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SITUATIONAL AWARENESS RATING TECHNIQUE (SART): THE DEVELOPMENT OF A TOOL FOR AIRCREW SYSTEMS DESIGN

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SUMMARY

Human engineering activities in aircrew system design traditionally have been concerned with the reduction and management of operator workload. Recent advances in automation technology have radically changed the role of the human operator and highlighted the essential human function for making adaptive decisions in situations involving uncertainty. Improving and enhancing operator 'situational awareness' has become the major crew station design driver for achieving survivability and mission effectiveness criteria. The purpose of the research reported in this paper is to investigate how aircrew understand "situational awareness" (SA) and to develop tools for its subjective estimation.

1. INTRODUCTION

Situational awareness is a relatively new concern in human factors (1,2). Its origins are probably in aircrew jargon - some say USAF F15 operators - because they need it and sometimes lack it. Based on a series of interviews with air combat experts, in 1979 KELLY et al (3) developed a taxonomy of skills, traits and performance measures important for air-to-air combat which included aggressiveness, decisiveness, hands-on flying skills, knowledge, ability and "situation awareness" which was described as "probably the sum of numerous perceptual and cognitive skills".

Operational requirements for situational awareness have implications for flight safety as well as combat effectiveness. In 1984, "Loss of situational awareness" was cited as a probable contributory factor in 20 out of 41 USAF operator-factor accident reviews (4). Loss of SA is related to and a potential contributor to spatial disorientation (SDO). However, SA is intended to be the broader term, encompassing more than spatial disorientation references, and including more clearly psychological aspects of attention and cognition as well as sensory physiology considerations. Recent accidents in advanced single-seat tactical fighter aircraft (F16,F18) involving controlled flight into terrain (CFIT) have prompted concern over loss of "attitude awareness" (5). In these accidents, the pilots seem to have collided unknowingly with the ground under circumstances not typically associated with SDO visual/vestibular conflict.

Awareness problems in advanced aircraft have important implications for crew-systems design and crew training. The major crew system integration implications concern the role of automation, its effect on operator functionality, and the management and cognitive quality of cockpit information. In retrospect, it seems inexcusable that advanced systems, such as the F16 and F18, can sense impending ground impact from height, speed and attitude data, and yet fail to communicate the situation to the pilot. The major training implications of awareness problems concern task prioritisation and attention management procedures. Much of the CFIT debate has focused on the usability and priority of HUD and ADI attitude references. It is disappointing that even after over 20 years flying experience there is still uncertainty about whether or not the HUD should be used as a primary flight reference.

Losing situational awareness has much in common with the factors contributing to geographical disorientation (6). Therefore, it is not surprising that improving situational awareness was recognised as a crew-system integration objective out of research on the design of advanced aircraft tactical situation displays. Looking forward to the cockpit of the year 2000, Reising and Emerson (7) noted that "the key advantage of pictorial formats is to provide the pilot with situational awareness not only in the tactical area, but also in all areas which are important for the successful completion of the mission". Notwithstanding the F16/F18 experiences, it should be possible to enhance pilot awareness by design if advanced automation and control/display technology are harnessed and applied using good engineering psychology practice. The potential in technology for enhancing pilot situational awareness intuitively, by design, without major training penalties, is identified as the major design driver behind advanced crew systems programs, such as Super Cockpit (8) and Pilots Associate (9). These programs aim to couple advanced AI computing techniques for mission and information management with intuitive 3-D virtual interfaces, pictorial formats and voice technology. This successful integration to form an "electronic crewmember" is intended to improve the pilot's situational awareness leading to improved decision-making, survivability and combat effectiveness.

Situational awareness is probably the pre-requisite state of knowledge for making adaptive decisions in situations involving uncertainty i.e. a veridical model of reality. As such, it creates the potential for behaving adaptively up to a knowledge based level, if only by trial and error minimisation. Since situational awareness is probably not a permanent nor a universally achieved state, it is understandable that there is uncertainty about what it means and about how it is created. Definitions of situational awareness are probably about as useful as lectures for octogenarians on how to evacuate eggs. This may be, as William James wrote in 1890 about definitions of attention, "Everyone knows what attention is..." His description of the antithesis is probably more interesting: "...the confused, dazed and scatterbrained state" (10). Notwithstanding, HQ USAF AFISC/SE Safety Investigation Workbook (AFP 127-1 Vol III 1986) defines Situational Awareness as "Keeping track of the prioritised significant events and conditions in one's environment." Confusion here may affect the sequence or priority of tasks to be performed (Getting behind the power curve)." Put more bluntly, and focusing on process rather than state implications, situational awareness means "What-on-earth-is-going-on?" (11). Other more pragmatic definitions describe relevant knowledge sources, e.g. "the crew's knowledge of both the internal and external status of the aircraft, as well as the environment in which it is operating" (12). The USAF Tactical Air Command definition (13) identifies five sources of relevant knowledge:

(a) Knowing where the friendlies are and what they are doing.
(b) Knowing where the threats are and what they are doing.
(c) Knowing what my flight knows and our options for attack/defence.
(d) Knowing what other flights know and what their intentions are.
(e) Knowing what part of the above is not known or is missing.

Knowledge state descriptions involve a degree of specificity which may be inappropriate for other situations and tasks. They also raise the issue of the organisation and structure of knowledge, in particular the role of implicit and explicit knowledge. Knowing what is not known is not a new concern. It was once addressed under the aetiology of "unawareness mistakes" (14,15). Unawareness errors continue to interest accident researchers (16). Recently, research has identified the dissociation between the performance of complex skills and the ability to make explicit, through verbal expression, conscious declarative knowledge of the tasks. The knowledge related to self-taught skills is frequently unavailable to conscious thought or verbal expression (17,18).

A comprehensive understanding of SA needs to take into account the active, dynamic characteristics of the process of maintaining awareness, as well as the role of knowledge structures in decision-making. Morshinge and Retelle (19), in a description of air combat and the Pilot's Associate program objectives, note that "Perhaps the key factor in the maturation of a fighter pilot is his ability to anticipate situations rather than simply to react to them". Failure to anticipate the danger in situations was identified as the primary cause of errors of inattention in the early Cambridge Cockpit studies on the disorganisation of behaviour (20). The validity of any understanding of aircrew jargon that relies on non-aircrew constructs will always be questionable. However, there clearly is work relevant to the understanding of situational awareness in research on human cognition such as on cognitive style (21), visualisation (22), models of human problem solving behaviour (23) and theories of attention (24).

The research strategy underlying the present study is influenced by experience with the workload paradigm. Optimising operator workload has been traditionally regarded as the Holy Grail of human engineering: A much sought after but never certainly achieved objective. Objective and subjective techniques for measuring workload abound, not in the least because it is a multifaceted, multidimensional construct (25,26). Subjective workload measures are used extensively during crew-systems integration activities because of their practical advantages (e.g. high face validity, ease of administration, low-intrusiveness) and their apparent sensitivity to changes in demand. They have mostly evolved pragmatically. Consequently, criticism of subjective workload methods has focused on considerations of validity, theoretical consistency and diagnostic power (27). Enhancing situational awareness would seem to be, at least at face value, a higher design objective than optimising operator workload, particularly for systems in which the essential human function is to make decisions in uncertainty. Optimum workload without situational awareness is probably more undesirable than the converse. The attractiveness of the awareness paradigm derives from its potential to focus more clearly on cognitive skills and on goals and intentions, rather than on activity-related analyses.

The intention of the present study is to derive methods for the subjective estimation of situational awareness in order to assist in the quantification and validation of design objectives for crew-systems integration. Like workload, situational awareness is probably a complex construct. Reliable predictions about decision-making performance are unlikely to be derived from single subjective measures of situational awareness. The intention is to use knowledge elicitation procedures to examine the dimensionality of aircrew constructs for situational awareness. It is hoped that this will achieve some construct validity for the estimation tools that emerge, since they are intended ultimately for aircrew use. Also, like workload estimation, the utility of subjective measures of situational awareness will depend on the contribution to decision-making performance of processes available to consciousness. The approach adopted thus rests on assumptions that human operators use some understanding of situations in making decisions, that this understanding is available to consciousness and that it can readily be made explicit and quantifiable.

2. METHOD

Eighty four Test and Operational RAF aircrew were interviewed in three phases: 1) Scenario Generation, 2) Construct Elicitation, 3) Construct Structure Validation. The interviews were semi-structured, conducted by psychologists according to a fixed protocol for knowledge elicitation, based on the Personal Construct/Repertory Grid Technique (28).

Interviews were supported by appropriate briefing material including a video film demonstrating advanced crew-systems integration concepts. The interviews took place at MOD(PE) Research Establishment (Royal Aerospace Establishment, Farnborough; Royal Aircraft Establishment, Bedford; A & AEE Boscombe Down) and at RAF Stations in UK and Germany (RAF Marham, RAF Laarbruch, RAF Bruggen).

2.1. SCENARIO GENERATION

Descriptions of flight scenarios involving SA were obtained from 10 test aircrew, mostly pilots, at RAE Farnborough and RAE Bedford, based on the following agreed working definition comprising both situational and awareness components:

"Situational awareness is the knowledge, cognition and anticipation of events, factors and variables affecting the safe, expedient and effective conduct of the mission".

The 43 scenarios obtained in this way were reduced to the set of 29 familiar, generic examples listed below.

F.1 LOW AWARENESS FLIGHT SCENARIOS:

1. Approaching to land at an unfamiliar airfield in poor weather in an unfamiliar aircraft fitted with poor handling qualities and displays.
2. In air combat over a smooth sea with a poor horizon, your opponent is unsighted.
3. On a low level transit sortie, you are flying over unfamiliar terrain with poor visibility, in an aircraft with inadequate handling qualities and displays.
4. In formation flight on a long duration transit at high level over sea.
5. Making a climbing accelerating turn on a hazy day when the ground is not clearly visible.
6. Whilst flying in formation in cloud as a wingman, you momentarily lose sight of your leader.
7. On a singleton low level transit sortie in VMC with no other task than transit from A to B.
8. Carrying out an exercise flown regularly over a familiar area.
9. Flying for a long period of time in an uncomfortable seat.
10. Flying a new aircraft with similar but different handling qualities to those already flown.
11. Whilst carrying out a routine repetitive task, a subtle but important change occurs in the environment which you do not notice.
12. Flying in formation in an unfamiliar aircraft working at the limit of your capacity.
13. You are flying in weather 3/8 puffy cloud and while completing an avoiding turn into the cloud, you have an extremely near miss with a glider.
14. On a night flying exercise, while attempting to change the radio frequency the initial input to the computer fails and consequently a long time is spent on the input.
15. On an instrument flying sortie, the autopilot fails whilst you are completing a manoeuvre.
16. You are crossing in combat with a similar aircraft, and through pulling g to gain the advantage, you overstretch your aircraft.
17. You are transiting at low level in formation and approaching bad weather. As leader, you attempt to penetrate the bad weather but then find you have to pull up and thus lose the integrity of the formation.
18. You complete a roll to the left but unknown to you your head-up display is frozen and so even though the rest of the instruments register the roll you attempt to roll again.

F.2 HIGH AWARENESS FLIGHT SCENARIOS:

1. Approaching to land in good weather at a familiar airfield, in a familiar aircraft fitted with good displays.
2. In air combat, you are behind your opponent and over a familiar area with good horizon and height cues.
3. In a single-seat aircraft, leading a 4 ship low level attack formation in poor visibility, approaching the Forward Edge of Battle Area with threat aircraft known to be in the vicinity.
4. Flying at low level through mountainous terrain wearing N.V.G.s.
5. You are nearing the end of a sortie and beginning the descent through cloud as approaching to land.
6. Flying straight and level at 20,000 ft on autopilot.
7. You are transiting at low level as leader in a 4 man formation and approaching bad weather. Call to close formation and turn to avoid.
8. Flying in deteriorating weather, an emergency occurs which requires a quick safe landing and so you turn towards the heading where, from the briefing, you knew the weather was OK.
9. On a low level transit sortie, you are flying over familiar terrain in good weather in an aircraft with good displays.
10. In manoeuvring flight, a fault occurs and you immediately recover your aircraft to a flight path and altitude which will lead to a safe haven.
11. On a general handling sortie, requiring a Ground Control Approach, maintaining position in the instrument pattern with four other aircraft overhead and a new controller.

2.2. CONSTRUCT ELICITATION

The 29 selected scenarios were presented to 15 test aircrew, mostly pilots, at A & AEE Boscombe Down to elicit knowledge of generic constructs. Each construct was elicited using the Repertory Grid triadic method of presentation. Three randomly selected scenarios were presented to the aircrew subject on each occasion. The subject was asked to imagine being in each situation. Then the subject was required to identify two of the scenarios which contained something important for situational awareness, in accordance with the agreed working definition, that was not a feature of the other scenario. The subject was then required to identify the discriminating characteristic, and the construct thus elicited was recorded. The elicited construct was then used to define the poles of a 7-point scale on which all 29 scenarios were subsequently rated. Additional constructs were elicited using different triads of scenarios. The procedure was repeated with each subject until no more original constructs were readily elicited. A total of 44 SA construct dimensions with associated scenario ratings were obtained in this way, ranging from one to four constructs per subject. The 44 elicited SA constructs, and their associated rating dimensions are listed in Table 1.

TABLE 1. ELICITED CONSTRUCTS AND RATING DIMENSIONS

SUBJECT/ CONSTRUCT NUMBER	CONSTRUCT	DIMENSION	
S1.C1	Attentional load	A lot of things to attend to	- Few things to attend to
S1.C2	Concentration	Low level of concentration	- High level of concentration
S2.C1	Risk	Low risk of failure	- High risk of failure
S3.C1	Familiarity	Familiar	- Unfamiliar
S3.C2	Consciousness	Conscious decision	- Instinctive decision
S3.C3	Attention switching	Low degree of attention switching	- High degree of attention switching
S3.C4	Motivation	Low level of motivation	- High level of motivation
S4.C1	Arousal	Low level of arousal	- High level of arousal
S4.C2	Familiarity	Familiar	- Unfamiliar
S4.C3	Receptivity	Unreceptive to additional information	- Receptive to additional information
C5.C1	Info. quality	Poor information quality	- Good information quality
C5.C2	Info availability	No information available	- All information available
C5.C3	Stability	Dynamic situation	- Static situation
S6.C1	Workload	Low level of workload	- High level of workload
S6.C2	Spare capacity	Low capacity to monitor external events	- High capacity to monitor external events
S6.C3	Distraction	Undistracted from situation	- Distracted from situation
S6.C4	Arousal	Low level of arousal	- High level of arousal
S7.C1	Variability	Few variables	- A lot of variables
S7.C2	Concentration	Low level of concentration	- High level of concentration
S8.C1	Stability	Stable	- Unstable
S8.C2	Complexity	Complex situation	- Simple situation
S8.C3	Anticipation	Attention concentrated on present	- Attention concentrated on future
S9.C1	Demand	Demanding	- Undemanding
S9.C2	Info. quality	Poor quality references	- Good quality references
S9.C3	Concentration	Attention not concentrated on task	- Attention concentrated on task
S10.C1	Info. quality	Poor information quality	- Good information quality
S10.C2	Familiarity	Familiar	- Unfamiliar
S11.C1	Division of attention	Divided attention	- Focused attention
S11.C2	Complexity	Low complexity	- High complexity
S11.C3	Info. quantity	No useful information	- A lot of useful information
S12.C1	Spare capacity	No spare capacity	- A lot of spare capacity
S12.C2	Focusing	Unfocused attention	- Focused attention
S12.C3	Control	Have control	- No control
S13.C1	Familiarity	Familiar	- Unfamiliar
S13.C2	Focusing	Broad attention	- Focused attention
S13.C3	Complexity	Low complexity	- High complexity
S13.C4	Info. quality	Poor information quality	- Good information quality
S14.C1	Concentration	Low level of concentration	- High level of concentration
S14.C2	Risk	High possible future risk	- No possible future risk
S14.C3	Info. quality	Poor information quality	- Good information quality
S14.C4	Familiarity	Familiar	- Unfamiliar
S15.C1	Attentional demand	Low demand on attention	- High demand on attention
S15.C2	Predictability	Unpredictable	- Predictable
S15.C3	Focusing	Broad attention	- Focused attention

2.3. CONSTRUCT RATINGS ANALYSIS

The structure of the elicited SA constructs was investigated by statistical analysis of construct/scenario ratings.

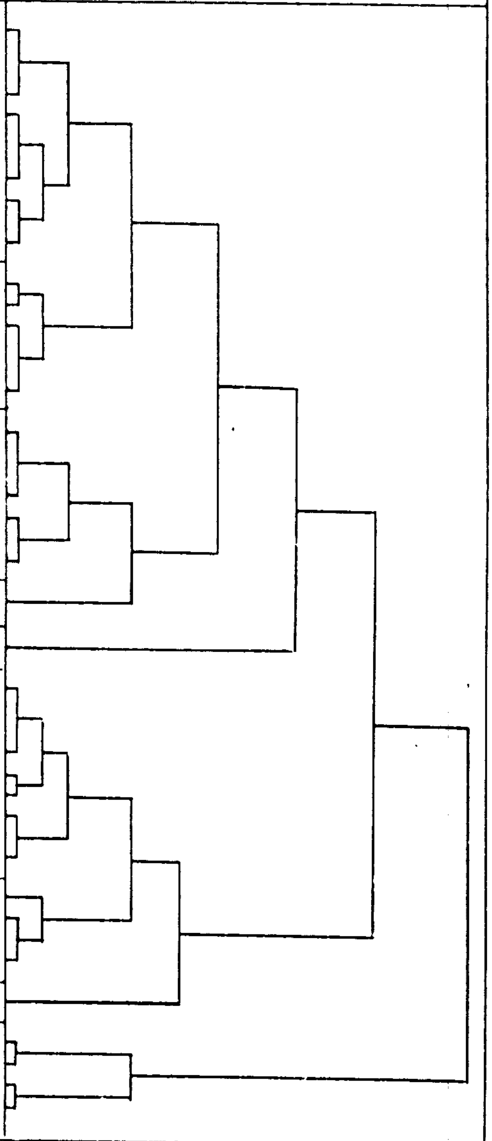
2.3.1. INITIAL CONSTRUCTS

Firstly, the construct/scenario ratings obtained during construct elicitation were subjected to Principal Components analysis with Varimax factor rotation. This analysis revealed that 4 components accounted for 65% of the total variability in the data. Constructs calculated as loading strongly on these 4 components are listed in Appendix Tables I-IV. The two major components, contributing 30% and 21% of the variance produced strong loadings for informational, attentional and, to a lesser extent, situational constructs. As a method of visualisation, the calculated loadings on the 4 factors were used to define a space which could be clustered using a single-link clustering algorithm based on Euclidean distance. The results are displayed in Figure 1. Guided by this analysis, generic constructs were selected for further evaluation using the criteria of elicitation frequency, strength of component loading and inter-correlation clustering. The 10 generic SA constructs selected in this way, with associated descriptions and dimensions, are listed in Table 2.

FIGURE 1. CORRELATION CLUSTERS

NO.	CONSTRUCT	COMPONENTS
S1.C1	Attentional load	1
S9.C1	Demand	1
S12.C2	Focusing	1
S15.C2	Predictability	1
S4.C3	Receptivity	1
S6.C2	Spare capacity	1
S9.C2	Information quality	1
S12.C1	Spare capacity	1
S5.C2	Information availability	1
S6.C1	Workload	1
S10.C1	Information quality	1
S3.C1	Familiarity	1,2
S13.C1	Familiarity	1,2
S4.C2	Familiarity	1
S8.C2	Complexity	1
S8.C1	Stability	1
S13.C3	Complexity	
S5.C3	Stability	3
S10.C2	Familiarity	1
S14.C2	Risk	3
S6.C3	Distraction	
S13.C2	Focusing	
S13.C4	Information quality	1
S15.C3	Focusing	3
S14.C3	Information quality	3
S7.C1	Variability	1
S1.C2	Concentration	2
S4.C1	Arousal	2
S6.C4	Arousal	2
S12.C3	Control	2
S7.C2	Concentration	2,3
S9.C3	Concentration	2
S3.C3	Attention switching	
S15.C1	Attentional demand	2
S11.C3	Information quantity	2
S2.C1	Risk	2
S11.C1	Division of attention	2
S11.C2	Complexity	2
S14.C1	Concentration	2
S14.C4	Familiarity	2
S3.C2	Consciousness	4
S5.C1	Information quality	
S3.C4	Motivation	4
S8.C3	Anticipation	4

CLUSTER LINKS*



* Link length inversely proportional to link strength

TABLE 2. GENERIC SITUATIONAL AWARENESS CONSTRUCTS

NO.	GENERIC CONSTRUCT	DIMENSION	DESCRIPTION	RELATED CONSTRUCTS
C1	Familiarity	Unfamiliar v Familiar situation	Degree of acquaintance with situation experience	S3.C1; S4.C1 S10.C2; S13.C1 S14.C4
C2	Focusing	Focused v Divided attention	Degree of distribution or focusing of one's perceptive abilities	S3.C3; S11.C1 S12.C2; S13.C2 S15.C3
C3	Information quantity	No v A lot of relevant information	Amount of knowledge received and understood	S5.C2; S11.C3
C4	Instability	Unstable v Stable situation	Likeliness of situation to change suddenly	S2.C1; S5.C3 S8.C1; S12.C3 S14.C2
C5	Concentration	Low level v High level of concentration	Degree to which one's thoughts are brought to bear on the situation	S1.C2; S6.C3 S7.C2; S8.C3 S9.C3; S14.C1
C6	Complexity	Simple v Complex situation	Degree of complication (number of closely connected parts) of situation	S8.C2; S11.C2 S13.C3
C7	Variability	Few v A lot of 'things' to attend to	Number of variables which require one's attention	S1.C1; S7.C1 S9.C1
C8	Arousal	Low level v High level of arousal	Degree to which one is ready for activity (sensory excitability)	S3.C4; S4.C1 S6.C4
C9	Information quality	Poor v Good quality of information	Degree of goodness or value of knowledge communicated	S5.C1; S10.C1 S13.C4; S14.C3
C10	Spare capacity	No v A lot of spare capacity	Amount of mental ability available to apply to new variables	S4.C3; S6.C1 S12.C1

2.3.2. GENERIC CONSTRUCTS

Next, the 10 generic SA constructs and 29 scenarios were presented to 10 test aircrew at RAF Farnborough for further scenario/construct ratings. The 29 scenarios were divided into two arbitrary sets. Five aircrew rated each set to give 2 independent sets of data. The ratings obtained are summarised in Appendix Tables V and VI, together with the results of an Analysis of Variance (ANOVA) across scenarios. The ANOVA results indicate the relative sensitivity of the constructs to the differences between the scenarios. Only Focusing (C2) and Information Quantity (C3) failed to achieve statistical significance (Set I scenarios only).

Both sets of ratings were subjected to Principal Components analysis with Varimax factor rotation. The resultant correlation matrices are reported in Appendix Tables VII and VIII. The Principal Components loadings are reported in Appendix Tables IX and X with a summary of the highly loaded constructs at Table 3. Three components accounted for 79% and 71% of the variance in the Scenario I and II sets respectively. In both data sets, Complexity (C6), Variability (C7) and Instability (C4) were strongly inter-correlated and loaded highly on the 1st Component. Similarly, Information Quantity and Information Quality were inter-correlated, and loaded highly on the 2nd Component in the Set I data, along with familiarity (C1), and loaded on the 3rd Component in the Set II data. Focusing (C2) loaded highly on the 3rd Component in the Set I data, and on the 2nd Component in the Set II data, along with Concentration (C5) and Arousal (C8). Spare Capacity (C10) was inter-correlated with Concentration (C5) and Arousal (C8), and loaded highly on the 1st Component in both data sets.

TABLE 3. CONSTRUCTS LOADING HIGHLY ON PRINCIPAL COMPONENTS FOR FLIGHT SCENARIOS

SCENARIO SET I		SCENARIO SET II	
1st Component (Var: 47.89%)		1st Component (Var: 36.52%)	
Arousal	0.919	Complexity	0.924
Concentration	0.914	Variability	0.915
Instability	-0.858	Spare capacity	-0.720
Complexity	0.849	Instability	-0.650
Spare capacity	-0.823	Arousal	0.607
Variability	-0.819	Concentration	0.571
2nd Component (Var: 19.75%)		2nd Component (Var: 20.15%)	
Information quantity	0.859	Focusing	0.859
Information quality	0.750	Concentration	-0.688
Familiarity	0.728	Arousal	-0.671
3rd Component (Var: 11.52%)		3rd Component (Var: 15.25%)	
Focusing	0.956	Information quantity	0.896
		Information quality	0.748

2.4. CONSTRUCT STRUCTURE VALIDATION

Guided by the analysis of the two independent sets of construct/scenario ratings, which showed similar data structures, and from an understanding of the theory of attention and cognition (29), on the basis of strength of component loading and inter-correlation clusters it was postulated that for purposes of simplification and theoretical consistency the SA constructs should be tentatively considered as comprising 3 broad categories or domains, namely:

(a) Demands on Attentional Resources (Instability, Complexity, Variability).

(b) Supply of Attentional Resources (Arousal, Concentration, Division of Attention, Spare Capacity).

(c) Understanding of the Situation (Information Quantity, Information Quality, Familiarity).

In order to examine the validity of this postulated structure, and to test its applicability to other situations, a further study was conducted using decision-making scenarios generated for an investigation of Human-Electronic Crew Teamwork (30).

2.4.1. VALIDATION METHOD

Descriptions of 12 scenarios involving tactical decision-making behaviour were obtained from eight operational Tornado aircrew at RAF Marham. Six scenarios concerned Navigator decisions and six concerned Pilot decisions. All the decisions in the scenarios were made without consultation with the second crew member. In each Pilot/Nav decision category, three scenarios described "High Trust" decisions and three scenarios described "Low Trust" decisions. Situational awareness was not a specified scenario variable. The 12 decision scenarios obtained in this way are described below.

PILOT DECISION SCENARIOS:

P1 EVASION: In a low level evasion scenario, the Pilot sees an enemy fighter in front. On the basis of ability to get a successful shot off, risk to own aircraft, ground threats, other air threats, hit probability and what the enemy will do if not killed first, without consultation, the Pilot decides to attempt a shot rather than to run away (HIGH NAVIGATOR TRUST).

P2 WEATHER: When flying low-level, the Pilot sees a potential weather problem ahead. On the basis of visual information on weather, and on terrain and map information, without consultation, the Pilot decides to change course right/left to avoid weather rather than to continue on course (HIGH NAVIGATOR TRUST).

P3 EW: When alerted by sidetone that a missile or electronic warfare threat is locked-on, the Pilot visually detects a missile. On the basis of the electronic visual strobe, electronic audio sidetone and visual information, without consultation, the Pilot decides to break right/left rather than to maintain course (HIGH NAVIGATOR TRUST).

P4 LOW LEVEL WEATHER ABORT: Flying at low-level with poor visibility conditions, the Nav considers that conditions are unfit to continue on course and queries whether it is safe to continue. On the basis of visibility, cloud base height, ground height and terrain shape, controlled airspace, safety altitude, without consultation, the Pilot decides to continue on course rather than to pull up (LOW NAVIGATOR TRUST).

P5 ROUTE CHANGE IN WEATHER: Flying low-level with bad weather ahead, the Pilot makes a late decision to turn left/right towards clearer weather area rather than maintain original course, without consulting the Nav regarding airspace restrictions (LOW NAVIGATOR TRUST).

P6 COUNTER STARBOARD: Flying low-level, with an enemy approaching unseen on starboard beam, on hearing a "counter-starboard" call from a buddy aircraft, without consultation, the Pilot decides to break port (LOW NAVIGATOR TRUST).

NAVIGATOR DECISION SCENARIOS:

N1 ROUTE CHANGE: In low-level combat, with the Pilot busy flying the aircraft, on basis of time, position, fuel and perceived threat, without consultation, the Nav calls a route change to come right/left, to cut short rather than extend route, to save rather than extend time and fuel (HIGH PILOT TRUST).

N2 AIR THREAT: In a combat formation of aircraft, the Nav perceives air threat in a threatening, firing position, loosing bullets. On the basis of disposition of own and enemy forces, position in space, perceived threat and assessment of likely actions by aggressor and counter threat success, without consultation, the Nav instructs the Pilot to weave, rather than buster (fast straight line), turn, climb, descend, drop bomb (for retard defence), chaff or flares (HIGH PILOT TRUST).

N3 COMMAND EJECTION: With the aircraft in a dive, and the Pilot not responding to 'recover' inputs, possibly suffering target fixation, and with ejection switch set to 'both', the Nav evaluates possibility of ground impact, lack of time, ground proximity and aircraft attitude, and chooses to eject rather than to take no action (HIGH PILOT TRUST).

N4 BOUNCE: When bounced on a pairs trip, the enemy fails to gain a good position and flies away out of view. Assuming that the bounce is over, the Nav decides not to continue to look out for return of the enemy, and without consultation, recommends the Pilot to return to track (LOW PILOT TRUST).

N5 WEATHER PENETRATION: Flying low-level in bad weather, the Pilot sees a hole (letter-box) under the weather, not observable from Nav's back-seat position. The Nav recommends the Pilot to pull-up to avoid the weather rather than continuing on course (LOW PILOT TRUST).

N6 RE-ROUTE: After being bounced, with Time-on-Target behind schedule, the Nav recommends the Pilot to speed up to cut corners and conserve fuel rather than re-route (LOW PILOT TRUST).

Next, the 12 decision scenarios were presented to 43 operational Tornado aircrew at RAF Laarbruch and RAF Bruggen for SA construct rating. Twenty four Pilots rated the 6 Pilot decision scenarios and 19 Navigators rated the 6 Navigator decision scenarios. Ratings were obtained on a 7-point rating scale - LOW (1) to HIGH (7) - for the 10 generic constructs, the 3 construct domains (Demand, Supply and Understanding) and the single dimension of Situational Awareness. The 14 constructs were presented and described as shown in Table 4.

TABLE 4. CONSTRUCTS FOR DECISION SCENARIO RATINGS

NO.	CONSTRUCT	DESCRIPTION
C.1	DEMANDS ON ATTENTIONAL RESOURCES	-
C.1.1	Instability of situation	Likeliness to change suddenly
C.1.2	Complexity of situation	Degree of complication
C.1.3	Variability of situation	Number of variables/factors changing
C.2	SUPPLY OF ATTENTIONAL RESOURCES	-
C.2.1	Arousal	Degree of alertness; readiness for activity
C.2.2	Concentration of attention	Degree to which thoughts are brought to bear
C.2.3	Division of attention	Distribution/spread of focus of attention
C.2.4	Spare mental capacity	Mental ability available for new variables
C.3	UNDERSTANDING OF SITUATION	-
C.3.1	Information quantity	Amount of knowledge received and understood
C.3.2	Information quality	Goodness or value of knowledge communicated
C.3.3	Familiarity	Degree of prior experience/knowledge
C.4	SITUATIONAL AWARENESS	Degree of situational awareness involved

2.4.2. VALIDATION RESULTS

The ratings obtained are summarised together with results of an ANOVA across scenarios in Appendix Tables XI and XII. The ANOVA results indicate that only Information Quality (C3.2) failed to achieve statistical significance (Pilot Decision Scenarios only). The additional postulated domain constructs - Demand (C1), Supply (C2), Understanding (C3) - and Situational Awareness (C4) were all sensitive to differences in the decision scenarios at the $p<0.05$ level.

Both sets of ratings were subjected to Principal Components Analysis with Varimax factor rotation. The resultant correlation matrices are reported in Appendix Tables XIII and XIV. The results of the Principal Components Analysis are reported in Appendix Tables XV and XVI, with a summary of the highly loaded constructs at Table 5. Four components accounted for 73% of the variance in both data sets. Both data sets exhibited similar structure. Instability (C1.1), Complexity (C1.2) and Variability (C13) were highly inter-correlated with Demand (C1) and all loaded highly on the same Principal Component. Arousal (C2.1) and Concentration (C2.2) were highly inter-correlated with Supply (C2) and to a lesser extent with Demand (C1), and all loaded highly on the Principal Component that accounted for the largest proportion of the variance. Information Quantity (C3.1) and Information Quality (C3.2) were highly inter-correlated with Understanding (C3) and to a lesser extent Situational Awareness (C4), and all loaded highly on the same Principal Component. Division (C2.3) and Spare Capacity (C2.4) were moderately inter-correlated with Familiarity (C3.3) and all loaded highly on the remaining Principal Component which accounted for the smallest proportion of the variance. However, it should be noted that Familiarity (C3.3) correlated positively with Understanding (C3) ($p<0.01$)) and that Spare Capacity (C2.4) correlated negatively with Demand (C1) ($p<0.001$).

The structure of the postulated construct domains showed some variation between the data sets. The correlations for the construct domains are shown in Tables 6 and 7. For Navigators, Understanding (C3) correlated with Supply (C2), and Situational Awareness (C4) correlated with all 3 construct domains. For Pilots, only Understanding (C3) correlated with Situational Awareness (C4). Generally, Demand (C1) positively correlated with Supply (C2), but only Understanding (C3) consistently correlated with Situational Awareness (C4).

TABLE 5. CONSTRUCTS LOADING HIGHLY ON PRINCIPAL COMPONENTS FOR DECISION SCENARIO

PILOT DECISIONS		NAV DECISIONS	
1st Component (Var: 22.10%)		1st Component (Var: 24.48%)	
Supply	0.826	Arousal	-0.894
Arousal	0.825	Concentration	-0.878
Concentration	0.809	Supply	-0.845
Demands	0.686	Demands	-0.591
2nd Component (Var: 19.69%)		2nd Component (Var:18.77%)	
Variability	0.830	Information quantity	-0.838
Complexity	0.807	Understanding	-0.833
Instability	0.774	Information quality	-0.815
Demands	0.496	Situational awareness	-0.501
3rd Component (Var: 18.89%)		3rd Component (Var: 16.27%)	
Information quantity	-0.899	Variability	0.885
Information quality	-0.795	Complexity	0.874
Situational awareness	-0.778	Instability	0.508
Understanding	-0.658	Demands	0.484
4th Component (Var: 12.61%)		4th Component (Var: 13.34%)	
Division	-0.820	Familiarity	-0.838
Familiarity	-0.696	Spare capacity	-0.695
Spare capacity	-0.635	Division	-0.651

TABLE 6. CORRELATION MATRIX OF DOMAIN CONSTRUCTS FOR PILOT DECISION SCENARIOS

NO.	CONSTRUCT	C1	C2	C3	C4
C1	Attentional Demand	1.000			
C2	Attentional Supply	0.601	1.000		
C3	Understanding	0.084	0.139	1.000	
C4	Situational Awareness	0.041	0.078	0.417	1.000

TABLE 7. CORRELATION MATRIX OF DOMAIN CONSTRUCTS FOR NAVIGATOR DECISION SCENARIOS

NO.	CONSTRUCT	C1	C2	C3	C4
C1	Attentional Demand	1.000			
C2	Attentional Supply	0.532	1.000		
C3	Understanding	0.133	0.489	1.000	
C4	Situational Awareness	0.497	0.649	0.557	1.000

3. DISCUSSION

Knowledge elicitation procedures indicate that three domains characterise aircrew situational awareness, namely Attentional Demands, Attentional Supply and Understanding. The study provides 10 aircrew constructs within these domains offering a deeper level of specificity. Quantification of these three construct domains is probably necessary and sufficient for a comprehensive measurement of SA. Uni-dimensional subjective estimation of SA offers little, if any, diagnostic power. A Situational Awareness Rating Technique (SART) can be proposed with alternative three-dimensional (3-D) and ten-dimensional (10-D) forms providing increasing specificity and diagnostic power. The most appropriate tool for a given application will depend on the degree of intrusiveness permitted by the measured task.

For highly dynamic real-time applications, such as flight simulation and flight trials, a relatively un-intrusive approach may be needed to minimise interference with the measured task. In such circumstances, the 3-D SART will be the more appropriate form, presented at intervals as a continuous or 7-point rating scale, or, with reduced visual and manual interference, as requiring a verbal report, such as LOW (1), MEDIUM (2) or HIGH (3) ratings, as in SWAT workload measurement (31). As an alternative to direct subjective estimation, conjoint scaling procedures or more simply, ipsative pair-wise comparisons could be used to calculate a uni-dimensional SA representation from the 3-D SART data. The 10-D SART will be a useful adjunct when a higher degree of specificity and diagnostic power is needed for projective and post hoc measurement of non-real time applications.

Whereas the 3-D SART probably offers the simplest multi-dimensional representation of SA - a 1-D or 2-D SART would be inadequate - the necessity and sufficiency of the 10-D SART is governed by the requirements for specificity and diagnostic power. Fewer constructs would shorten the form and make it speedier to implement. Some semantically dissimilar constructs within domains are highly correlated in all data sets and appear to be redundant, namely: Complexity, Variability and Instability; Information Quantity and Information Quality; Arousal and Concentration. However, contraction across these constructs would reduce diagnostic power in situations and tasks where they are dissociated. On the other hand, alternative or additional domain constructs may improve diagnostic power for a particular application. Additional Understanding constructs could be particularly useful since, for decision-making scenarios at least, Understanding correlates highly with Situational Awareness. However, some caution should be exercised since arbitrary additions raise validity issues.

The 10-D SART is valuable because it is derived directly from aircrew constructs and this gives it validity as an aircrew tool. Some constructs are not always highly correlated within domains such as Concentration with Division of Attention, and Familiarity with Information Quantity. This is a good reason for their inclusion. Indeed, the decision scenario data suggest that one feature of the 3-D SART is that ratings of Supply may not be influenced by consideration of Division of Attention. Division, focusing, distribution and rate of switching of attention are important constructs that characterise the structure of attention or the attentional style. Dissimilar constructs and orthogonal dimensions are the source of diagnostic power.

Differences were found between the structure of the Pilots and Navigators 3-D SART data. These differences could be due to variations in content between the two sets of decision scenarios. However, this finding also raises the possibility that SART may be sensitive to differences in role playing and attentional/cognitive style (32). The relationship between self-awareness and situational awareness is probably important if both draw upon and compete for common resources. Demands on resources arising from self awareness may reduce the supply of resources for situational awareness, and vice versa. In life-threatening situations, situational awareness is probably affected by individual differences in psychological defence mechanisms, coping strategies and emotional/affective style (33,34). People who are terrified may not notice what is going on around them.

Further work is needed to demonstrate the applicability of SART to the measurement of situational awareness in real tasks. So far, the development of SART has been based on imaginary, though familiar, scenarios. Refinement of the SART scales through clarification of ambiguous working, standardisation of briefing, presentation procedures, data analysis and interpretation should be based on real task applications. Real task assessments are also needed to investigate the relationship between SA and task performance, and to check the primary assumption that situational awareness is important for decision-making. Experimental work is also needed to investigate the role of implicit and explicit knowledge in decision-making and to establish and improve the sensitivity of SART to knowledge variables.

Finally, it may be useful to use the SA paradigm and SART constructs to draw together some of the major implications for crew-systems integration. Situational Awareness and decision-making can be enhanced by systems design, or through the Electronic Crewmember, in three broad ways:

1. Control Demands on Attentional Resources This can be achieved by automation of unwanted workload, by fusing data and by reducing uncertainty.

2. Improve the Supply of Attentional Resources This can be achieved in several ways: a) By prioritising and cueing tasks to obtain the optimum attention-allocation strategy in accordance with mission goals and objectives; b) By organising the structure of tasks to exploit the available resource modalities; c) By maintaining pilot involvement and activity at the optimum level for resource availability.

3. Improve Understanding Methods for improving understanding by design include: a) By the presentation of information in cognitively compatible forms (3-D voice and pictorial multi-modal displays); b) By making accessible and sharing a wider knowledge base through knowledge communication/dialogue techniques such as interrogation, explanation and critiquing; c) By extension of the pilot's relevant experience by simulation training through mission planning and preview facilities.

4. CONCLUSIONS

Knowledge elicitation procedures can be used to identify aircrew constructs for structural awareness. Aircrew constructs provide a multi-dimensional characterisation of situational awareness consistent with the theory of attention and cognition. Rating scales for the subjective estimation of situational awareness can be derived from these constructs that are sensitive to differences in a variety of flight and tactical decision-making scenarios. The simplest representation of situational awareness comprises three dimensions or domains corresponding to constructs for situational demands on attentional resources, for the supply of attentional resources in response to situational demands, and for the understanding of the situation. Further research is needed with real tasks to investigate the diagnostic power of subjective estimation of situational awareness, and to refine the technique as a tool for aircrew systems design.

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7. APPENDIX

TABLE I. LOADINGS ON 1ST PRINCIPAL COMPONENT (VARIANCE: 29.77%)

NO.	CONSTRUCT	LOADING
S10.C1	Information quality	-0.907
S6.C2	Spare capacity	-0.893
S12.C1	Spare capacity	-0.878
S4.C3	Receptivity	-0.870
S5.C2	Information availability	-0.812
S9.C1	Demand	-0.794
S6.C1	Workload	+0.783
S9.C2	Information quality	-0.783
S7.C1	Variability	+0.743
S13.C1	Familiarity	+0.728
S3.C1	Familiarity	+0.727
S12.C2	Focusing	+0.700
S8.C1	Stability	+0.688
S1.C1	Attentional load	-0.668
S8.C2	Complexity	-0.643
S10.C2	Familiarity	+0.585
S4.C2	Familiarity	+0.558
S13.C4	Information quality	-0.544
S15.C2	Predictability	-0.539

TABLE II. LOADINGS ON 2ND PRINCIPAL COMPONENT (VARIANCE: 20.75%)

NO.	CONSTRUCT	LOADING
S9.C3	Concentration	+0.874
S1.C2	Concentration	+0.753
S2.C1	Risk	+0.743
S14.C1	Concentration	+0.736
S15.C1	Attentional demand	+0.682
S11.C3	Information quantity	-0.676
S11.C2	Complexity	+0.643
S4.C1	Arousal	+0.643
S14.C4	Familiarity	+0.641
S12.C3	Control	+0.615
S7.C2	Concentration	+0.596
S6.C4	Arousal	+0.574
S13.C1	Familiarity	+0.574
S11.C1	Division of attention	-0.570
S3.C1	Familiarity	+0.501

TABLE III. LOADINGS ON 3RD PRINCIPAL COMPONENT (VARIANCE: 8.49%)

NO.	CONSTRUCT	LOADING
S14.C3	Information quality	-0.821
S7.C2	Concentration	-0.556
S15.C3	Focusing	-0.547
S5.C3	Stability	+0.534
S14.C2	Risk	+0.515

TABLE IV. LOADINGS ON 4TH PRINCIPAL COMPONENT (VARIANCE: 6.16%)

NO.	CONSTRUCT	LOADING
S3.C2	Consciousness	0.689
S3.C4	Motivation	0.578
S13.C3	Complexity	-0.554
S8.C3	Anticipation	-0.502

TABLE V. SUMMARY OF RATING MEANS (N = 5) AND ANOVA's FOR SET I FLIGHT SCENARIOS

FLIGHT SCENARIO	CONSTRUCTS									
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
F1.1	1.2	5.2	4.0	2.0	7.0	6.0	6.6	6.4	2.4	1.8
F1.3	2.6	4.4	3.8	2.4	6.4	5.2	5.6	5.4	2.4	4.0
F1.5	4.6	4.4	3.2	5.2	4.2	2.8	2.8	3.4	3.8	4.8
F1.7	6.8	4.0	4.8	6.4	3.0	2.2	2.2	2.4	6.2	6.2
F1.9	6.6	4.2	5.3	6.8	3.2	1.4	0.7	3.0	4.3	4.8
F1.11	3.6	4.9	2.9	2.8	2.5	2.4	2.8	2.4	1.2	5.0
F1.13	3.2	3.8	5.0	2.0	6.2	3.6	3.4	6.6	5.0	3.6
F1.15	4.0	3.6	4.2	2.4	5.6	4.8	4.8	4.8	5.2	3.0
F1.17	4.2	4.4	4.6	2.6	6.4	6.0	5.8	5.8	4.2	2.8
F2.1	6.6	3.6	6.2	6.6	3.6	2.6	3.0	3.2	6.6	6.4
F2.3	4.4	5.8	5.0	1.0	7.0	7.0	5.8	7.0	4.4	2.8
F2.5	6.4	3.6	4.8	5.0	4.4	3.0	4.2	3.4	5.4	4.8
F2.7	5.8	4.2	4.8	2.8	5.8	4.4	4.6	5.4	4.2	4.0
F2.9	6.6	5.0	5.4	5.4	4.0	3.2	3.4	3.8	6.2	5.2
F2.11	4.6	3.6	4.8	3.4	5.4	3.6	4.8	5.2	3.6	3.6
MEAN	4.74	4.31	4.58	3.79	4.98	3.88	4.04	4.54	4.34	4.18
F RATIO	8.22	0.619	1.753	11.16	7.00	7.02	6.97	6.59	10.91	3.04
PROB.	0.001	NS	NS	0.001	0.001	0.001	0.001	0.001	0.001	0.01

TABLE VI. SUMMARY OF RATING MEANS (N = 5) AND ANOVA's FOR SET II FLIGHT SCENARIOS

FLIGHT SCENARIO	CONSTRUCTS									
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
F1.2	4.2	4.4	2.6	2.0	6.4	4.2	3.6	6.0	3.4	4.0
F1.4	5.8	4.4	4.2	5.8	3.0	2.4	2.6	2.2	5.4	5.6
F1.6	4.4	3.8	2.4	1.2	6.8	5.2	3.6	6.6	2.6	2.4
F1.8	7.0	4.4	5.5	6.2	2.4	2.8	2.7	2.4	5.6	6.8
F1.10	3.4	2.4	6.2	3.4	5.8	5.8	5.8	5.4	4.6	3.2
F1.12	2.6	2.0	5.0	2.0	6.8	4.4	4.8	6.2	4.2	1.8
F1.14	4.6	3.6	3.9	3.5	4.6	3.2	4.2	4.8	3.9	3.4
F1.16	5.0	2.6	5.0	3.2	5.8	2.8	2.8	5.4	5.6	3.6
F1.18	3.2	5.2	5.0	2.4	4.4	4.4	5.0	4.2	1.6	3.2
F2.2	5.6	2.8	3.6	3.6	6.0	3.0	3.0	6.2	6.2	4.8
F2.4	4.0	3.2	4.6	2.6	6.6	4.8	4.4	5.4	3.6	2.8
F2.6	4.8	6.0	3.6	6.8	1.4	1.2	1.2	1.2	5.6	6.4
F2.8	5.0	4.6	4.0	2.0	6.6	6.2	5.8	6.0	3.8	3.0
F2.10	5.2	3.2	5.0	4.0	5.8	5.4	4.8	5.4	3.8	3.4
MEAN	4.62	3.75	4.38	3.48	5.17	3.99	3.88	4.81	4.28	3.88
F RATIO	2.02	1.97	2.38	7.57	11.72	5.56	4.42	13.41	4.41	7.62
PROB.	0.05	0.05	0.05	0.001	0.001	0.001	0.001	0.001	0.001	0.001

TABLE VII. CORRELATION MATRIX OF CONSTRUCTS FOR SET I FLIGHT SCENARIOS

NO.	CONSTRUCT	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
C1	Familiarity	1.000									
C2	Focusing	-0.039	1.000								
C3	Info. quantity	0.439	0.002	1.000							
C4	Instability	0.458	-0.207	0.115	1.000						
C5	Concentration	-0.488	0.211	-0.072	-0.793	1.000					
C6	Complexity	-0.373	0.320	-0.088	-0.727	0.766	1.000				
C7	Variability	-0.313	0.355	-0.026	-0.657	0.728	0.811	1.000			
C8	Arousal	-0.402	0.227	0.024	-0.805	0.846	0.757	0.680	1.000		
C9	Info. quality	0.583	-0.182	0.442	0.456	-0.379	-0.394	-0.475	-0.307	1.000	
C10	Spare capacity	0.397	-0.176	0.151	0.674	-0.744	-0.683	-0.765	-0.711	0.472	1.000

TABLE VIII. CORRELATION MATRIX OF CONSTRUCTS FOR SET II FLIGHT SCENARIOS

NO.	CONSTRUCT	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
C1	Familiarity	1.000									
C2	Focusing	0.06[illegible]	1.000								
C3	Info. quantity	0.077	-0.106	1.000							
C4	Instability	0.25[illegible]	0.136	0.076	1.000						
C5	Concentration	-0.203	-0.374	-0.027	-0.652	1.000					
C6	Complexity	-0.206	0.109	0.161	-0.558	0.560	1.000				
C7	Variability	-0.297	0.055	0.210	-0.488	0.478	0.858	1.000			
C8	Arousal	-0.285	-0.337	0.048	-0.698	0.817	0.527	0.525	1.000		
C9	Info. quality	0.161	0.046	0.421	0.417	-0.268	-0.356	-0.328	-0.213	1.000	
C10	Spare capacity	0.304	0.114	-0.057	0.615	-0.647	-0.558	-0.591	-0.651	0.322	1.000

TABLE IX. LOADINGS OF CONSTRUCTS ON PRINCIPAL COMPONENTS FOR SET I FLIGHT SCENARIOS

NO.	CONSTRUCT	PRINCIPAL COMPONENTS		
		1st	2nd	3rd
		VAR: 47.89%	VAR: 19.75%	VAR: 11.52%
C1	Familiarity	-0.398	0.728	0.122
C2	Focusing	0.147	-0.016	0.956
C3	Information quantity	0.088	0.859	-0.002
C4	Instability	-0.858	0.206	-0.047
C5	Concentration	0.914	-0.145	0.037
C6	Complexity	C.849	-0.123	0.248
C7	Variability	0.819	-0.113	0.333
C8	Arousal	0.919	-0.026	0.045
C9	Information quality	0.343	0.750	-0.197
C10	Spare capacity	-0.823	-0.225	-0.077

TABLE X. LOADINGS OF CONSTRUCTS ON PRINCIPAL COMPONENTS FOR SET II FLIGHT SCENARIOS

NO.	CONSTRUCT	PRINCIPAL COMPONENTS		
		1st	2nd	3rd
		VAR: 36.52%	VAR: 20.15%	VAR: 15.25%
C1	Familiarity	-0.335	0.142	0.214
C2	Focusing	0.202	0.859	-0.086
C3	Information quantity	0.200	-0.026	0.896
C4	Instability	-0.650	0.434	0.283
C5	Concentration	0.571	-0.688	-0.113
C6	Complexity	0.924	0.002	0.011
C7	Variability	0.915	-0.002	0.063
C8	Arousal	0.607	-0.671	-0.045
C9	Information quality	-0.365	0.046	0.748
C10	Spare capacity	-0.720	0.376	0.103

TABLE XI. SUMMARY OF CONSTRUCT RATING MEANS (N = 24) & ANOVAs FOR PILOT DECISION SCENARIOS

NO.	CONSTRUCT	DECISION SCENARIO						MEAN	F VALUE	PROB <
		P1	P2	P3	P4	P5	P6			
C.1	Attentional demand	5.62	4.15	6.03	5.24	4.13	5.47	5.11	16.60	0.001
C.1.1	Instability	5.50	4.21	5.50	5.00	4.33	5.79	5.05	6.40	0.001
C.1.2	Complexity	5.54	3.71	5.17	4.83	3.92	5.13	4.72	11.36	0.001
C.1.3	Variability	5.88	4.04	5.33	5.04	4.25	5.46	5.00	11.17	0.001
C.2	Attentional supply	5.60	4.66	5.75	4.94	4.70	5.38	5.17	6.52	0.001
C.2.1	Arousal	6.42	4.83	6.46	5.25	4.71	6.08	5.62	22.90	0.001
C.2.2	Concentration	6.21	4.79	6.29	5.17	4.71	5.58	5.46	16.97	0.001
C.2.3	Division	3.96	4.71	3.54	3.92	4.00	3.96	4.01	2.88	0.05
C.2.4	Spare capacity	3.83	5.04	3.13	4.13	4.75	3.67	4.09	10.19	0.001
C.3	Understanding	5.17	5.45	5.00	4.89	4.72	4.28	4.92	3.37	0.01
C.3.1	Information quantity	4.79	5.00	4.75	4.67	4.54	3.83	4.60	3.17	0.05
C.3.2	Information quality	4.25	4.79	4.71	4.33	4.42	4.50	4.50	0.79	NS
C.3.3	Familiarity	4.50	5.58	3.67	5.21	5.38	4.83	4.86	10.14	0.001
C.4	Situation awareness	5.50	5.08	5.46	5.26	4.71	4.61	5.10	2.42	0.05

TABLE XII. SUMMARY OF CONSTRUCT RATING MEANS (N= 19) & ANOVAs FOR NAV DECISION SCENARIOS

NO.	CONSTRUCT	DECISION SCENARIO						MEAN	F VALUE	PROB <
		N1	N2	N3	N4	N5	N6			
C.1	Attentional demand	4.64	5.71	5.64	4.29	5.00	4.57	4.97	3.01	0.05
C.1.1	Instability	4.79	5.63	4.42	5.63	4.50	3.89	4.81	3.01	0.05
C.1.2	Complexity	4.32	5.32	4.[illegible]	4.37	3.26	3.32	4.23	5.47	0.001
C.1.3	Variability	4.79	5.68	4.84	5.11	4.00	4.47	4.81	2.81	0.05
C.2	Attentional supply	4.74	5.56	5.68	4.21	5.21	4.86	5.04	4.26	0.01
C.2.1	Arousal	5.26	6.26	6.11	4.95	5.47	5.05	5.52	3.78	0.01
C.2.2	Concentration	4.89	6.32	6.26	4.47	5.42	4.74	5.35	6.96	0.001
C.2.3	Division	4.42	3.16	2.63	4.58	3.89	4.58	3.88	5.14	0.001
C.2.4	Spare capacity	4.37	3.47	2.47	4.58	4.58	4.79	3.99	8.92	0.001
C.3	Understanding	5.57	5.59	5.50	4.28	5.06	5.62	5.27	4.29	0.01
C.3.1	Information quantity	5.32	5.47	4.68	3.84	4.32	5.05	4.78	3.98	0.01
C.3.2	Information quality	5.21	5.32	4.74	3.74	4.68	5.11	4.80	3.64	0.01
C.3.3	Familiarity	5.63	4.42	3.58	5.11	5.11	5.26	4.85	5.50	0.001
C.4	Situational awareness	5.74	5.63	5.84	4.00	4.95	5.00	5.19	4.99	0.001

TABLE XIII. CORRELATION MATRIX OF CONSTRUCTS FOR PILOT DECISION SCENARIOS

NO.	C1	C1.1	C1.2	C1.3	C2	C2.1	C2.2	C2.3	C2.4	C3	C3.1	C3.2	C3.3	C4
C1	1.000													
C1.1	.506	1.000												
C1.2	.675	.561	1.000											
C1.3	.664	.619	.871	1.000										
C2	.601	.346	.430	.452	1.000									
C2.1	.698	.424	.477	.498	.687	1.000								
C2.2	.659	.400	.485	.488	.593	.770	1.000							
C2.3	-.214	-.030	-.077	-.057	-.076	-.055	-.012	1.000						
C2.4	-.612	-.369	-.546	-.446	-.283	-.399	-.383	.444	1.000					
C3	.084	-.161	-.180	-.126	.139	.062	.101	.154	.232	1.000				
C3.1	-.124	-.147	-.260	-.197	-.058	-.084	-.091	.134	.442	.607	1.000			
C3.2	-.173	-.131	-.284	-.269	-.096	-.152	-.191	.178	.337	.426	.638	1.000		
C3.3	-.315	-.182	-.237	-.222	-.012	-.212	-.146	.283	.484	.422	.181	.229	1.000	
C4	.041	.010	-.022	.010	.078	.123	.139	.140	.272	.417	.595	.461	.227	1.000

(R = 0.21 p<0.05; R = 0.27 p<0,01; R = 0.34 p<0.001)

TABLE XIV. CORRELATION MATRIX OF CONSTRUCTS FOR NAVIGATOR DECISION SCENARIOS

NO.	C1	C1.1	C1.2	C1.3	C2	C2.1	C2.2	C2.3	C2.4	C3	C3.1	C3.2	C3.3	C4
C1	1.000													
C1.1	.260	1.000												
C1.2	.541	.333	1.000											
C1.3	.364	.281	.718	1.000										
C2	.532	.078	.191	.223	1.000									
C2.1	.507	.090	.256	.190	.796	1.000								
C2.2	.568	.068	.309	.166	.739	.862	1.000							
C2.3	-.291	.028	-.207	-.165	-.101	-.119	-.200	1.000						
C2.4	-.419	-.182	-.345	-.244	-.190	-.207	-.282	.513	1.000					
C3	.133	.120	.134	.145	.489	.358	.32[illegible]	.069	.143	1.000				
C3.1	.243	.137	.251	.151	.337	.281	.361	.094	.083	.723	1.000			
C3.2	.202	.078	.073	.051	.462	.358	.333	.055	.088	.682	.634	1.000		
C3.3	-.083	-.123	.049	.227	.090	.047	-.005	.331	.394	.313	.225	.167	1.000	
C4	.497	.042	.266	.116	.649	.585	.566	.080	-.108	.557	.537	.540	.209	1.000

(R = 0.23 p<0.05; R = 0.30 p<0.01; R = 0.38 p<0.001)

TABLE XV. LOADINGS OF CONSTRUCTS ON PRINCIPAL COMPONENTS FOR PILOT DECISION SCENARIOS

NO.	CONSTRUCT	PRINCIPAL COMPONENTS			
		1st	2nd	3rd	4th
		VAR: 22.10%	VAR: 19.69%	VAR: 18.89%	VAR: 12.61%
C.1	Attentional demands	0.686	0.496	-0.019	0.323
C.1.1	Instability	0.217	0.774	0.036	0.030
C.1.2	Complexity	0.354	0.807	0.153	0.104
C.1.3	Variability	0.361	0.830	0.100	0.049
C.2	Attentional supply	0.826	0.178	0.002	-0.017
C.2.1	Arousal	0.825	0.299	0.000	0.101
C.2.2	Concentration	0.809	0.295	0.017	0.029
C.2.3	Division	-0.098	0.138	-0.077	-0.820
C.2.4	Spare capacity	-0.346	-0.350	-0.316	-0.635
C.3	Understanding	0.346	-0.297	-0.658	-0.211
C.3.1	Information quantity	-0.063	-0.120	-0.896	-0.068
C.3.2	Information quality	-0.183	-0.093	-0.795	-0.073
C.3.3	Familiarity	0.071	-0.313	-0.176	-0.696
C.4	Situation awareness	0.102	0.106	-0.778	-0.147

TABLE XVI. LOADINGS OF CONSTRUCTS ON PRINCIPAL COMPONENTS FOR NAVIGATOR DECISION SCENARIOS

NO.	CONSTRUCT	PRINCIPAL COMPONENTS			
		1st	2nd	3rd	4th
		VAR: 24.48%	VAR: 18.77%	VAR: 16.27%	VAR: 13.34%
C.1	Attentional demands	-0.591	-0.092	0.484	0.285
C.1.1	Instability	0.179	-0.320	0.508	0.293
C.1.2	Complexity	-0.186	-0.079	0.874	0.090
C.1.3	Variability	-0.114	0.000	0.885	-0.114
C.2	Attentional supply	-0.845	-0.289	0.085	0.002
C.2.1	Arousal	-0.894	-0.157	0.097	0.024
C.2.2	Concentration	-0.878	-0.167	0.118	0.122
C.2.3	Division	0.188	-0.155	-0.158	-0.651
C.2.4	Spare capacity	0.263	-0.160	-0.327	-0.695
C.3	Understanding	-0.256	-0.833	0.053	-0.181
C.3.1	Information quantity	-0.184	-0.838	0.144	-0.092
C.3.2	Information quality	-0.278	-0.815	-0.059	-0.036
C.3.3	Familiarity	-0.080	-0.120	0.196	-0.838
C.4	Situation awareness	-0.652	-0.501	0.097	-0.113