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Measuring the Meta and Cognitive abilities of Air Defence Operators

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ABSTRACT

Introduction: This study aimed to understand more fully some factors that influence decision confidence and accuracy related to air defence. To investigate the metacognitive abilities of air defence operators a Within-Subjects Confidence-Accuracy (W-S C-A) measure was used. Specifically, therefore, this study investigated the impact of Decision Criticality (DC) and Task Stress (TS) on decision making, measures of confidence, accuracy, and the W-S C-A relation. Personality constructs, workload and situation awareness were also included. **Method:** Participants were allocated to either a high, moderate or low task stress condition. Each participant then took part in a computer generated air defence scenario where they were required to make various decisions and provide a confidence rating for each of those decisions. Confidence, accuracy and W-S C-A were calculated. **Results & Discussion:** DC impacted both on decision confidence and accuracy, with low DC increasing confidence in decisions and high DC increasing accuracy in decisions.

KEYWORDS

Decision Making; Command and Control; Situation Awareness/Situation Assessment; Military

INTRODUCTION

Air defence operators are an integral part of any warship. Operators must detect, locate and identify potential air threats, making complex and cognitively demanding decisions in dynamic environments. The aim of this paper is to introduce a metacognitive methodology to increase understanding of air defence decision making. Previous naturalistic decision making (NDM) research examining metacognition has used less numerically-based methods, such as think aloud protocols (Cohen, Freeman & Wolfe, 1996; Fyre & Wearing, 2013). However, more experimentally-based methods may be of benefit to NDM research (Lipshitz, Klein, Orasanu & Salas, 2001).The method proposed in this paper uses realistic decision-making scenarios and provides a combination of subjective measures of confidence alongside objective scores of accuracy to investigate the metacognitive abilities of air defence operators.

Decisions made in warfare are characteristically made under high levels of uncertainty and time pressure (Jenkins, Stanton, Salmon, Walker & Rafferty, 2010). In a naval warship, this is combined with the complex and knowledge-rich environment of a ship’s Operations Room (OR). The OR is the focal point of the ship with significant amounts of incoming information from various data sources that must be processed and attended to by OR personnel in order to make both tactical and strategic war-fighting decisions. This study aims to examine metacognitive decision making, in light of both internal and external influences surrounding air defence.

The term metacognition refers to an awareness of ones’ performance, and the ability and willingness to reflect on ones’ thinking processes (Parker & Stone, 2014). It has been argued that metacognitive confidence should be included in the study of decision making because it is an important indicator of real-world outcomes (Jackson & Kleitman, 2014) and critical to performance (Rousseau, Tremblay, Banbury, Breton & Guitouni, 2010). Further, confidence in one’s own ability plays an important role in the decision made (Griffin & Tversky, 1992) and assessments of confidence can be used to guide current and future decisions (Kepecs & Mainen, 2012). Ensuring confidence is correctly placed has important implications. For example, over (too much) confidence has been linked to underestimation of risk which could have a direct impact on the evaluation of future events (Lovallo & Kahneman, 2003). However, it is not only how confident one is in a decision (i.e., decision confidence) but the corresponding accuracy (i.e., whether a response is correct or incorrect) of a decision that is relevant. Strong positive relationships between confidence and accuracy (i.e., the more confidence expressed in accurate decisions) are highly beneficial as they demonstrate an individual's ability to weight information and subsequent decisions appropriately (Stichman, 1962).

In light of this, metacognition sensitivity can be assessed by using decision confidence. Fleming and Lau (2014) argue that the relationship between decision confidence and accuracy can provide a quantitative measure of metacognition. Hence, one metacognitive measure which has been used to assess the relationship between confidence and accuracy in decision making is the Within-Subject's Confidence-Accuracy (W-S C-A) measure. W-S C-A has been used successfully in domains such as forensic, investigative and legal psychology (Wheatcroft & Woods, 2010; Wheatcroft, Kebbell & Wagstaff, 2004; Wheatcroft, Wagstaff & Manarin, 2015), perceptual tasks (Koriat, 2011), and general knowledge tasks (Buratti, Allwood & Kleitman, 2013). More specifically, W-S C-A is a measure of metacognitive sensitivity and has been defined as a "calculation which enables expression of individual confidence in each incorrect or correct response made" (Wheatcroft & Woods, 2010; p.195). Thus it can provide a method to assess individual awareness of the accuracy of decisions made and can also be used to assess group responses. Put simply, the method is able to calculate the statistical relationship between the levels of confidence individuals might place in responses given relative to their corresponding correctness. A positive relation between the two means that individuals are more confident in correct decisions than their incorrect counterparts. Whilst a subjective metacognitive measure, it has real and critical potential to affect the amount of resources applied to an action (Bingi, Turnipseed & Kasper, 1999) which are crucial in air defence environments.

Prior research has demonstrated external factors which may be influential to this relationship. For example, the difficulty of a decision (Wheatcroft, Wagstaff & Manarin, 2015) have been shown to impact on the W-S C-A relationship. Such research highlights the potential for the W-S C-A relationship measure to be beneficial in adding to understandings of the external factors which influence the decision maker – such as the criticality of the decision to be made and the level of stress experienced during a situation. Both these are crucial factors on board a warship as operators must be able to cope with varying levels of decision criticality and stressful environments effectively and respond accurately to the presenting situation.

Moreover, research is required to increase awareness of the individual differences that impact on air defence decision making and highlight the internal factors that influence those decisions to ensure that the decisions taken are effective. Individual differences are concerned with how individuals differ from one another and research has suggested that is plays a key role in decision making (Jackson & Kleitman, 2014). One particular individual difference which has been considered when assessing confidence and accuracy in decision making is personality. Personality is important to decision making as it can influence how people think, feel and behave (Roberts, 2009) between and within contexts. Similarly, this study is also interested in the role of decision style, ambiguity and decisiveness. For example, in terms of ambiguity, in the context of critical decision making, a low acceptance of uncertainty may be psychologically advantageous in that decisions may be made which are less influenced by the need to reduce uncomfortable feelings in complex circumstances and decision making contexts.

In summary, to begin to uncover some of the factors related to decision making in an OR air defence role and their implications on confidence, accuracy and W-S C- A, this study investigates the impact of task stress and decision criticality on confidence, accuracy and W-S C-A. Individual differences in personality and decision related tendencies are also considered. Additionally, this study aims to establish how W-S C-A fits into the wider measurements currently used in the human-machine interaction decision making literature such as Workload and Situational Awareness.

METHOD

Participants

60 participants were recruited through opportunity sampling from The University of Liverpool. The participants consisted of 30 females and 30 males with a mean age of 26, ranging from 18-27. None of the participants had any prior experience in naval warfare. The study received approval from the University of Liverpool's Institute of Psychology Health and Society Ethics Committee, and a favourable opinion from the Ministry of Defence Research Ethics Committee.

Design

A mixed measures quasi-experimental design was employed. 3 (Task Stress: Low, Moderate, High) X 3 (Decision Criticality: Low, Medium, High); with repeated measures for the Decision Criticality independent variable.

The independent variables (IV) were Group, Task Stress and Decision Criticality. The dependent variables (DV) were confidence, accuracy, W-S C-A, personality (NEO-PI, Costa & McCrae, 1992) decision tendencies

(Tolerance to ambiguity, Budner, 1961, Decision style Roets & Van Hiels, 2007), workload (NASA TLX, Hart, 2006) and situational awareness (SART, Taylor, 1990).

Materials

Decision logs

To ensure as high ecological validity as possible in a quasi-experimental design an air defence scenario was created with the guidance and assistance of subject matter experts (SMEs). The scenario depicts a realistic set of events using a Peace Enforcement (PE) environment. A series of events and associated event decision logs were also created and agreed by SMEs. The event decision logs specify three decision options of reasonable equivalence for each event presented to the operator. SMEs have agreed one option per decision made as the 'optimal/best' decision option given the current situation.

Computer Scenario

The visual display used as the stimulus for the experiment was created using VAPS XT (Virtual Avionics Prototyping Software) software. The screen depicted a pseudo-realistic radar screen which included an airlane, a No Fly Zone (NFZ), a coastline and a border. A textbox to display additional information to assist in the decision making and a timer which counted down from 20 seconds at each decision event was also included (see Figure 1). The algorithms used to animate the visual display symbols were created using Matlab/Simulink. The symbology used is as specified by APP-6c (NATO, 2008). Microsoft Movie Maker was used to edit the video (e.g., to apply timer).The display was verified as being sufficiently realistic by the SMEs.

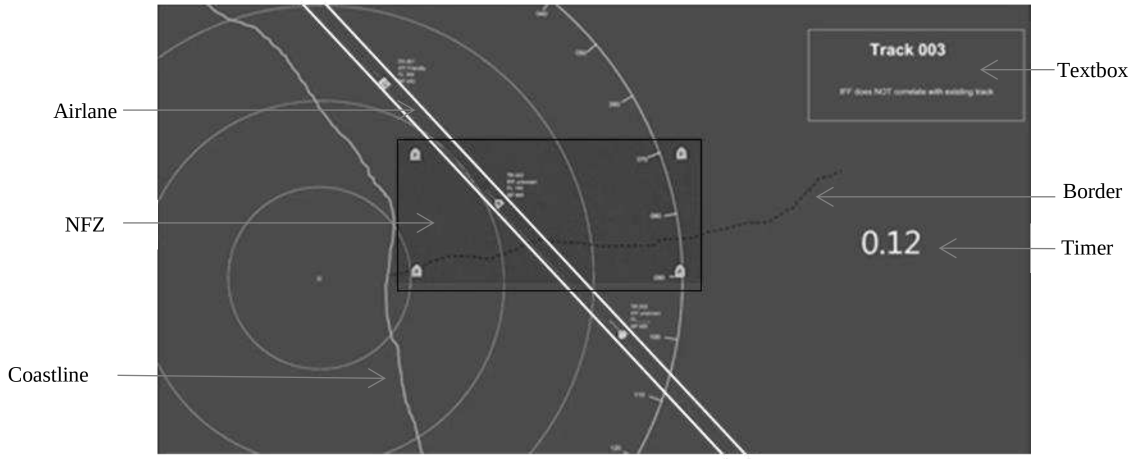

Figure 1. Visual display

Questionnaires

Situation Awareness Rating Technique (SART; Taylor 1990) was used to measure SA. To measure WL the NASA-TLX (Hart, 2006) will be utilised. NASA-TLX is a subjective workload assessment tool. Personality was assessed by the NEO-PIR (Costa & McCrae, 1992).

PROCEDURE

Participants were randomly allocated to a High, Moderate, or Low stress condition. Participants first completed participant demographic forms which collected data on age, gender and occupation. Participants were also asked to complete paper-based questionnaires to gauge the relevance of a number of measures across groups (e.g., general personality constructs, thinking and reasoning) where they may be relevant to particular questions. Following this, participants were provided with the task booklet to read. The task booklet provided the participants with information needed to assist them in the decision making task, including air defence terminology and symbols. Once they had read the booklet, participants undertook a practice trial. The questionnaire booklet presented three (3) separate decision options based on the events of the scenario. One choice was required to be selected by placing a tick by the option they believed to be the 'best option given the current situation'. Participants were then required to rate how confident they were in the options chosen on a Likert scale, where 0 = not at all confident to 5 = extremely confident. After twenty (20) seconds, the screen was blanked out to signal to the participants that the allocated decision time has ended. All participants then undertook the experimental air defence scenario, following the same procedure as described for the practice.

Thirty (30) decision events were presented during the experimental simulation. A decision event was defined as an occasion where a decision may need to be made by an operator. For example, an unknown data link track appears on the screen. The Decision Criticality was varied across the decision events presented (i.e., 10 high, 10 medium, and 10 low, DC) and the event occurrences varied depending on Task Stress condition. The scenario video ran for 20 minutes, 30 minutes, or 45 minutes for the High, Moderate and Low conditions, respectively. Once completed participants completed Situational Awareness and Workload questionnaires. Participants were fully debriefed to ensure each understood the nature of the study and given the opportunity to ask further questions.

RESULTS

A number of statistical analyses were performed on the data for Accuracy, Confidence and W-S C-A using Analysis of Variance (ANOVA).

Accuracy

A 3 x 3 mixed measures ANOVA was also carried out to assess the relationship between task stress and DC on individuals' decision accuracy.

A main effect of DC was found F (2,114) =16.71, p<0.01, $\eta^2_{p} =$ 0.23. Bonferroni corrected post hoc tests showed participants were more accurate in high DC decisions (M=5.3 SD=2.0) than low DC decisions (M= 3.5, SD=2.0). Additionally, participants were more accurate in medium DC decisions (M=4.9, SD= 1.8) than low DC decisions both p<0.01.

However, no main effect of task stress F (2, 57) =2.03, p>0.05 and no interaction effect was observed F (4,114) =1.77, p>0.05 (see Table 1).

Table 1. Means and Standard Deviations for Accuracy

CONDITION	Overall	High DC	Medium DC	Low DC
High	13.8 (4.2)	5.2(2.3)	4.6(1.8)	4.1(2.2)
Moderate	12.3(3.6)	4.5(1.6)	4.7(1.8)	3.2(2.0)
Low	14.9(3.8)	6.1(1.7)	5.4(1.7)	3.4(1.7)
TOTAL	13.7(3.9)	5.3(2.0)	4.9(1.8)	3.5(2.0)

Standard Deviations are in parenthesis

Confidence

Again, a 3 x 3 mixed measures ANOVA was carried out to assess the impact of Task Stress and Decision Criticality (DC) on decision confidence. As Mauchly's test of sphericity was found to be significant, Greenhouse-Geisser was used.

A main effect of DC was found F (2, 88) =3.29, p<.05, $\eta 2p =$ 0.55. A Bonferroni corrected post hoc test showed that participants were significantly more confident in Low DC decisions (M=37.3, SD=9.6) than medium DC decisions (M=35.1, SD= 7.2) p=0.02. No significant differences were found between high DC and low DC or medium DC and high DC.

No main effect of the Task Stress condition was found, F (2, 57) = 1.32, p>0.05) and no interaction effect was observed F (4, 88) =2.13, p>0.05 (see Table 2).

Table 2. Means and Standard Deviations for Confidence

CONDITION	Overall	High DC	Medium DC	Low DC
High	102(26.8)	32.5(11.9)	32.9(8.8)	36.7(13.7)
Moderate	111(21.7)	38.8(7.4)	36.0(7.0)	37.4(8.6)
Low	113(14.9)	38.6(5.6)	36.3(5.4)	37.7(5.1)
TOTAL	109(21.9)	36.6(9.1)	35.1(7.2)	37.3(9.6)

Standard Deviations are in parenthesis

W-S C-A

As before, a 3 x 3 mixed measures ANOVA was performed on the relationship between task stress and DC on individuals within-subjects confidence-accuracy (W-S C-A).

There was no main effect of DC F (2, 98) =0.62, p>0.05 and no main effect of task stress F (2, 49), 1.61, p>0.05 found. No interaction was observed F (4, 98) =0.61, p>0.05. An observation of the descriptive statistics shows that individual W-S C-A was found to be lowest between subjects in moderate task stress and within subjects in medium DC (see Table 3). W-S C-A was found to be highest between subjects in low task stress condition and within- subject in high DC. Overall W-S C-A scores were very low and not negative (M=0.02).

Table 3. Means and Standard Deviations for W-S C-A

CONDITION	Overall	High DC	Medium DC	Low DC
High	0.02 (0.2)	0.04(0.4)	-0.05(0.4)	0.05(0.3)
Moderate	-0.04 (0.7)	0.09(0.3)	-0.08(0.3)	-0.03(0.4)
Low	0.08 (0.2)	0.06(0.3)	0.10(0.2)	0.08(0.4)
TOTAL	0.02 (0.2)	0.06(0.3)	-0.00(0.3)	0.03(0.4)

Standard Deviations are in parenthesis

WORKLOAD (WL) AND SITUATIONAL AWARENESS (SA)

To assess the relationship between workload and SA a series of Pearson's correlations were calculated.

A significant negative relationship was found between SA and WL was found r= -0.53, p<.0.01. Higher levels of reported WL were related to lower feelings of SA.

A one way ANOVA was conducted to assess the relationship between SA and task stress. There was a significant effect of task stress condition on SA F (2, 57) = 6.44, p<0.01. Participants in the low task stress condition reported higher levels of subjective SA (M=21.4, SD=4.7) than participants in the high task stress (M=14.3, SD=5.4).p<0.01. See Table 4.

No significant relationship was found between WL and task stress F (2, 57) =3.00, p=0.06.

Table 4. Means and Standard Deviations for SA and WL

CONDITION	Overall SA	Overall WL
High	14.3 (5.4)	64(14.4)
Mod	18.7(8.3)	60.8(15.4)
Low	21.4(4.6)	53.3(12.4)
TOTAL	18.1(6.9)	59.4(14.1)

Standard Deviations are in parenthesis

Relationships between WL, SA and Accuracy, Confidence and W-S C-A

A significant moderate negative relationship was found between overall WL and confidence, r= -0.42, p< 0.01. As subjective measures of workload increased, confidence in decisions decreased.

A significant strong positive relationship was found between overall SA and confidence, r=0.63, p=<0.01. Higher scores in subjective SA were related to higher scores of confidence in decisions.

No significant relationships were found between SA, WL and W-S C-A. No significant relationships were found between SA and accuracy or WL and accuracy in decisions, all comparisons, p>.05. No significant relationship was found between-subjects confidence and accuracy, p>0.05.

Personality Constructs

Pearson's correlations were conducted to establish whether accuracy, confidence, and W-S C-A were related to the psychometric scores.

A significant negative relationship was found between Tolerance to Ambiguity (A) and Accuracy r = -0.34, p<0.01. Those who scored higher on the tolerance to ambiguity scale (i.e., less tolerant) were less accurate.

A significant negative relationship was also found between Decision Style and Accuracy r = -0.35, p<0.01. High scorers on the decision style scale were less accurate. Decision style explicitly probes the need for quick and unambiguous answers.

No other relationships were found to be significant, p>.05.

DISCUSSION

This study investigated operators' decision making during an air defence scenario. The aim was to assess the impact of Decision Criticality (DC) and Task Stress on measures of confidence, accuracy, and W-S C-A. Personality constructs, workload (WL) and situation awareness (SA) were also included.

The results from this study show that DC impacts on the accuracy of a decision. In accordance with the SME's validated correct decisions, participants made more accurate decisions in high DC than both low DC and medium DC, suggesting that accuracy increases with DC. The outcome supports previous literature in that participants make fewer errors in highly critical scenarios (Hanson, Bliss, Harden & Papelis, 2014). Furthermore, research has shown that performance in a task increases when participants find the task more important (Kliegel, Martin, McDaniel, & Einstein, 2004). These results may therefore indicate that individuals believed that the high DC decisions were more important in the context in which the task was operating. Additionally, the findings suggest that some measures of cognitive ability are not necessarily impaired when making critical decisions.

The work demonstrates that the criticality of the decisions did influence confidence. In particular, individuals were significantly more confident in low DC decisions than medium DC decisions. This lends some support to previous literature that has demonstrated that as difficulty increases confidence decreases (Chung & Monroe, 2000; Kebbell, Wagstaff & Covey, 1996). Nevertheless, it is the corresponding confidence which relates to an individual's awareness of the accuracy of these decisions that is important. W-S C-A remained unaffected, with no significant differences found in W-S C-A across Task Stress and DC. However, research has shown that training and experience improves calibration (Lichstenstein & Fischhoff, 1977). It would therefore be beneficial to conduct further experiments with those with particular cognitive skills, and relevant naval and air defence participants with appropriate experience.

An interesting finding emergent from this study is that although no significant differences were found in confidence, accuracy and W-S C-A in the different task stress conditions, individuals did report differences in subjective feelings of WL and SA across the different task stress conditions. In support of this finding, previous literature has found that stress impacts on WL and SA by reducing attentional resources and working memory (Endsley, 1995).

The broad personality constructs (i.e., neuroticism, extraversion, openness to experience, agreeableness, conscientiousness) using NEO-PIR were not related to confidence, accuracy, W-S-C-A, WL or SA. Nevertheless, this study did however find relationships existed with other cognitive constructs. Individuals who were less tolerant to ambiguity were less accurate in their decisions and high scorers on the decision style scale were also less accurate. The latter findings have implication for air defence personnel as the OR environment is both complex and at times ambiguous meaning operators need to be able to deal with such situations. Consequently, it has been demonstrated here that tolerance to ambiguity is a measurable skill which is required to increase the possibility of making accurate decisions in air defence.

CONCLUSIONS, IMPLICATIONS, LIMITATIONS AND FUTURE WORK

The aim of this paper was to introduce the methodology of W-S C-A to measure an element of the metacognitive abilities of air defence operators in a realistic decision making scenario. It has been previously argued that NDM research should use a mixture of measures to reduce the limitations of using a single methodology (Lipshiz et al., 2001). Overall, the study combined objective measures alongside subjective measures in order to measure metacognitive abilities. As such, it is envisaged that the proposed method will provide a wider view of metacognition in critical decision making environments.

One key finding from this study is that DC had a significant impact on both decision accuracy and confidence. Although previous research has shown that DC plays a role in decision making in a business setting (Dunegan, Duchon & Barton, 1992), there has been a dearth of research into the effects of DC in complex decision making environments. However, as this work demonstrates, DC can contribute to both decision confidence and decision accuracy; hence, future work should certainly consider the impact of the criticality of decision.

No research is without its limitations. One such limitation was the use of novice participants rather than experts. Nevertheless, it is envisaged that future research will use experts to further validate the work. Further, participants were allocated 20 seconds to make a decision. It is possible the timeframe could affect the processes individuals use to make their decisions; though due to the nature of air defence decision making it is realistic to expect operators to be under some time pressure during the circumstances that surround these types of decisions.

In summary, this study provides a sound basis for future research, the aim of which is to investigate the internal and external factors that are involved in the meta and cognitive abilities in air defence decision making. The results from this study will later be compared with other populations, including military personnel, thus comparing experts and novices. The overall rationale is to uncover the skill sets which are of benefit to metacognitive abilities in air defence.

More broadly, the implications of this research include the potential for the approach and outcomes to be used to prioritize training, individual needs, and selection, in order to improve the effectiveness of decision making in air defence.

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