn Martin, L. E., Zobarich, R. M., & Lamoureux, T. (2007). Decision requirements analysis for the combat identification process. Contractor Report CR 2007–132. DRDC – Toronto Research Centre.

[48] CAE professional Services (Canada) Inc. (2012). Decision support for dismounted soldiers: Final report. Contractor Report CR 2012–035. DRDC – Toronto Research Centre.

[49] Boyd, C. S., Collyer, R. S., Skinner, D. J., Smeaton, A. E., Wilson, S. A., Krause, D. W., Dexter, R. M., Perry, A. R., & Godfrey, J. (2005). Characterisation of combat identification technologies. Proceedings of TENCON 2005 – 2005 IEEE Region 10 Conference (pp. 568–573). Piscataway, NJ: Institute of Electrical and Electronics Engineers.

[50] Vilhena, P. G. S., Zobarich, R. M., & Lamoureux, T. M., (2007). CID literature review. Contractor Report CR 2007–131. DRDC – Toronto Research Centre.

[51] Bryant, D. J., & Smith, D. G. (2013). Impact of blue force tracking on combat identification judgments. *Human Factors*, 55, 75–89.

[52] Bryant, D. J., & Smith, D. G. (2009). Impact of uncertain cues on combat identification judgments. Technical Report (Submitted). DRDC – Toronto Research Centre.

[53] Glenn, R. W., Paul, C., Helmus, T. C., & Steinberg, P. (2007). People make the city: Joint urban operations observations and insights from Afghanistan and Iraq. Report to the United States Joint Forces Command. Rand Corporation: Santa Monica, CA.

[54] Bryant, D. J., (2012). Sequential Evidence Accumulation for Combat IDendtification (SEACID). Technical Report TR 2012–046. DRDC – Toronto Research Centre.

[55] Rasmussen, R. E. (2007). The wrong target: The problem of mis-targeting resulting in fratricide and civilian casualties. Unpublished Masters Thesis. Joint Advanced Warfighting School. Norfolk, VA.

[56] Bryant, D. J., 2012. Impact of Civilians on the Effectiveness of Blue Force Tracking. TM 2012–100. DRDC – Toronto Research Centre.

[57] Hedges, L.V. (1981). Distribution theory for Glass's estimator of effect size and related estimators. *Journal of Educational Statistics*, 6, 107–128.

[58] Ho, G., Hollands, J. G., Tombu, M., Ueno, K., & Lamb, M. (2013, September). Blue Force Tracking Effects of Spatial Error on Soldier Performance. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting (Vol. 57, No. 1, pp. 182–186). SAGE Publications.

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Annex A   List Project Deliverables

CAE professional Services (Canada) Inc. (2012). Decision support for dismounted soldiers: Final report. Contractor Report CR 2012–035. DRDC – Toronto Research Centre.

Bryant, D.J., 2012. *Sequential Evidence Accumulation for Combat IDendtification (SEACID)*. TR 2012–046. DRDC – Toronto Research Centre.

Bryant, D.J., 2012. *Impact of Civilians on the Effectiveness of Blue Force Tracking*. TM 2012–100. DRDC – Toronto Research Centre.

Bryant, D. J. *Decision Support for Dismounted Soldier Systems*. Paper presented at the Defence Personnel Research Symposium, Ottawa, ON, June 2012.

Humansystems Inc. (2012). *Section Level Experimentation: Blue Force Tracking and Identification Friend or Foe*. Scenarios developed for experimentation.

Bryant, D.J., & Smith, D.G. (2013). Impact of blue force tracking on combat identification judgments. *Human Factors, 55*, 75–89.

Ho, G., Hollands, J. G., Tombu, M., Ueno, K., & Lamb, M. (2013, September). Blue Force Tracking Effects of Spatial Error on Soldier Performance. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting (Vol. 57, No. 1, pp. 182–186). SAGE Publications.

Bryant, D.J. (2014). Strategy selection in cue-based decision making. *Canadian Journal of Experimental Psychology, 68*, 97–110.

List of Symbols/Abbreviations/Acronyms/Initialisms

3D	Three dimensional
ARP	Applied Research Project
BFT	Blue Force Tracking
C2	Command and Control
CAF	Canadian Armed Forces
CID	Combat Identification
COA	Course of action
COTS	Commercial Off The Shelf
DRDC	Defence Research & Development Canada
FA	False alarm
FOV	Field of view
FY	Fiscal Year
GOTS	Government Off The Shelf
GPS	Global Positioning System
HQ	Headquarters
IFF	Interrogate Friend Foe
INCIDER	Integrative Combat Identification Entity Relationship
ISSP	Integrated Soldier System Program
MANET	Mobile Adhoc Network
NVGs	Night Vision Goggles
ROE	Rules of Engagement
SA	Situation Awareness
SEACID	Sequential Evidence Accumulation for Combat IDentification
TTB	Take-the-Best

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The purpose of this report is to summarize the work conducted within Project 04dq "Decision Support for Dismounted Soldiers." The report begins with a review of the project objectives and provides some background concerning the need for this work. The project achievements are summarized with descriptions of the major research accomplished. Among the major outcomes are: a) a model of the human cognitive processes of CID, b) preliminary experimentation to validate this model and provide insight into the likely effects of blue-force tracking and rifle-mounted combat identification assist systems on human decision making, and c) a proof of concept prototype mobile ad hoc network field BFT test bed. A complete list of lessons learned from the project is provided. The report ends with discussion of potential avenues for exploitation of the project results and suggestions of future research and development directions.

Le présent rapport résume les travaux réalisés dans le cadre du projet 04dq intitulé « Aide à la décision à l'intention des soldats débarqués ». Il débute par un rappel des objectifs du projet et justifie, dans une certaine mesure, sa raison d'être. Les résultats obtenus y sont résumés, assortis de la description des principales recherches effectuées. On compte parmi les principales réalisations dans le cadre de ce projet a) un modèle des processus cognitifs humains se rapportant à l'identification au combat (IDCbt); b) l'expérience préliminaire servant à valider le modèle, de même qu'à saisir les effets possibles des systèmes montés sur arme pour le suivi de la force bleue et l'aide à l'identification au combat dans les processus décisionnels humains; c) un prototype de validation de principe d'un banc d'essai du réseau mobile ad hoc pour le suivi de la force bleue sur le terrain. La liste complète des leçons retenues en cours de projet est jointe. Le rapport se termine par une discussion des moyens possibles d'exploiter les résultats et des suggestions d'orientations pour la recherche et le développement à venir.

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Combat identification, blue force tracking, decision making.