



Cardiovascular and Subjective Measures of Task Demand in a Low Workload Monitoring Task

SUMMARY REPORT

Carole D. Braby

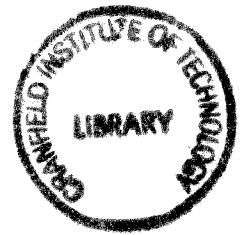
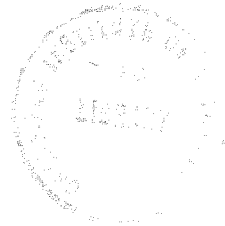
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*"The views expressed herein are those of the authors alone and do not
necessarily represent those of the Institute."*

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ABSTRACT

The study was conducted in response to a general lack of research in to the assessment of the workload which is experienced by the pilot at low levels of task demand.

Four existing indices of workload were investigated regarding their sensitivity to two low task demand situations ie. **low demand and very low demand**. These included:

- (a) The Bedford Workload scale
- (b) A five point Alertness scale (Kitchin and Graham, 1974)
- (c) Heart rate - measured as the mean inter-beat interval
- (d) Heart rate variability - measured as the standard deviation of the inter-beat interval

A further multidimensional Subjective scale which was developed during the study was also employed. This scale consisted of 30 adjectives and phrases which described eg. feelings of frustration, boredom, and fatigue.

THE TASKS

A 30 minute video recording was taken of the fluctuations in the instruments of an analog '180' training simulator. Two monitoring tasks of low and very low demand were developed from this single recording. The level of demand was varied according to the number of instruments to monitor and the number of fluctuations to detect. The video recording was replicated to form a 65 minute task with a 5 minute interval between each 30 minute period.

PROCEDURE

16 male students from the Cranfield Institute of Technology were assigned to one of the two conditions. The Alertness and Subjective adjective scales were administered along with the Bedford workload scale immediately following the first and second 30 minute periods of the task; ECG was recorded continuously throughout task.

RESULTS

Statistical analysis of the Subjective data indicated that the Alertness and Bedford workload scales did not significantly distinguish between the two conditions for each period. However, the Subjective Adjective Scale, which was developed during the study, distinguished perfectly between the two conditions for the first 30 minute period and correctly classified 13 cases for the second period.

The ECG data was analysed as heart rate and heart rate variability. These values were standardized to enable a comparison between the two groups whilst maintaining the variability associated with each subjects ECG recording. Statistical analysis of both heart rate and heart rate variability data indicated no significant differences between the two conditions.

CONCLUSIONS

It is suggested as a result of these findings the concept of workload should be expanded to include an assessment of the states which contribute to the mental load in the absence of high task demand. The usefulness of the multidimensional Subjective Scale reflects the type and complexity of the workload states which are induced in the low task demand situations. This in turn limits the use of unidimensional measures in the assessment of these workload states. The study also suggests the physiological measures heart rate and heart rate variability are of limited usefulness in distinguishing between the two monitoring tasks.

INTRODUCTION

AUTOMATION AND THE ROLE OF THE PILOT

The automation of flight deck functions previously performed by the pilot is becoming increasingly apparent in the new technology cockpits. This has caused the role of the pilot to shift from the high task demand situation where the pilot was the sole controller and monitor of flight deck functions to the relatively low demand situation where the pilot is a 'supervisory controller', (Sheridan and Johannessen, 1976) and is relieved of the moment to moment control and monitoring tasks.

Despite the automation of various control and monitoring tasks instances may arise which require their manual operation . For example, the pilot may be required to intervene to avoid storms seen on the radar map, to comply with instructions from ATC or in the ultimate situation due to malfunctions in the flight management or automatic control systems. In order to respond promptly and appropriately to these situations the human pilot must remain actively and continuously involved in determining and directing the future flight path of his aircraft and its appropriate performance parameters ie. **speed, altitude, power, rate of climb/descent.**

Curry and Wiener (1983) have identified three major reasons for the implementation of automation which include Technological advances, Economy and Safety. Despite the proposed benefits of automation, particularly in the reduction of human error, there is serious concern about the impact of automation on flight-deck **performance, workload** and ultimately on aviation **safety**. These concerns have arisen from anecdotal evidence in incident and accident reports which have questioned such matters as failure detection, manual takeover, skill degradation, job satisfaction and the self-concept of pilots and flight engineers operating highly automated equipment.

WORKLOAD

To date most studies of pilot workload have concentrated on an increase in pilot performance through a corresponding decrease in task demand. This is reflected in the increasing implementation of automation. However, there has been a lack of research concerning the level to which task demand should be reduced. This problem may be partly resolved through an investigation of the workload states which are induced in the operator at low levels of demand.

The following research was undertaken to examine this problem through an investigation of the subjective feelings or workload 'states' which are experienced by the operator at low levels of task demand and an assessment of the sensitivity of selected existing indices to the workloads experienced at these levels of low demand. A summary of this research will be presented in the following sections with an emphasis on the development of a **multidimensional Subjective Scale**.

INDICES OF WORKLOAD

Four existing metrics of workload were investigated regarding their sensitivity to two low task demand situations ie. **low demand** and **very low demand** these included:

- (a) The Bedford workload scale - a modified version of the Cooper Harper scale
- (b) A five point Alertness scale developed by Kitchin and Graham (1974)
- (c) Heart Rate - measured as the mean inter-beat interval
- (d) Heart Rate Variability - measured as the standard deviation of the inter-beat interval

A further multidimensional Subjective Adjective scale (SAS) which was developed during the course of the study was also employed. The development and structure of this scale will be briefly discussed in the following section.

DEVELOPMENT OF THE SUBJECTIVE ADJECTIVE SCALE

Two scenarios were developed which described a low and a high demand flight task. The demand in the two situations was created by varying the characteristics of the flight task according to the four criteria outlined by Kibler (1965). The criteria were as follows:

- (i) display complexity
- (ii) degree of motor involvement
- (iii) decision complexity
- (iv) signal metrics intensity, duration and frequency.

On the basis of the above characteristics a high demand flight task was described which required the individual to:

- (i) monitor comparatively more instruments than in the low demand situation
- (ii) perform tasks which required manual control and in turn motor involvement
- (iii) perform tasks which required mathematical calculations and therefore decision making
- (iv) detect frequent fluctuations in the cockpit instruments

By comparison the low task demand scenario described a flight task in which the individual was required to

(i) monitor only two of the instruments in the cockpit

All other tasks which included the control of the aircraft and mathematical calculations were assumed to be performed automatically.

Furthermore, during the flight there were no fluctuations in those instruments which were monitored.

These two scenarios were presented to a sample of 13 students at the Cranfield Institute of Technology. The subjects were instructed to express by using single words or phrases how they would feel in each situation. A total of 30 adjectives and phrases were generated which included feelings of **frustration, irritation, drowsiness and anxiety**. The Subjective Adjective Scale was formed by randomly arranging these adjectives and phrases to form a total of 30 separate items. The responses to each item were recorded as Yes or No. A copy of this scale is provided in Appendix I.

DEVELOPMENT OF THE LOW DEMAND AND VERY LOW DEMAND MONITORING TASKS

Two monitoring tasks of low and very low demand were developed from the ~~same~~ 30 minute video recording of fluctuations in the instruments of an 'analog 180' instrument flying simulator. The video recording was replicated to form a 65 minute task with a 5 minute interval between each 30 minute period.

The two levels of demand - low and very low were formed by manipulating the number of instruments to be monitored (ie. display complexity) and the number of fluctuations to detect (ie. signal frequency). Variations in the amount of motor involvement occurred as a result of variations in the number of fluctuations to detect. However for both conditions any degree of motor involvement did not include the control of the instruments. A degree of decision complexity was introduced as the subject was required to decide, on the basis of previous instructions, whether a signal had occurred.

A summary of the type of instruments to be monitored and the total number of signals to be detected for each level of demand, for the 65 minute duration of the task is presented in Table 1 below:

TABLE 1

CONDITION	INSTRUMENT TYPE	NUMBER OF STIMULI
LOW DEMAND	ALTITUDE	6
	AIRSPPEED	8
	HEADING*	0
	TOTAL	14
VERY LOW DEMAND	ALTITUDE	6

*Heading was included as a further instrument to be monitored in order to increase the level of task demand although it did not contribute to the number of stimuli to detect.

PROCEDURE

16 male students from the Cranfield Institute of Technology were assigned to one of the two conditions. The **Alertness** and **Subjective Adjective scale** were administered before the task and administered along with the Bedford workload scale immediately following the first and second 30 minute periods of the task; **ECG** was recorded continuously throughout the task.

The instruments to be monitored and the parameters of the signals to be detected were explained to the subjects at the beginning of the experiment. Subjects in the low demand condition were asked to detect specified fluctuations in altitude, airspeed and heading by pressing the event button once for airspeed, twice for altitude and three times for heading. Subjects in the very low demand condition were instructed to respond only to the specified fluctuations in altitude. The subjects in both conditions were informed that their responses would not alter the position of the indicator(s).

RESULTS

In the following sections the existing subjective and physiological indices of workload will be considered in terms of their ability to discriminate between the two levels of low task demand. The results of the Subjective Adjective Scale will be considered in greater depth in a later section.

TREATMENT OF DATA

(i) BEDFORD AND ALERTNESS SCALE

The mean ratings for the Bedford scale and the alertness scale were calculated for each **group** for each 30 minute period and for the task as a whole. For the alertness scale a mean rating was also calculated for the pre-experimental period.

(ii) HEART RATE AND HEART RATE VARIABILITY

In contrast to previous research this study assessed differences between **group** values of heart rate and heart rate variability. Considering the idiosyncratic nature of the E.C.G a comparison between groups of subjects using raw values was not considered meaningful. To overcome this problem the values of heart rate and heart rate variability, obtained for every 30 **second** period, were standardized for each subject using previously obtained basal values. This enabled the calculation of mean values of heart rate and heart rate variability for each group according to each 30 **minute** period.

FINDINGS

The statistical analyses of the above indices suggested the following:

(a) Considering the subjective measures

- (i) **The Bedford scale and the Alertness scale did not significantly distinguish between the two levels of task demand..**

(b) Considering the physiological measures

- (ii) **Both heart rate and heart rate variability did not significantly distinguish between the two levels of task demand.**

For the purposes of this report the results of the Subjective Adjective Scale will be considered in more detail in the following section.

SUBJECTIVE ADJECTIVE SCALE

Statistical analyses were performed to determine the extent to which the low demand and very low demand monitoring tasks could be separated on the basis of responses on this scale. Once again both 30 minute periods were considered separately. The results for each period will be discussed in the following sections.

A comparison of the number of subjects who responded 'YES' to each item for the first and second periods suggested an **increase** in the number of respondents who felt tired, annoyed, frustrated, easily disturbed and fatigued as the task went on. The results also suggested a **decrease** in the number of respondents who felt active, concentrating, pressured and alert.

A **PRINCIPAL COMPONENTS ANALYSIS (PCA)** was performed to obtain the factor weights for each variable and enable the calculation of metavariabls. The analysis was performed for both periods. The Factor loadings for each period are presented with a description of each factor in Appendix II.

A : For period 1

(i) **The analysis yielded 8 factors with eigenvalues greater than 1 which accounted for 88% of variance.**

B : For period 2

(ii) **By comparison 7 factors were generated which accounted for 84.6% variance.**

A **DISCRIMINANT FUNCTION ANALYSIS DFA** was performed to determine the extent to which the two administrations of the scale could discriminate between the two conditions. Metavariabls from the PCA were created for both administrations of the scale to increase the subject to variable ratio. The metavariabls were calculated by multiplying the standardized score for each subject on a variable in the factor by its factor weight. A total of 8 metavariabls were formed for the first administration and 7 metavariabls for the second administration of the scale.

The results of the DFA's were as follows:

A : For period 1

(i) The DFA classification matrix correctly classified all of the 16 cases into the workload 'groups' on the basis of the metavariabes.

(ii) The metavariabes contributing most to the discrimination between the two groups were 'general workload state; 'preparedness'; 'frustration' and 'daydreaming'.

(iii) As a result of the above finding a consideration of the group means for each metavariabes suggested subjects assigned to the very low demand were more likely to obtain a low score on the general underload variable and obtain a high score on the preparedness, frustration and daydreaming metavariabes.

B : For period 2

(i) The classification matrix correctly classified 13 of the 16 cases into the workload 'groups' on the basis of the metavariabes.

(ii) Metavariabes contributing most to this discrimination between the two groups were 'boredom', 'involvement' and 'drowsiness'.

(iii) This result when considered in conjunction with the group means for each metavariabes, suggested subjects in the very low demand condition were more likely to obtain a low score on the metavariabes 'boredom' and 'involvement' and a high score on the metavariabes 'drowsiness'.

DISCUSSION

When considering previous research eg. Opme and Krol (1973), the fact that heart rate and heart rate variability did not distinguish between the two conditions infers that no significant changes in levels of arousal and mental effort occurred between the two conditions. When taking into consideration the complexity of the relationship between task demand and workload as noted by Hart (1987), it is possible to suggest that the two levels of task demand resulted in very similar levels of workload.

The above argument however is not conclusive as these measures have been previously used to measure workload in the high task demand situation, where the pilot is more likely to experience wide variations in mental effort and arousal during the flight task. This suggests that heart rate and heart rate variability may not necessarily be sensitive to the different workload states experienced at low levels of task demand. Furthermore previous research has also provided conflicting results concerning the usefulness of both heart rate and heart rate variability in the assessment of workload Kalsbeek and Sherman (1973)

It may also be argued that the concept of mental effort which reflects the operators reaction to the input load (Jahn, 1973), is not a suitable concept upon which to distinguish the workload states induced by the low demand situation. This may partly explain the insensitivity of the Bedford scale at the lower end. This however does not suggest that a mental load is not apparent in the low demand tasks. For example, Sanders (1979) suggested that **emotions, tensions and frustrations** all contribute to mental load which may suggest a mental load in the absence of any task requirement. Thus although it is important to consider the demands imposed on the subject and the demands imposed as a result of the interaction of the subject with the task (Hart, 1987) it is becoming increasingly necessary to assess the subjects response to a lack of 'task demand.'

When considering the components of the Subjective Adjective Scale (SAS), eg. Frustration, Tiredness, Alertness and Irritation, the latter point may account for this scale being the only measure which was sensitive to the different states induced in the two levels of low task demand. The sensitivity of this scale over the other measures may also be attributed to its multidimensional nature. This supports the need to regard workload as a multidimensional concept.

When considering this scale in the context of previous multidimensional subjective scales it is interesting to note that the dimension 'frustration' which was also included in the NASA scale. Furthermore 'own performance' may be analogous to the dimension 'preparedness' on the SAS. When considering the Simpson-Sheridan scale the dimension 'fraction of time busy' may be considered similar to the dimension 'inactivity' generated on the SAS. This relationship is, however, very tentative and does not suggest any relationship between the dimensions other than in terms of the descriptions assigned.

CONCLUSIONS

The main findings of the study suggest the concept of workload should be expanded to include an assessment of the states which contribute to the mental load in the absence of high task demand. The usefulness of the multidimensional Subjective Adjective Scale reflects the type and complexity of the workload states which are induced in the low task demand situations. This in turn limits the use of unidimensional measures in the assessment of these workload states. The study also suggests the physiological measures of heart rate and heart rate variability are of limited usefulness in distinguishing between the two low demand monitoring tasks. It should however be noted that the usefulness of these measures may lie in an initial detection of low task demand.

These conclusions, however, have to be considered in the context of the experimental situation. Although the task was not intended to simulate the monitoring task inflight, and the fact that the study was performed in this situation using a sample of non-pilots, limits the generalizability of the results to the inflight situation. It must be emphasised that this study was exploratory due to the limited research and understanding of the states or combinations of subjective feelings which are experienced in low task demand situations. This in turn emphasises the need to perform further research.

FUTURE RESEARCH

Further research will be undertaken to increase the generalizability of this workload index to the in-flight environment. An outline of a proposed programme of research is provided in the following sections. This research will be performed over a period of two years.

For the purposes of this research workload will be initially considered as the **combination of subjective feelings which are experienced by the subject as a result of low levels of task demand**. This state may be composed of feelings of frustration, boredom, irritation, fatigue as defined by the Subjective Adjective Scale.

STAGE ONE

1. AN ASSESSMENT OF THE SUBJECTIVE FEELINGS OF THE PILOT DURING DIFFERENT LEVELS OF LOW TASK DEMAND

To determine those factors which influence low levels of task demand it is suggested that a questionnaire is administered to a **sample of airline pilots** to determine what they consider to be the factors which cause low levels of task demand. It is suggested that these factors may include the duration of the flight task and the extent to which the pilots task is automated.

To understand the subjective feelings which are experienced during flight it is suggested that:

A large sample of pilots will be asked to provide information concerning

- a) the type of aircraft and flight routes which they have recently flown
- b) the subjective feelings which are experienced during a typical flight

The Subjective Adjective scale will be modified to include these adjectives and phrases.

2. AN ASSESSMENT OF THE SENSITIVITY OF THE SUBJECTIVE SCALE

The sensitivity of the scale to varying levels of low task demand will be assessed using a flight simulator. This will enable a manipulation of those variables which are considered to influence the amount of demand experienced.

During the simulated flight the pilot will be required to complete the subjective scale at specified intervals. It is suggested that the scale is completed pre-flight, following take-off, during flight and post-flight. The usefulness of these particular intervals will be investigated.

Following this task the pilots will be asked to comment on the suitability of the items on the scale and furthermore whether they would be prepared to complete the scale in-flight.

3. RELIABILITY AND VALIDITY OF THE SUBJECTIVE SCALE

The reliability of the scale will be assessed using simulated flight tasks. During these tasks a further subjective measure of workload will be administered to assess the validity of the Subjective scale.

4. ADMINISTRATION OF THE SUBJECTIVE ADJECTIVE SCALE IN-FLIGHT

It is suggested that this will be undertaken in aircraft which show varying levels of flight-deck automation eg. a Boeing 727 compared to the new and comparatively highly automated 737-300/400.

STAGE TWO

The above description is very much an outline of the main areas which will be investigated. The second stage of the research will examine:

1. The influence of personality upon the subjective feelings which are experienced by the pilot.

It is suggested that an understanding of the particular personality profiles which are most suited to the automated environment will be usefull in the selection of future airline pilots.

2. The implementation of physiological measures to augment the subjective feelings of the pilot.

It is suggested that physiological measures may be implemented to assess levels of eg. fatigue and arousal.

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SUBJECTIVE CHECKLIST

PLEASE TICK EITHER YES OR NO TO EACH OF THE ADJECTIVES WHICH BEST DESCRIBES HOW YOU FELT DURING THE PREVIOUS SECTION OF THE EXPERIMENT.

PLEASE COMPLETE THIS SCALE WHEN THERE IS A PAUSE IN THE VIDEO.

	YES	NO
STRETCHED.....	☐	☐
TIRED.....	☐	☐
ANNOYED.....	☐	☐
ACTIVE.....	☐	☐
FRUSTRATED.....	☐	☐
SATISFIED.....	☐	☐
CONCENTRATING.....	☐	☐
INACTIVE.....	☐	☐
QUITE TIRED.....	☐	☐
EASILY DISTRACTED.....	☐	☐
VERY BORED.....	☐	☐

IRRITATED.....	☐	☐
IN CONTROL.....	☐	☐
PRESSURED.....	☐	☐
INTERESTED.....	☐	☐
UNCHALLENGED.....	☐	☐
ABSORBED.....	☐	☐
ALERT.....	☐	☐
BORED.....	☐	☐
UNSATISFIED.....	☐	☐
FREE FROM CONCENTRATION.....	☐	☐
BUSY.....	☐	☐
STIMULATED.....	☐	☐
DISINTERESTED.....	☐	☐

ANXIOUS.....	☐	☐
RELAXED.....	☐	☐
FREE TO THINK OF OTHER THINGS.....	☐	☐
SLEEPY.....	☐	☐
DAYDREAMING.....	☐	☐
FATIGUED.....	☐	☐

APPENDIX II

FACTOR LOADINGS FOR PERIOD ONE

FACTOR ONE		FACTOR TWO		FACTOR THREE	
QUESTION	LOADING	QUESTION	LOADING	QUESTION	LOADING
Very Bored	0.86	Pressured	0.89	Anxious	0.84
Sleepy	0.86	Fatigued	0.89	Stimulated	0.80
Unsatisfied	0.84	Relaxed	-0.85	Unchallenged	-0.60
Free from concentration	0.83	Free to think of other things	-0.68	Daydreaming	-0.53
Easily disturbed	0.73	Absorbed	0.62	Satisfied	0.52
Alert	-0.60			Absorbed	0.51
Tired	0.54				
Eigenvalue	8.07		5.90		2.69
% Variance	28.80		21.10		9.60

FACTOR FOUR		FACTOR FIVE		FACTOR SIX	
QUESTION	LOADING	QUESTION	LOADING	QUESTION	LOADING
Frustrated	0.84	Disinterested	0.81	Busy	-0.88
Concentrating	-0.77	Interested	-0.76	Inactive	0.88
In Control	-0.75	Bored	0.73		
Eigenvalue	2.19		1.95		1.48
% Variance	7.80		7.00		5.30

FACTOR SEVEN		FACTOR EIGHT	
QUESTION	LOADING	QUESTION	LOADING
Active	-0.84	Irritated	0.88
Free to think of other things	0.63	Tired	0.58
Daydreaming	0.54		
Eigenvalue	1.48		1.22
% Variance	4.30		4.10

FACTOR LOADINGS FOR PERIOD TWO

FACTOR ONE

QUESTION	LOADING
Annoyed	0.97
Irritated	0.97
Anxious	0.97
Relaxed	-0.97
Unchallenged	-0.78
In control	-0.69
Interested	0.61
Bored	-0.53

Eigenvalue 7.10

% Variance 27.3

FACTOR TWO

QUESTION	LOADING
Easily disturbed	0.79
Very bored	0.77
Satisfied	-0.75
Unsatisfied	0.66
Active	-0.60
Inactive	0.57
Frustrated	0.43

5.04

19.40

FACTOR THREE

QUESTION	LOADING
Quite tired	0.83
Disinterested	0.72
Interested	-0.51

2.68

10.30

FACTOR FOUR

QUESTION	LOADING
Absorbed	0.97
Busy	0.97

Eigenvalue 2.18

% Variance 8.40

FACTOR FIVE

QUESTION	LOADING
Free from concentration	0.88
Concentrating	-0.72
Sleepy	0.63

1.94

7.40

FACTOR SIX

QUESTION	LOADING
Alert	0.86

1.77

6.80

FACTOR SEVEN

QUESTION	LOADING
Daydreaming	0.89
Fatigued	-0.68

Eigenvalue 1.28

% Variance 4.90

A description of each factor for period One

FACTOR 1

Describes a 'General state of underload where the subject is very bored, sleepy, unsatisfied, is not concentrating on the task, is easily disturbed, tired and not alert.

FACTOR 2

Describes a state of 'Involvement' where the subject is pressured, fatigued and absorbed but not relaxed or free to think of other things.

FACTOR 3

This is a state of 'preparedness' where the subject is anxious, stimulated and satisfied but not daydreaming or unchallenged.

FACTOR 4

Describes a state of 'frustration' where the subject feels frustrated and not in control, concentrating or alert.

FACTOR 5

Describes a state of 'disinterest' in the task and boredom.

FACTOR 6

Describes a state of 'inactivity'.

FACTOR 7

This is a state where the subject is able to think of other things and daydream.

FACTOR 8

Describes a state where the subject is irritated and tired.

A description of each factor for period two

FACTOR 1

May be described again as a 'general state' resulting from the low task demand, where the subject feels annoyed, irritated, anxious and interested although not relaxed, unchallenged in control or bored.

FACTOR 2

The items which load on this factor describe a general state of boredom where the subject is easily disturbed, unsatisfied, inactive and frustrated.

FACTOR 3

Describes a state of tiredness and disinterest.

FACTOR 4

This factor may be described as a state of 'involvement' in the task, where the subject is busy and absorbed.

FACTOR 5

Describes a state of 'drowsiness' where the subject is free from concentration and sleepy.

FACTOR 6

This factor is uniquely described by the item 'alert'.

FACTOR 7

Describes a state where the subject is daydreaming but is not fatigued.