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Toward a Methodology for Evaluating the Impact of Technologies on Infantry Situation Awareness

Madeleine C. Guille and Han Tin French

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ABSTRACT

One of the key force modernisation initiatives for infantry operations is to enhance situation awareness (SA) capabilities. The design and acquisition of technologies that optimise the performance of the combat soldier must therefore be guided by the goal of enhancing and maintaining SA. Determining the value of these technologies requires a means of objectively evaluating a combat soldier's SA. In this study, the impact of Intra-Section Radios, which form part of the Soldier Combat System (SCS) enhancements, on SA was evaluated. The Situation Awareness Global Assessment Technique provides an objective measure of SA by comparing the real and perceived situation. In this study, the Direct Questioning Technique (DQT), an adapted version of the SAGAT was used to evaluate changes in SA under baseline and enhanced conditions during two loosely scripted exercises involving Australian Air Field Defence Guards. Results showed a significant increase in overall group SA during the enhanced patrol vignette. No significant results were found for the section attack vignette. The DQT appears to be a valid and viable methodology that can be used in the evaluation of specific SCS technologies.

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Toward a Methodology for Evaluating the Impact of Soldier Combat System Technologies on Situation Awareness

Executive Summary

This report describes a methodology for measuring infantry situation awareness (SA). It is part of the development of a formal analysis methodology that can be applied by agencies involved in evaluation of future technologies. In this study the impact of the intrasection radio (ISR) on SA was assessed. The ISR has been identified as one of the Soldier Combat System (SCS) technologies that provides high pay-off in terms of enhancing performance. Part of the purpose of this work was to identify the strengths and weaknesses of the method.

As technology advances, the enhancement of operator situation awareness has become a major design goal for those developing new technologies to increase performance. The ability to objectively evaluate the impact of technology on SA is therefore essential. The Situation Awareness Global Assessment Technique (SAGAT) provides an objective measure of SA through a comparison between the real and perceived situation. The SAGAT consists of a pool of questions that elicit information from an operator in a simulated environment across all three levels of SA, namely perception, comprehension and projection. The simulation is 'frozen' at random while the operator answers a series of randomly selected questions about the current situation. These questions correspond to the operator's SA requirements.

A study consisting of a baseline and enhanced free-play exercise was conducted to investigate the effect of the ISR on SA. Ten Air Field Defence Guards participated in two vignettes, loosely scripted around the mission scenario ' Exercise Silicon Shrike'. In the enhanced trial, the contribution of the ISR to the SA of the individual section members was evaluated. Two vignettes (Ready Reaction Force (RRF) Patrol; Section Attack) appropriate for a section activity were used in each trial. The Direct Questioning Technique (DQT), a modified version of the SAGAT, was used to provide an objective measure of SA. The DQT differs from the original SAGAT technique in that it is applied in a live exercise rather than a computer simulation.

During both trials, the scenario was frozen at three 'natural breaks', during which subjects answered a randomised subset of questions about the current situation, based on the SA requirements of the soldier. After the completion of the exercise, subjects' answers were evaluated by a subject matter expert (SME) on the basis of what was actually happening during the activities. Questions were scored based on a 'percentage correct' method. A post-experiment interview with the two Military SME was also used to get a qualitative account of the use of the ISRs during the enhanced trial.

Results showed that in the enhanced RRF Patrol vignette, subjects overall showed a significant increase in SA compared to baseline conditions. This result seems logical as even though the ISR was not used extensively (as indicated by the post-experiment interview), there was still a greater dissemination of information throughout the section. There was no significant difference in SA between the baseline and enhanced section attack. Given that the ISR was hardly used during this activity (as indicated by the post-experiment interview), this result again seems logical.

The DQT and free-play methodology was able to successfully discriminate between baseline and enhanced conditions, even with the small sample size. The key strength of the method is that it assesses the subjects' SA by directly asking them for information pertaining to the operational environment. It is therefore more objective than subjective measures that rely on self-assessment or expert judgements on how good or poor the subject's SA is. In the future, further validation of the methodology, consisting of additional trials with larger samples and a higher number of probes, is essential. Audio and video recordings of the activities may be useful to support the determination of the 'ground truth' by the SMEs. The DQT appears to be a valid and viable methodology that can be used in the evaluation of future technologies such as Head Mounted Displays and Night Vision Goggles, for acquisition.

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In 2003 Madeleine C. Guille undertook a year long research placement as an Industry-based learning student in the Land Operations Division of DSTO. During her placement Madeleine was involved in Human Factors Research in the Human Sciences Discipline, specifically in the area of Infantry Situation Awareness. A Bachelor of Arts graduate with a major in Psychology, Madeleine returns to fulltime study in 2004 at the University of Adelaide to complete her Arts/Law double degree, with a possibility of undertaking Honours in Psychology in 2005.

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Contents

1. Introduction

The modern battlespace, especially that occurring in an urban area, presents a complex and dynamic operational environment. An increased prevalence in digitisation, joint warfighting and coalition operations has emphasised the importance of situation awareness (SA) in tactical environments. Within the combat arms of the military, the infantry is one of the most difficult and demanding professions. Physically, cognitively and morally challenging, it is also extremely dangerous. The infantry is often the most exposed of the combat arms, with little or no physical barrier between its soldiers, the enemy and the environment. Operating against enemies that are not easily identified, and differentiating between friendly, enemy and civilians, is but one example of the more cognitively challenging aspects of infantry operations in the urban environment.

The Land 125 Soldier Combat System (SCS) is a program to modernise the dismounted infantry and provide them with advanced capabilities including new technologies. The intra-section radio (ISR) has been identified as a technology that provides high pay-off in terms of enhancing performance [1]. The use of ISRs facilitates communication between section members and may be expected to enhance their SA. On the other hand SA may decrease if the radios are used inappropriately.

Previous research [1-3] evaluating the impact of technological enhancements on Australian soldiers' capabilities have used performance-based measures as the primary dependent variable.

In the current study the impact of the ISRs on SA is assessed using the Direct Questioning Technique (DQT) [4] based on the Situation Awareness Global Assessment Technique (SAGAT) [5]. It is part of the development of a formal analysis methodology that can be applied by agencies involved in evaluation of future technologies. As such, part of the purpose of the work is to identify the strengths and weaknesses of the method.

2. Situation Awareness

2.1 Definition

The Australian Army acknowledges that the development and maintenance of SA is a key component in both operational decision-making and effective command and control; whilst poor SA can lead to catastrophic errors [6].

Although the phrase 'situation awareness' is frequently used by the armed forces from different nations, there is no universally accepted definition. At its most basic conception, situation awareness is generally understood to mean "knowing what is going on around you" [7]. Within the research community the definition of SA put forward by Endsley [5] has been widely accepted in various domains: "the perception of elements in the environment within a volume of time and space, the comprehension of their meaning and projection of their status into the near future". This definition is useful as it provides structure to the SA construct by dividing it into three hierarchical levels. Level 1, the lowest level of SA, involves perceiving cues from the environment. Level 2 involves integrating these perceptual cues with other information and comprehending their meaning and significance. Level 3, the highest level of SA, involves projecting from current events and anticipating future events.

2.2 Model

Based on this definition, Endsley [8] developed a model of SA in dynamic decision making. A diagram of Endsley's model is shown in Figure 1.

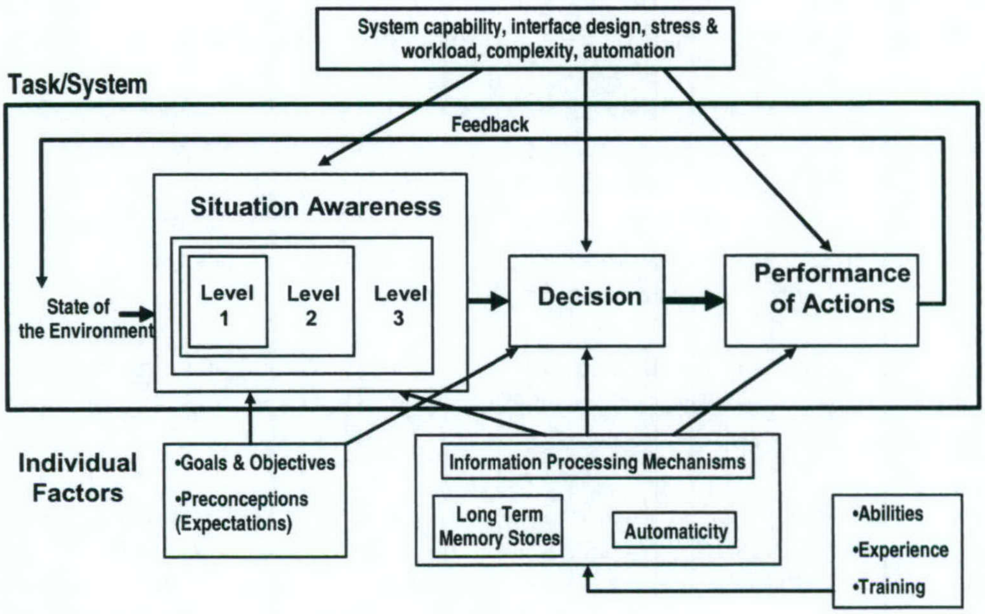

Figure 1: Model of SA in dynamic decision making [8]

According to the model, SA is clearly separated from decision making and performance. Decision making and performance are shown as separate stages that will proceed directly from SA. A high level of SA does not however guarantee high quality decision making or performance. Several major factors are shown to influence this process. All three stages of the process can be influenced by individual factors such as innate abilities, experience, training, fatigue, propensity for risk taking[1], and task factors such as workload, stress, and complexity.

2.3 SA Measures

As technology advances, the enhancement of operator situation awareness has become a major design goal for those developing new technologies to increase performance. The ability to objectively evaluate the impact of the technology on SA is therefore essential. To this end various methods have been developed for measuring SA. Several of these measures which are relevant to infantry SA are reviewed in the following section.

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[1] The propensity for risk-taking is expected to affect only the latter two stages of the process.

2.3.1 Objective Measures of SA

2.3.1.1 Situation Awareness Global Assessment Technique

SAGAT [5] is a direct experimental technique for measuring SA through queries or probes and provides an objective assessment of SA through a comparison between the real and perceived situation. The SAGAT, originally developed for the aviation domain (commercial pilot, fighter pilot, air-traffic control e.g. [9-11]), has also been applied, sometimes in a modified form, in many other domains including infantry (section, platoon and brigade level in real and virtual environments e.g. [4, 12, 13]), automotive (driving, navigation e.g. [14-18]), nuclear energy (nuclear power plant operation, tele-operations of nuclear materials handling e.g. [19-20], and medicine [21]).

The SAGAT consists of a pool of questions that elicit information from an operator in a simulated environment across all three levels of SA. The simulation is 'frozen' at random while the operator answers a series of randomly selected questions about the current situation. These questions correspond to the operator's SA requirements. Temporary freezes in the simulation must be of a short duration to minimise intrusiveness and memory decay. Randomisation of questions is necessary to counter any possible learning effects. After the completion of the simulation, the answers are evaluated on the basis of what was actually happening during the simulation.

The main advantage of SAGAT is that it allows an objective, unbiased index of SA [22]. The SAGAT also measures SA directly by asking subjects for information pertaining to the operational environment. Another strength of the method is that it possesses a high degree of content validity[2] based on the SA requirements analyses used to create the queries. SAGAT has also been shown to have criterion validity[3], predicting operator performance in an air combat task [24].

The main disadvantage of the SAGAT is the perceived intrusiveness of freezes in the exercise/simulation to collect data, and the criticism that the technique might not provide a true reflection of operator's SA as it relies on memory [22].

2.3.1.2 Behavioural Measures for Inferring SA

Infantry leaders and soldiers might be expected to act in certain ways based on their SA. Therefore, some information about SA may be inferred from examining behaviours on specific subtasks of interest [25]. Such behavioural indices might include reaction time to make a response (verbal/non-verbal), time to complete a scenario, loss exchange ratio, and decision making, whereby a particular conclusion is used to infer the SA that underlies the decision [25].

The advantage of using behavioural indices to infer SA, is that the measures are objective, readily observable and usually non-intrusive. A disadvantage of these measures is that they assume what appropriate behaviour should be, given the soldier's SA. These assumptions may not always be warranted. For example, different soldiers may respond very differently to the same situation if they choose different combat

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[2] Content validity refers to the extent to which a measure of some variable samples a domain, such as a field of knowledge or a set of job behaviours [23].

[3] Criterion validity refers to the extent to which a test predicts performance [23].

procedures, and may prioritise tasks differently than expected, or not act in an overt way, even though they recognise and understand the information at hand [25].

2.3.1.3 *Performance Measures for Inferring SA*

While behavioural and performance measures are similar, in general, performance measures also reflect the ability of the soldier to carry out the desired action (e.g. marksmanship) as well as his choice of behaviours (e.g. shoot at the target) [25].

Like behavioural measures, the advantage of using performance measures as indicators of SA is that the measures are objective, observable and usually non-intrusive. Several limitations exist in using performance data to infer SA however. Global performance measures (e.g. success in meeting a goal, kills in a battle) suffer from problems of diagnosticity and sensitivity. Many moderating factors can influence the link between SA and performance, so global performance measures will only provide an indirect indication of SA. Determining appropriate measures for discrete task performance is also difficult. This stems from the interactive nature of SA sub-components. For example, a new system or training technique enhancing SA on one factor may simultaneously reduce SA on another, unmeasured factor. Unless performance measures are chosen carefully, these problems may not be detected. In addition, it is quite easy for participants to bias their attention to a single issue which is under evaluation if they know or suspect the purpose of the study [25].

2.3.2 Subjective Measures of SA

2.3.2.1 *Situation Awareness Behaviourally Anchored Rating Scale*

SABARS [26] is a direct subjective measure of SA that uses expert observations to rate an operator on behaviours linked to SA. SABARS, originally developed for the infantry domain, measures SA at the platoon level, and is based on the SA requirements analysis of infantry platoon leaders.

The SABARS metric consists of 27 behaviours and actions linked to SA in Military Operations in Urban Terrain (MOUT) missions. During virtual or field simulated missions, observers/controllers observe the platoon leaders and rate performance on a five point scale (very poor to very good) at the end of each mission.

SABARS has several advantages for rating SA in the field. Firstly, it is relatively unobtrusive – unlike SAGAT it does not require periodic stopping of the exercise. Secondly, the SABARS items describe concrete behaviours that are readily observable, thus it is a relatively direct and objective approach to assessing SA. Thirdly, the method is viewed as relevant and acceptable by users. For example, the Royal Norwegian Army Academy plans to incorporate SABARS into its after action review procedures [27].

The main disadvantage of the method it that the SABARS items are mission specific, like SAGAT. Therefore a SA requirements analysis or other method must be employed to generate SABARS items for each specific type of mission that is being evaluated [27].

2.3.2.2 *Situation Awareness Rating Technique*

SART [28] is a subjective SA measure that uses operator self-ratings to assess perceived SA. SART assumes that operators use understanding of situations in making decisions, that this understanding is consciously available, and that it can be quantified and made unambiguous.

Originally developed for the aviation aircrew domain, SART uses a self-rating questionnaire to measure subjective SA in 3 or 10 dimensions. The 3-dimensional (3-D) SART is an abbreviated version of the 10-dimensional (10-D) SART that is used when the 10-D version would be too intrusive or time consuming for the measured task.

The SART dimensions reflect generic SA constructs, and were derived from an extensive study of the subjective descriptions of 43 different air warfare scenarios by 86 pilots. Because the constructs are general in nature they are applicable to other domains. The 10 generic SA constructs are: instability of situation, variability of situation, complexity of situation, arousal, spare mental capacity, concentration, division of attention, information quantity, information quality, and familiarity. The 10 SA constructs are grouped into three broad domains to form the 3-D SART. *Attentional demand* encompasses constructs of instability of situation, variability of situation, and complexity of situation; *attentional supply* includes the constructs of arousal, spare mental capacity, concentration, and division of attention; and *understanding* incorporates information quantity, information quality, and familiarity.

SART analysis begins with the creation of scenarios or stimulations that feature the situations of interest. During these trials or scenarios, the operator is provided with either a 3-D or 10-D SART chart to record his/her perceptions of SA at a given point in time. When using the 3-D SART, the subjects typically mark their rating along the 3 dimensions on a continuous 100-millimeter line with the endpoints *low* (0 mm) to *high* (100 mm). Current implementations of the 10-D SART employ a 7-point rating scale from *low* to *high* for each of the 10 SA constructs, along which the subjects quantify their qualitative observations. The scores from the charts are then statistically analysed to determine how aspects of the task affect SA. In addition to scale ratings on the 3-D version, a summative score is derived that is interpreted as an estimate of overall SA. This score is derived from the following algorithm: SA(calc) = Understanding — (Demand — Supply). This formula was derived from theoretical understandings of how the three domains interact.

An advantage of SART is that it provides a certain level of diagnosticity [29]. Resolving SA into individual SART dimensions provides some diagnostic and predictive indicators for delineating the strengths and weaknesses associated with SA as measured by the scale.

Proponents suggest that workload is an integral part of the SA construct and that understanding the relationship between SA and workload is essential in order for SA to be an effective design evaluation measure [28]. Thus, an advantage of SART is that since it takes into account the supply and demand of attentional resources, it should provide some measure of how changes in workload affect SA [29].

A criticism of SART is that including workload elements within the SA scale confound the measure of SA by confusing it with workload [29]. SART has been shown to be correlated with performance measures, but it is uncertain whether this is due to the workload component or understanding (SA) component of the scale [30].

Another disadvantage of the method is that the necessity and sufficiency of the 10 general constructs within the 3 domains has not been clearly established, and the developers acknowledge that considerable scope for scale development remains [29].

2.3.2.3 Mission Awareness Rating Scale

The MARS [30] is a modified version of the Crew Awareness Rating Scale (CARS) [31] adapted to the military infantry domain.

The instrument consists of two subscales. One assesses SA content (Content Subscale) and the other assesses SA workload (Workload Subscale). Each subscale consists of four questions that address the three levels of SA as defined by Endsley [5] – *identification, understanding, prediction*. In addition, a fourth question deals with how well mission goals can be identified. The Content Subscale contains questions relating to the subject's *ability* to identify, comprehend, predict and decide in the given mission. The Workload Subscale contains questions relating to the subject's *difficulty* in identifying, comprehending, predicting and deciding in the given mission.

At the completion of a virtual or field simulated mission, participants are asked to self-assess their level of SA and the amount of workload required to achieve that level of SA along a scale from very easy/well/aware to very difficult/poor/unaware.

The main advantage of MARS is that it is generic and does not need to be tailored to each specific mission or usage. MARS is also easy for respondents to understand and use, and is acceptable in field training exercises due to its unobtrusiveness [27].

A disadvantage of MARS is that it is not yet clearly established that the instrument in fact measures SA. In order to demonstrate that MARS actually measures SA per se, it is necessary to compare MARS responses against a more objective and validated measure e.g. SAGAT [5].

2.3.2.4 Post Trial Participant Subjective SA Questionnaire

The PSAQ [33] is a three-item instrument designed to assess a subject's perceived level of SA, workload and quality of performance. The PSAQ is administered at the conclusion of a scenario and each item is rated on a five-point scale. Subjects are asked to self-rate how hard they were working (1 = not hard; 5 = extremely hard), how well they performed (1 = extremely poorly; 5 = extremely well), and how aware they were of the evolving situation during the scenario (1 = not aware; 5 = completely aware). Subjects are also given the opportunity to write down any further 'comments' at the end of each item. The PSAQ is a relatively new technique, and as such its utility and validity has not yet been extensively tested.

3. Method

3.1 Exercise Silicon Shrike

3.1.1 Introduction

The study consisted of a free-play exercise. Free-play exercises realistically replicate most of the critical aspects of a soldier's environment and are a standard method of training individuals and units in fundamental combat skills. In each trial, ten Air Field Defence Guards participated in two vignettes, loosely scripted around the mission scenario 'Exercise Silicon Shrike' [3]. In the enhanced trial, the contribution of the ISR (Motorola GP300 Radios) to the SA of the individual section members was evaluated. A diagram of the communication flow during baseline and enhanced trials is shown in Figure 2.

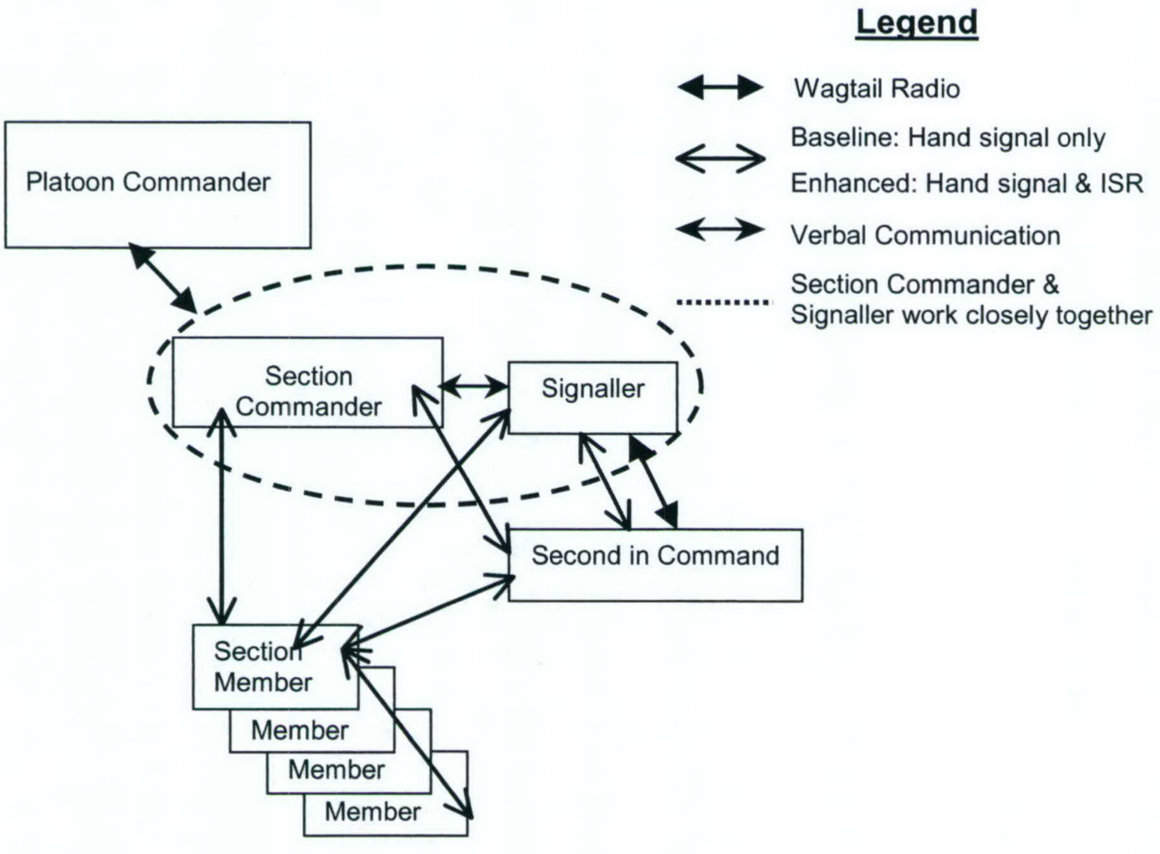

Figure 2: Baseline and enhanced section communication flow

3.1.2 Silicon Shrike Scenario

The Silicon Shrike scenario involved a Ready Reaction Force (RRF) section being tasked to respond to a theoretical enemy - Musorian Armed Forces Special Forces (MAF SF) - activity within Tactical Area of Responsibility (TAOR) Bulldog. The intent of the MAF SF was to resupply and regroup before conducting further operations against Australian Defence and Government installations and personnel. The mission of the RRF section was to destroy all enemy elements within TAOR Bulldog in order to deny their resupply and further operations against Commonwealth infrastructure and personnel.

3.1.3 RRF Section

The section is commanded by a Section Commander, who is responsible for three smaller manoeuvre groups within the Section;, these are the scout group, the rifle group and the assault group. The scouts, who operate forward of the Section, are responsible for gathering information and reporting signs of enemy activity. The second-in-command (2IC) is the leader of the gun group. This group carries one of the machine guns in the Section and is usually used to provide fire support during a Section assault on an enemy position. The assault group is usually employed to close with and assault the enemy position. For the purpose of the current study, a differentiation is made between the command group, namely the section commander and 2IC, and the rest of the section. The command group has a higher responsibility for the whole section. This means their SA requirements are more extensive than those of the other section members, as has been reported previously [25].

3.1.4 Subjects

Ten Air Field Defence Guards from 1-Air Field Defence Squadron (AFDS) participated in the experiment. Subjects' age ranged from 18 to 37 years (M=23.31, SD= 5.54). The overall military experience was low, with time in service ranging from 10 months to 5 years (Median = 1). In both baseline and enhanced trial, seven section members comprised the friendly force and three section members comprised the enemy force. Two military subject matter experts (SME) participated in the trial, one as the Platoon Commander (CAPT) for the RRF section as well as an observer for the study, and one as an observer (WO2) but only for parts of the activities

3.1.5 Murray Bridge Range Complex

The experiment was conducted at the Murray Bridge Range Complex at Murray Bridge, South Australia. The Area of Operations (AO) was a 4 km^2 site north east of the Range Complex. The vegetation consisted mainly of gum trees, with density ranging from scattered to medium to the north, and medium to dense to the south. Prominent features found within the AO included enemy village (six buildings), Mobile Mechanical Range (MMR; 2 buildings and 1 tower), high features (76 m, 84 m), quarry, gates (three), razor wire fence and unsealed roads. A map of the TAOR Bulldog is shown in Figure 3.

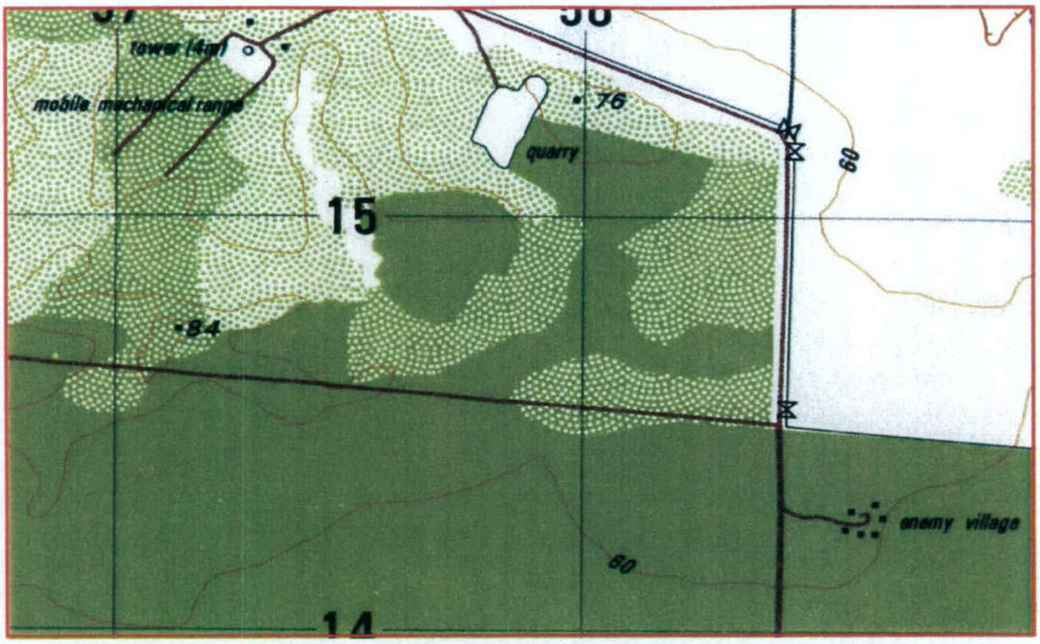

Figure 3: Murray Bridge Range Complex- TAOR Bulldog

3.1.6 Free-play Vignettes

Two free-play vignettes appropriate for a section activity were used in each trial. The study was conducted over two days. The activities to be performed were basic Infantry Minor Tactics (IMTs) at a baseline section level. At this level, Air Field Defence Guards are suitable subjects, as they are trained to perform similar activities to Army infantry. This was confirmed by SME observation of the exercise. The first vignette was a RRF patrol. The patrol distance of 2.15 km took 1 hr 48 min to complete at patrol pace. During the baseline trial the section patrolled from the MMR to the Enemy Village. During the enhanced trial the section patrolled from the Enemy Village to the MMR. The second vignette was a section attack. In both trials the section attack took 20 minutes to complete, and occurred approximately 500 m south from the end location of the Patrol. The baseline RRF patrol followed by baseline section attack occurred on the first day. On the second day the participants undertook the enhanced RRF patrol and, subsequent to that, enhanced section attack.

3.2. SA Question Development

A crucial part of the DQT is the development of the pool of SA questions. During the exercise SA questions that are appropriate to the situation must be asked. Since SA covers many aspects, only a subset of these can be elicited at a particular time. In the current study, the aim was to include as many SA elements as possible in the limited number of probing sessions available.

SA questions are developed from the knowledge of the information required by the operators, given the scenario, mission and goals. A comprehensive analysis, which generally requires an intensive effort, is needed to elicit the information requirements. For SA in infantry section activities, information requirements have been investigated in detail by other researchers [1-2, 4, 12-13, 25-26, 31, 33-39]. It reduced considerably the amount of analysis required for the present study. A list of information requirements was compiled based on the published papers, supported by military publication [6, 40-41]. This list was divided into those requirements critical for an RRF Patrol and Section Attack and structured around the military SMEAC [40] (Situation, Mission, Execution, Administration & Logistics, Command & Signals) concept. This is a concept used by the Army when preparing orders. These information requirements were then converted to question form. A total pool of 68 questions was created and validated by three SMEs with extensive military experience. (These were the same SMEs as those mentioned in Section 3.1.4, aided by a Lieutenant).

The validation by the SMEs focussed on three aspects: (i) the relevance of the questions to the specific scenario and mission for the exercise, (ii) the appropriateness of the questions in relation to the roles of the section members, (iii) the language used in the questions to ensure that it could be understood by the potential subjects.

Due to the need to minimise the intrusiveness during the trials, the SMEs were asked to identify the most critical questions out of the pool so as to limit the temporary freezes to five minutes. SMEs were also asked to identify to whom the questions were relevant (ie. Section Commander, Section Member). Following this process, a total pool of 46 questions, covering all three levels of SA, was obtained. Results from the validation process indicated that critical SA requirements varied according to the level of command. Therefore, whilst the number of questions for the Section Commander and 2IC remained at 46, the pool of SA questions for the section members was reduced to 33. (The pool of questions is shown in Appendix A).

The classification of the questions to the three SA levels was performed by the researchers based on the definition of SA utilised in the study. Questions relating to the perception of cues were classified as level 1, as were those that elicited information provided to the subjects in the exercise brief, for example "Outline the patrol route on the map". Questions that required the subjects to integrate several pieces of information to assess the significance of cues addressed comprehension and were classified as level 2. An example is "Did the Patrol help you discover any habits of the MAF SF? If so, give details". Finally, level 3 questions were those that required the subjects to make a prediction of future events, for example "Mark on the map the most likely enemy OP positions". An examination of the questions and their classification as shown in Appendix A may give the impression that the classification of the questions to the different levels is arbitrary. This is not the case, as it depends on whether the information is provided to the subjects or whether they have to derive it from perceptual cues integrated with other pieces of information. For example, if the enemy strength is given as part of the brief, it is level 1. If it is concluded from observations combined with other information, it is level 2. It is true that in some cases the delineation into the different levels is not clear-cut.

Questions were then allocated to the baseline and enhanced conditions, albeit ensuring that all three levels of SA were represented. In addition, various questions were allocated to the different phases of the exercise by the researchers in consultation with the SMEs. These were based on the intimate knowledge of the terrain, what the subjects were expected to do, given the scenario, mission, and cues planted to indicate "enemy" activities. For example it would be pointless to ask the question "mark on the map any prominent objects and reference points" on the phase where such objects did not exist. Not all of the questions were so specific in nature, in which case they could be asked at different phases.

A summary of the distribution of questions is shown in Table 1.

Table 1: Distribution of SA questions

Free-play Vignette	Number of SA Questions	
	Sect Comd/ 2IC	Section Member
RRF patrol - Baseline	13	9
RRF patrol - Enhanced	11	8
Section attack - Baseline	11	8
Section attack - Enhanced	11	8

The SA questions consist of three forms. The participants are required to: (i) indicate locations on a copy of a map, (ii) sketch a diagram showing where the members of the section are, or (iii) simply provide written answers to specific questions. The questions do not include those that require either a "yes" or "no" answer or those of multiple-choice form.

3.3 Data Collection Technique

The DQT [4], a modified version of the SAGAT was used to provide an objective measure of SA. The DQT differs from the original SAGAT technique in that it is applied in a live exercise rather than a computer simulation. This has three main implications. Firstly, all the questions are in a paper-based rather than electronic form. Secondly, the comparison of the real and perceived situation is performed by a SME rather than comparing subjects' answers to data collected from the simulation computers. Thirdly, the live exercise is 'frozen' at naturally occurring breaks rather than in a totally random fashion.

For the current study the DQT was piloted in activities that included a reconnaissance patrol within a specific scenario. Six Army personnel conducted the exercise that took place on the eastern area of DSTO Edinburgh. It provided the opportunity for the researchers to refine the data collection technique and analysis. The subjects involved in the pilot study did not participate in the study conducted at Murray Bridge.

Prior to the start of the activities on the first day at the Murray Bridge Range complex, the subjects were provided with a short brief about the aim of the study and the method by which the data was going to be collected. They were also asked to read a sheet containing information about the study and their part in it, following which they were requested to sign a consent form.

During both baseline and enhanced trials, the free-play exercise was frozen at three naturally occurring breaks in the normal course of events, each of five-minute duration. At the start of the break, subjects were informed that they had to answer the SA questions. The folders containing the appropriate sheets were distributed. The subjects sat down and wrote their responses, after which the folders were collected. Subjects answered a subset of the pool of questions about the current situation, based on the situation awareness requirements of the soldier. All the section members received the same question set. The Section Commander and 2IC received the same set with a few additional questions relating more specifically to their roles.

After the completion of the exercise, subjects' answers were evaluated by one of the SMEs (CAPT) on the basis of what was actually happening during the activities, supported by quantitative Tactical Engagement Simulation System (TESS) and Global Positioning System (GPS) data. Questions were scored with 1 for a completely correct answer and 0 for an incorrect answer. A score between 0 and 1 was possible if the answer was only partially correct. For example if a question has four components, 0.25 will be awarded for each correct response. A "don't know" or nil response was regarded as a totally incorrect answer. Scores were then summed for each vignette for each person. The final score was expressed in terms of the total correct score as a percentage of the total maximum possible score.

A post-experiment interview with the two military SMEs was also used to get a qualitative account of the use of the ISRs during the enhanced trial.

4. Results

4.1. Quantitative Analysis

Each of the subjects' responses to the SA questions were scored by the SME (CAPT) in the presence of the researchers. During this process, three questions (Q11, Q12, Q35) were removed from the question pool as they were found to be irrelevant for the specific activities.

4.1.1 SA scores

The SA scores are shown in Figure 4. It shows the individual scores for each of the seven subjects when they participated in the four activities, namely baseline RRF patrol, baseline attack, enhanced RRF patrol and enhanced attack. The examination of the data provided some insights on how the scores changed as the different activities were performed.

Individual analysis revealed that Subject 4, the highest ranked (CPL) and most experienced soldier (5 years), had the highest total correct responses summed across all vignettes (M=0.89, SD=0.27).

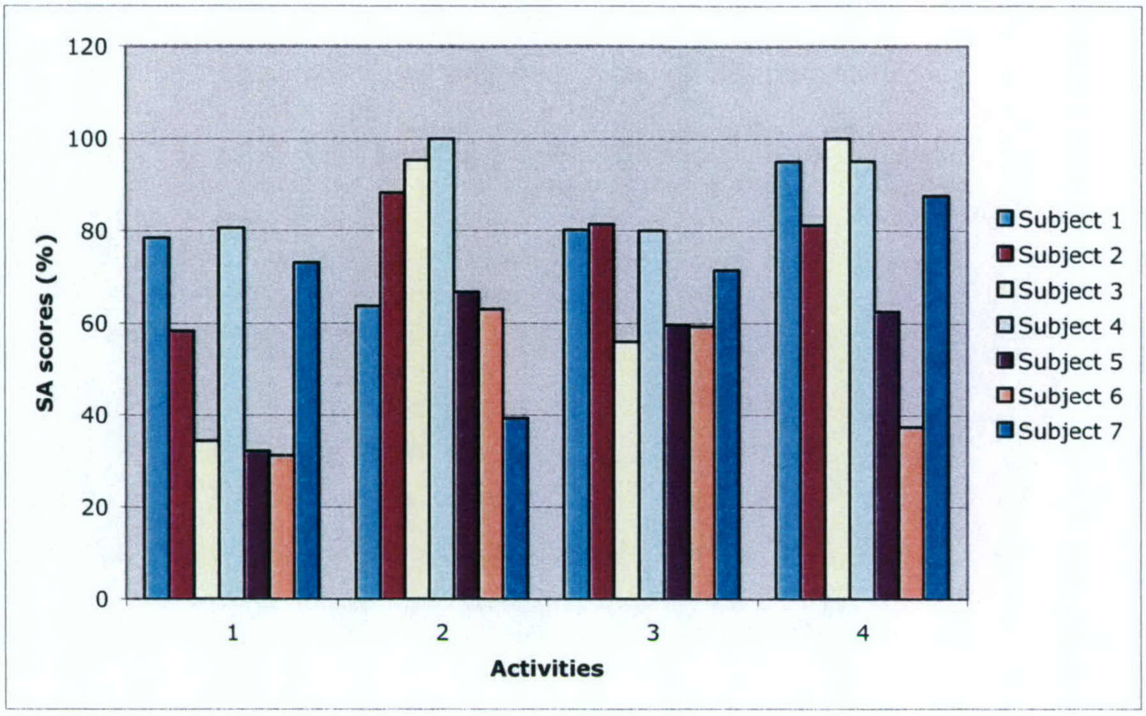

Figure 4: Individual SA scores across the four activities (1-baseline RRF patrol, 2-baseline attack, 3-enhanced RRF patrol, 4-enhanced attack)

4.1.2 Paired Samples T-test

Two paired samples t-tests were computed to analyse whether there was a significant difference in SA between baseline and enhanced trials. An alpha of 0.05 was used for all statistical tests. Since it was hypothesised that SA may increase or decrease depending on whether the ISR was used correctly, two-tailed paired samples t-tests were used. Results revealed a significant increase in enhanced RRF patrol (M= 0.55, SD=0.22) compared to the baseline RRF Patrol (M=0.70, SD=0.11): t(6)=2.75 p=0.03. The η^2 statistic of 0.56 indicated a large effect [42]. No significant differences in SA were found between the baseline section attack (M=0.74, SD=0.22) and enhanced section attack (M=0.80, SD=0.22): t(6)=0.64 p=0.55. These results are presented graphically in Figure 5. The small amount of data and the small sample size did not permit further analysis of the results in terms of SA level 1, 2 and 3.

There was no significant difference in SA between the baseline and enhanced section attack.

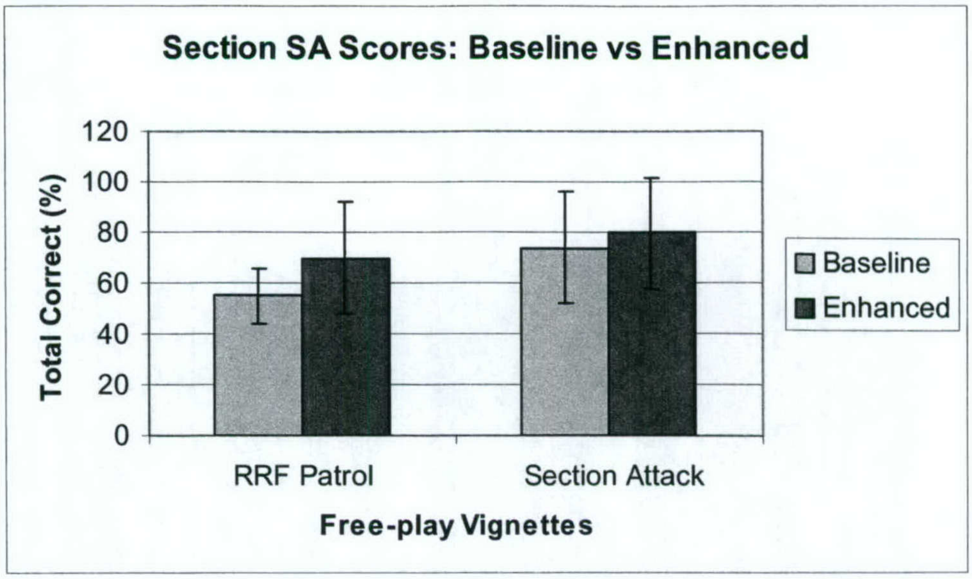

Figure 5: Comparison of total percentage of correct responses during baseline and enhanced freeplay vignettes.[4]

4.2. Qualitative Analysis

4.1.3 Post-experiment interview

A debrief with the two SMEs was conducted to get a qualitative account of the actual use of the ISR during the baseline and enhanced trials. It was found that even with the availability of the ISRs in the enhanced trials, the Section Commander relied mainly on hand-signals to communicate with the section members. As noted by the SME, the Section Commander was very disciplined in employing the radio.

During the enhanced patrol activities, the ISRs were used in two main ways:

- As a substitution for handsignals when the Section Commander wanted to pass on a simple message (e.g. "move in").
- To provide instructions during more complex activities e.g. obstacle crossings, building clearances, and approaching enemy location.

Overall it was estimated that the ISRs were used approximately 35 times in the patrol activities – approximately one-third during obstacle crossings, one-half during enemy approaches and building clearances, and one-quarter for simple instructions. For all scenarios, the direction of the communication flow was from the Section Commander to the rest of the section, except during obstacle crossings and building clearances when section members sometimes needed to initiate communications.

During the enhanced attack activities the ISRs were used in two main ways:

- To provide target indications.
- To enable the Section Commander to get an initial overview of the situation.

[4] Although the SA scores for the Section Attack vignettes appear higher overall than the scores for the RRF Patrol vignettes, the pool of SA questions were not standardised but were rather contextualised to the particular activities to be performed. Therefore the SA scores are not comparable between vignettes.

During the enhanced section attack the radio was not used extensively. During the height of the attack, the ISR was not used, for three main reasons. Firstly the noise of the firefight made hearing the radio communications very difficult. Secondly, when communications were effected, subjects were shouting into the receiver which distorted the transmission, again making it difficult to understand. Thirdly, shortly after the initial communications between the Section Commander and the Scout, the airwaves became 'clogged' with transmissions from many different section members. It was at this point that the Section Commander abandoned the use of the radio and returned to verbal commands. Towards the end of the section attack, only the Gunner and Rifleman had not been eliminated in exercise play. Dispersed approximately 60 metres from each other, the ISR was used several more times, to give target indications and navigational directions so that they could locate one another.

5. Discussion

5.1 Comparison with Previous Research

Two previous studies [12, 35] have used a free-play methodology and a modified version of the SAGAT to assess the impact of enhanced technologies on SA in the infantry domain.

Redden & Blackwell [35] investigated the impact of MOUT Advanced Technology Concept Demonstrator (ATCD) technologies on the SA of a joint Army and Marine Company using a free-play methodology. The units conducted day and night vignettes at the McKenna MOUT Site, Fort Benning, under baseline (using their current equipment) and enhanced (using the MOUT ACTD technology) conditions. A freeze frame technique was used to stop the exercise at three phases: before the attack; consolidation; after the counter-attack (post-vignette). SA was assessed using a modified version of the SAGAT, called the Questionnaire Assessment of Knowledge Technique. This technique was shown to have both face[5] and content validity.

The results indicated that overall the technology contributed significantly to the SA of the participants. This contribution was not significant during the daytime but was highly significant at night. The technology contributed significantly to SA in the consolidation phase of the exercise . During this phase, the troops were more dispersed and the use of the MOUT ACTD intra-squad radio appeared to increase SA. The MOUT ACTD did not significantly impact SA during the attack and mission completion phases of the exercise.

In another study Redden & Blackwell [12] investigated the impact of the intra-section radio on the SA of a Ranger Squad. The Squads conducted day and night vignettes at the McKenna MOUT site, Fort Benning under baseline (no intrasection radio) and enhanced (intrasection radio) conditions. The vignettes were taken from a Ranger Battalion scenario. SA was again assessed using the Questionnaire Assessment of Knowledge Technique.

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[5] Face validity refers to the extent to which a measure looks as though it measures what is intended [23].

The results showed that overall the intrasquad radio contributed significantly to the SA of the participants. The intrasquad radio did not have a significant impact on SA during the day, however soldiers' SA was significantly better at night with the radio. A comparison between results for day and night vignettes revealed a significant degradation in SA at night under baseline conditions. There was no significant difference between the SA scores during the enhanced day and night vignettes indicating that the use of the intrasquad radio negated the SA degradation experienced at night.

A direct comparison of the results from the current study with previous research [12, 35] was not possible for three main reasons. Firstly, the current study was conducted in a rural environment whilst previous studies [12, 35] were conducted in a MOUT environment. Secondly, a direct comparison between the free-play vignettes was not possible as the vignettes used in the current study (RRF Patrol; Section Attack) were based on Tactics Techniques and Procedures (TTPs) applicable to the rural environment, in contrast to the vignettes used in previous studies which were based around TTPs applicable to MOUT mission scenarios e.g. building clearances. Thirdly, the majority of subjects used in the current study (AFDGs, ranked Aircraftman) were far less experienced than the subjects used in previous studies (Platoon Leader, Platoon Sergeant, Squad Leaders [35]; Rangers [12]).

Despite this it is worth noting that:

- The non-significant difference in SA between the baseline and enhanced section attack in the current study is consistent with Redden & Blackwell's [35] finding that the MOUT ACTD did not significantly impact SA during the attack phase of the exercise.
- The increase in SA in the enhanced RRF Patrol in the current study is comparable to Redden & Blackwell's [35] finding that the MOUT ACTD technology significantly contributed to the consolidation phase of the exercise when troops were more dispersed and the intrasquad radio appeared to increase SA.
- The increase in SA in the enhanced RRF Patrol in the current study is comparable to Redden & Blackwell's [12] finding that overall SA was higher with the use of the intrasquad radio. Although the radio did not have a significant impact on SA during the day, Redden & Blackwell [12] note that the conditions of the experiment were probably the toughest conditions for showing the contributions of the radio. Firstly, the MOUT vignettes required less dispersion than several other tactical situations (e.g. reconnaissance), so the soldiers were within eye contact of each other a vast majority of the time. Secondly, the soldiers used in the experiment (Rangers) were much more experienced in MOUT operations than typical infantry soldiers, and as such were more highly trained in the use of non-verbal communications (e.g. hand-signals), which reduced the need for the radio in many instances.

Results from the current study are also consistent with the SME observations of the exercise. The significant increase in overall group SA with the use of the ISRs during the patrol is logical as even though SME observation revealed that the ISR was not used extensively, there was still a greater dissemination of information throughout the section. This was because the absence of radio communications reflected that nothing was happening, as opposed to the baseline patrol where 'silence' may have reflected not knowing what was going on.

The non-significant difference in SA between the baseline and enhanced section attack is also logical given that SME observation of the section attack revealed that the ISR was hardly used during this activity.

5.2 Validity of DQT

The DQT and free-play methodology was able to successfully discriminate between baseline and enhanced conditions in the RRF patrol vignette, despite the small sample size (n=7). The large effect size indicated that the impact of the ISR on SA was worthy of further studies.

5.2.1 Sensitivity

The range of total correct responses obtained, 31% to 81% for Patrol vignettes; 39% to 100% for Attack vignettes, shows that the DQT has good sensitivity as it is able to reflect the differences in subjects' SA over a large range of scores.

5.2.2 Face Validity

The SME validation of the SA question set and observation of the free-play exercise gave the methodology face validity. In addition, individual analysis revealed that the most experienced soldier, Subject 4, had the highest total correct responses summed across all vignettes This result suggests that the methodology has good face validity as it is able to discriminate between experienced and novice subjects.

5.2.3 Content Validity

Although a formal content validity analysis was not conducted, the critical information requirements which formed the basis of the SA questions were derived from a literature review of scientific and military publications and included infantry information requirements lists that had been previously validated by military SMEs. In addition, the SA questions used in this study were validated by three SMEs (CAPT, LT, WO2) with extensive military experience.

5.2.4 Construct Validity

A strength of SAGAT is that it taps directly into the theoretical SA construct of perception, comprehension and projection, and therefore has a high construct validity [22]. In principle the DQT emulates SAGAT; only its implementation differs slightly from SAGAT. Therefore the degree of construct validity of the DQT is expected to be comparable to that of SAGAT.

Two criticisms have been levelled at SAGAT, (i) the perceived intrusiveness of freezes in the exercise/simulation to collect data, and (ii) the degree to which they reflect memory.

5.2.4.1 *Intrusiveness*

In this study, an attempt was made to minimise intrusiveness by stopping the free-play exercise at 'natural breaks' of a short 5 minute duration. In addition, several studies have shown that a temporary freeze in a simulation/exercise to collect SAGAT data does not impact performance. Endsley [43] conducted two studies to investigate the impact of temporary freezes in the simulation under SAGAT technique. In the first study she investigated how long after a freeze in the simulation, SA information could be obtained. In the second study she investigated whether temporarily freezing the simulation resulted in any change in subject behaviour. Results showed that freezes (as many as 3) to collect SAGAT data did not have a significant effect on subject performance, and that subjects were able to report their SA using the SAGAT technique for as long as 5 or 6 minutes without apparent memory decay. Endsley [24] also investigated whether operator performance could be affected by the mere threat of a stop to collect SAGAT data. That is, whether operators somehow altered their behaviour during trials when they felt that they may be stopped and tested on their SA. Results of this study confirmed previous findings and showed that both a stop or even the threat of a stop to collect SAGAT data did not have a significant impact on performance.

It should be noted that the studies conducted by Endsley mentioned above took place in an aviation domain, involving pilots in high tempo operations. In the current study in the infantry domain, the tempo of the activities was much lower. Based on Endsley's findings, it is unlikely that the 5 minute breaks in the infantry exercise would have had any significant impact on performance.

5.2.4.2 *Memory*

SA measures such as DQT and SAGAT tap into memory stores (either working memory or long-term memory) as an index of SA. A criticism of the technique surrounds whether it provides a good representation of operator's SA or whether it is in fact hindered by being dependent on memory [18].

It has been widely reported [44] that retrospective memory for past cognitive events is poor, and so a technique that depends on retrospective memory would clearly represent a problem for SA measurement. DQT and SAGAT, however, seek to probe into concurrent memory by placing the queries immediately following the event's occurrence.

Both working memory and long term memory stores are important for SA. Working memory is relevant to the active manipulation and use of information, and is where dynamic information is stored. It makes sense therefore, that the contents of working memory are exactly what needs to be tapped by an SA measure. This information also needs to be obtained immediately to avoid memory decay.

Long term memory is important for SA, particularly for experienced operators. Endsley [10, 43] found that experienced pilots' abilities to report their SA via SAGAT was unaffected by how long after the freeze the questions were asked (testing intervals from 20 seconds to 6 minutes). The current study appeared to support Endsley's finding, that SA information was available for quite some time after a freeze indicating that long-term memory has a role in SA as well as working memory.

An explanation for this result was that the experienced expert operators had long-term memory stores (such as schemata and mental models) that served to organise information and have an effect on its availability for a measure such as SAGAT.

Another concern that has been raised is whether information even needs to be in the subject's memory (or mental representation) in the first place. If it were sufficient that subjects merely reference the information on their displays when needed, SA as a dynamic mental representation of the environment would not be needed. However, one of the most frequent causal factors for SA errors involves situations where all of the information is available to the operator but it is not attended to for various reasons [45]. An operator's real challenge is to dynamically locate and integrate needed information from the plenitude available in the environment. For this reason, SA, as a measure of the operator's ability to form the needed understanding of the dynamic situation and predict future events in the short term, under the constraints of many opposing demands, is the measure of interest. This was tested in the current study through SA level 2 and level 3 questions.

5.2.4.3 Selective Attention

By including a range of SA questions an attempt was made to prevent the participants from focussing their attention on a narrow range of factors which they knew they would be questioned [22]. This appears to have been successful as the scores did not consistently increase with time as the trial progressed (See Figure 4).

5.2.4.4 Learning Effects

A possible learning effect was that the patrol route for the baseline trial was the opposite to that for the enhanced trial. As the section did not traverse exactly the same route and covered different grounds, the effect was judged to be minimal. However, learning effects could not be entirely ruled out. If they were present, the current method could not discriminate the contribution of the learning effects and the use of the ISR.

5.2.5 Limitation of the study

The scarcity of resources placed a limitation on the design of the study. Only one group of subjects were available and only for a limited time. The group had to work together as an infantry section and could not be split into smaller entities. Had two groups been able to undertake the activities, counterbalancing the use of the ISR would have been undertaken. With just the one group, little would have been gained by changing the order in which the ISR was used. In addition, only one primary SME was available for the whole study, with another providing assistance from time to time. The primary SME was therefore involved in all phases of the study, from the development of the scenario and SA questions to the scoring of the responses to the SA probes. Inter-rater reliability test was not performed because the second SME was not available to observe the entire activities and therefore did not know the correct answers.

The reliability of the method was not tested in the study, but SAGAT has been shown to have a high reliability in studies in other domains, such as those involving fighter pilots, nuclear plant operators and car drivers [22].

6. Conclusion

6.1 Strengths of Method

The key strength of the DQT method is that it assesses SA directly by asking subjects for information pertaining to the operational environment. Another advantage of the DQT method is that it is relatively inexpensive because no special equipment is needed in order to apply the method.

6.2 Weaknesses of Method

A limitation of the DQT method is that intensive effort is required to develop the SA questions, which have to be contextualised to the activities to be performed by the subjects. Another disadvantage of the method is that it is often difficult to determine the 'ground-truth' in free-play exercises. Individual factors such as the lack of motivation in answering the questions may also affect the results significantly.

One may consider employing a SABARS type technique for assessing SA in which experts observe and rate operators' behaviours linked to SA (see Section 2.3.2.1). It would have been difficult to implement SABARS in the current study. The nature of the terrain and activities meant that the section was spread out over a large area and at times some section members were obscured by vegetation. An observer could reasonably make an attempt to collect data from one or two subjects simultaneously, but not more. The use of several observers might well be distracting to the participants who are required to move in a covert fashion.

A record of communication between the members of the section may be expected to provide some insights on the group processes, such as co-ordination. This should be considered in future studies. However, even such a record will not provide a complete representation of communication as the Section members still use hand-signals, the tracking of which is difficult to accomplish.

6.3 Future Studies

The DQT appears to be a valid and viable methodology that can be used in the evaluation of the impact of specific SCS technologies on SA. Future work is indicated below.

6.3.1 Further Validation of Method

Further validation of the methodology is essential. This could be achieved through:

- additional trials involving a higher number of stops thereby allowing more SA probes to be administered
- larger sample sizes
- Australian Army Infantry sample population
- audio and video recordings to support the determination of 'ground truth'
- recording of radio communication when ISR is used
- formal training in the ISR operating procedures prior to commencement of field exercises

6.3.2 Comprehensive Data Analysis

Due to the small sample size and the high variability of the data set the assumptions of many non-parametric statistical tests were violated. Thus only elementary statistical analysis was possible. Future studies with a larger sample size could avoid many of these violations, allowing for a more rigorous statistical analysis. Where parametric statistical analysis is not possible, non-parametric alternatives should be considered.

6.3.3 Tactics, Techniques and Procedures

In the selected free-play vignettes, overall the ISR was not used extensively. Therefore, it may be beneficial in future trials to select TTPs that would more appropriately show take-up of the ISR than the ones used.

6.3.4 Shared SA

As well as examining aggregated group SA , it would also be beneficial to examine shared SA within the section. The members of an infantry section do not work individually. They work as a team to achieve a specific mission. Future studies should be conducted to provide an understanding of team SA and shared SA in addition to individual SA.

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Appendix A: SA Question Pool

A.1. RRF Patrol Questions

Free-play Vignette	SA Level	Question Number	Question
RRF Patrol	1	1	What is the order of march?
		2	Mark on the map your location at the start of the Patrol.
		3	Outline the patrol route on the map.
		4	What group sizings are the MAF SF operating in?
		5	What are the suspected current activities of the MAF SF?
		6	What is your mission?
		7	Mark on the map the route out and in.
		8	What is the current intent of the MAF SF?
		9	What signs of MAF SF activity have been observed so far? (Baseline Patrol)
		10	What signs of MAF SF activity have been observed so far? (Enhanced Patrol)
		11*	Draw a rough sketch of all members of the patrol. (Baseline)
		12*	Draw a rough sketch of all members of the patrol. (Enhanced)
	2	13	Mark on the map any prominent objects and reference points.
		14	Mark on the map any prominent objects and reference points observed during patrolling.
		15	Were there any obstacles/booby traps? If so, give details.
		16	Did the Patrol help you discover any habits of the MAF SF? If so, give details.
		17	Where are you currently located on the map? (Baseline Patrol)
		18	Where are you currently located on the map? (Enhanced Patrol)
		19	What are the strengths and weaknesses of the MAF SF?
	3	20	How likely is contact? How is this affecting the movement of the Patrol?
		21	What is the anticipated reaction of the MAF SF on discovery?
		22	Did you observe any likely enemy RV locs, enemy FUPs or enemy hides? If so, give details.
		23	Mark on the map the most likely enemy OP positions.
		24	What are the possible methods of infiltration into the TAOR that may be used by the MAF SF?

* These questions were found to be irrelevant and were removed.

A.2. Section Attack Questions

Free-play Vignette	SA Level	Question Number	Question
Section Attack	1	25	What is the dress of the MAF SF?
		26	Did you hear the target indications given? If so, where were they?
		27	What was the direction of contact by the MAF SF?
		28	What is the order of succession in the chain of command in case of casualties?
		29	What weapons did the MAF SF have?
		30	Sketch a rough diagram of the distribution of all section members at the point of contact. (Baseline Attack)
		31	Sketch a rough diagram of the distribution of all section members at the point of contact. (Enhanced Attack)
		32	Who was on your left and right during the assault?
	2	33	How many casualties does the enemy have?
		34	What are the actions on contact of the MAF SF?
		35*	What is the section's current ammunition status?
		36	How many casualties do you have?
		37	How did you maximise cover and concealment?
		38	At what point did you feel confident of the enemy's disposition, if at all?
		39	What course of action did you take (e.g. close with/withdraw) and why?
	3	40	How likely is contact with the MAF SF? Explain why.
		41	Where are the most likely enemy approaches into your TAOR?
		42	What is the most likely course of action of the MAF SF upon contact?
		43	Where is the most likely enemy withdrawal route? (Baseline Attack)
		44	Where is the most likely enemy withdrawal route? (Enhanced Attack)
		45	Where is the most likely enemy rendezvous point?
		46	What are the strengths and weaknesses of your section?

* This question was found to be irrelevant and was removed.

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Madeleine C. Guille and Han Tin French

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19. ABSTRACT
One of the key force modernisation initiatives for infantry operations is to enhance situation awareness (SA) capabilities. The design and acquisition of technologies that optimise the performance of the combat soldier must therefore be guided by the goal of enhancing and maintaining SA. Determining the value of these technologies requires a means of objectively evaluating a combat soldier's SA. In this study, the impact of Intra-Section Radios, which form part of the Soldier Combat System (SCS) enhancements, on SA was evaluated. The Situation Awareness Global Assessment Technique (SAGAT) provides an objective measure of SA by comparing the real and perceived situation. In this study, the Direct Questioning Technique (DQT), an adapted version of the SAGAT was used to evaluate changes in SA under baseline and enhanced conditions during two loosely scripted exercises involving Australian Air Field Defence Guards. Results showed a significant increase in overall group SA during the enhanced patrol vignette. No significant results were found for the section attack vignette. The DQT appears to be a valid and viable methodology that can be used in the evaluation of specific SCS technologies.