Boeing Commercial Airplane Group
P.O. Box 3707
Seattle, WA 98124-2207

February 15, 1995
B-U01B-15140-ASI

BY FACSIMILE: [redacted]

Mr. Thomas Haueter, AS-10
National Transportation Safety Board
490 L'Enfant Plaza East SW
Washington DC 20594-2000

BOEING

Subject: USAir 737-300 Accident, N513AU/PP033, near Pittsburgh, Pennsylvania, September 8, 1994 - Investigation Items

Reference: a) Pre-hearing conference, January 19, 1995
b) Public Hearing Action Item List, January 20-27, 1995

Dear Mr. Haueter:

During the reference (a) meeting you requested from all parties suggestions of additional items that the NTSB should consider for the subject investigation. It was understood that any areas of interests are in addition to the reference (b) items, and items that are currently under investigation in the NTSB Systems Group, Performance Group and the CVR/Spectrum Analysis Group. In response Boeing has assembled the following list of items that we believe warrant additional investigation:

1. Human Factor issues; Use of Rudder; Control Column issues; and Cockpit Resource Mangement issues (see enclosure).

2. Determine if unusual attitude training programs are useful for the industry.

3. Evaluate whether it would be useful to examine pilot response to rapid accelerations associated with this accident on a large excursion motion base simulator.

4. Rerun the CVR/FDR correlation with pilots, engineers and test engineers in an attempt to identify noises on the CVR tape.

5. Collect the database for CVR spectrum analysis and compare with noises on the CVR tape for this accident.

You also asked parties to submit their recommendations on how to preserve the wreckage. Recognizing that the ideal preservation of leaving the wreckage "as is" may not be a practical solution for all parties in the investigation, we would suggest that the reconstruction be carefully grid mapped and located in a secure area in accessible containers that are well labeled with the map location and 8x10 photos showing the container contents.

As always, Boeing remains willing to assist the NTSB in its investigation of these issues and any other topics that merit attention in the continuing investigation of this accident.

BOEING

If you have questions, please contact Rick Howes, [redacted] or me.

Very truly yours,

FLIGHT TEST

[redacted]

for

John W. Purvis
Director, Air Safety Investigation
Org. B-U01B, M/S 14-HM
Telex 32-9430, STA DIR PURVIS
[redacted]

Enclosure: Boeing Disscussions on Human Factor issues; Use of Rudder; Control Column issues; and Cockpit Resource Mangement issues

1. Human Factors Issues

Airplane N513UA was engaged in a two degree per second roll rate to the right at the moment immediately before its unexpected encounter with the wake turbulence from the Delta 727. Thereafter, during the first five seconds of the encounter with the wake turbulence, the peak roll rates experienced were: thirteen degrees per second to the left (to a twenty degree left wing down attitude); ten degrees per second to the right (to a fourteen degree left wing down attitude); and eighteen degrees per second to the left (to a thirty-eight degree left wing down attitude).

In his testimony at the Public Hearing, FAA Flight Test Pilot Les Berven described an unexpected encounter with wake turbulence as "nothing like you encounter in normal flight . . . It basically feels like some giant hand grabbed the airplane and just took it right away from you . . ." (Transcript of NTSB Public Hearing at 307-08.) The sounds experienced and the comments made by the flight crew during the first five seconds of the encounter with wake turbulence corroborate Bervyn's testimony:

Hot- 1: sheeez.

Hot- 2: zuh.

Cam: [sound of thump]

Cam: [sound of"clickety click"]

Hot - 1: [sound similar to person inhaling/exhaling quickly one time]

Cam: [sound of thump of less magnitude than the first thump]

Hot- 1: whoa.

Cam: [sound of "clickety click"]

Cam: [clicking sound similar to trim wheel turning at auto-pilot trim speed]

Hot - 1: *hang on.*

Cam: [sound similar to aircraft engines increasing in RPM]

Hot - 2: [sound similar to pilot grunting]

Hot - 1: hang on.

(NTSB Public Hearing Exhibit 12A, pages 28-30.)

There are studies that address a flight crew's ability to perform when confronted with an unexpected and alarming situation. In general, acute stress can have a negative effect on a crew's performance. In his article "Causes of Aircrew Error in the Royal Air Force" (attached), John Chappelow comments upon the causes of 149 military flying accidents. Chappelow attributes 26% of the accidents studied to "overarousal" and 17% of the accidents to "cognitive failure."

Overarousal is defined as a non-adaptive response to stressors of an exciting or alarming nature. Cognitive failure is a type of error in which actions fail to meet intentions, usually because an intended action is omitted or because an unintended action is committed. In five accidents that he studied, cognitive failure was an effect of overarousal. Chappelow states that a crewmember's personality is thought to be a contributory factor in numerous overarousal-related accidents. Chappelow finds that the origin of acute overarousal can be a perceived emergency or operating hazard.

In another study, "Performance Recovery Following Startle: A Laboratory Approach to the Study of Behavioral Response to Sudden Aircraft Emergencies" (attached), Dr. Richard Thackray of the FAA's Civil Aeromedical Institute summarized the information available on a person's response to an unexpected and startling event. Dr. Thackray's studies had been conducted, in part, "to estimate pilot response time to potentially critical situations, such as unexpected clear air turbulence . . ." (see page 2 of Dr. Thackray's article)

Dr. Thackray found that the arousal levels experienced in response to a startling event can disrupt perceptual and motor performance for up to ten seconds, and affect tasks involving decision making and information processing for a longer period of time. According to his analysis, "the frequency of incorrect responses (representing errors in information processing) was found to be significantly greater in the startled than unstartled group during the first minute following stimulation." (see page 5 of Dr. Thackray's article). Dr. Thackray has concluded from all of the research examined in this area, that "more complex perceptual-motor behavior, such as that requiring continuous psychomotor control, is likely to show maximum disruption during . . . [the] 1- to 3- second period [following stimulation] . . ., although significant, but lesser, disruption may still be present for 10 seconds following stimulation," and that "evidence from several studies suggests that the ability to process information may be impaired for 17 to 60 seconds following a startling event . . ." (see page 6 of Dr. Thackray's article).

The NTSB should explore, from a review of the literature and all available data bases and records, whether the Flight 427 flight crew could have responded to the unexpected and startling encounter with significant wake turbulence by (1) making an inadvertent application of left rudder, or (2) having an accidental or cognitive failure that led to an application of left rudder.

A related question is: "What do the captain's complete training and medical records at USAF, Pilgrim, Braniff and USAir, and first officer's complete training and medical records Piedmont and USAir show about their ability to correctly diagnose inflight upsets or emergencies, handle stress and correctly use the flight control systems?"

2. Use of Rudder

General Robert Oaks testified at the Public Hearing about the appropriate response to the encounter with wake turbulence:

> Now, when the wing drops, it drops five degrees and what do you do? You say what's that? And so you are immediate[ly] alerted. At the first degree you know something is different. And what is that? And so you are alerted and it goes five and it keeps going, your immediate reaction, as natural as breathing, or as natural as putting one foot before the other when you walk is you put . . . [in] aileron. You immediate[ly] spin that yoke to lift that left aileron [wing] up. And at the same time you kick that right rudder because you have got to bring that up. And those are the two controls that you are taught from the first day you . . . [get] in an airplane.

(Transcript of NTSB Public Hearing, pages 1307-08.)

The training material provided by United Airlines to the NTSB on unusual attitude recovery shows that crews are being taught to use both aileron and rudder to recover from high bank angles. (NTSB Public Hearing, Exhibit 2B, pages 4, 9, 16 and 18.) However, as stated in the material provided by United Airlines, a "problem" encountered in pilot responses to certain unusual attitude training exercises has been a "failure to ascertain and apply the correct rudder." (NTSB Public Hearing, Exhibit 2B, pages 6 and 20.)

Their are numerous examples of accidents, events and training mistakes in which a pilot applied the wrong rudder. These include:

- A September 6, 1985 crash of a Midwest Express DC-9 after takeoff at Milwaukee, in which 31 people died. The NTSB found that four to five seconds after the right engine malfunctioned, the crew mistakenly applied right rudder followed by aft control forces, causing the airplane to stall and eventually crash.

- A 1992 Air National Guard C-130 accident near Evansville, Indiana in which the flight crew was returning to its home base. The first officer applied the wrong rudder causing the aircraft to roll excessively and crash.

- An October 26, 1986 Trans Australia Airlines 737-300 event in which the crew encountered oscillations in roll and yaw on approach to landing at Canberra. The first officer was commanding the aircraft while using the autopilot system. The autopilot was disengaged when the aircraft entered its downwind leg for landing. The crew then encountered roll oscillations. The captain took over, performed a go-around, and no further problems were encountered. On the next pass, the first officer was again in command, and again encountered oscillations. The captain took over and landed the aircraft without difficulty. The first officer later commented that the wheel felt "heavy" during the segments in which the oscillations were encountered. It was determined from an examination of the FDR, however, that on both approaches when the first officer encountered the oscillations, he had cross-controlled the aileron and rudder, applying right rudder and left wheel. On both approaches, the rudder pedal input increased to near full right deflection.

- A January 1, 1979 Eastern Provincial Airways 737 event in which the crew encountered several sudden roll maneuvers during the final approach to Gander, Newfoundland. The pilot believed he had made left wheel and left rudder inputs during a 180-degree turn onto his final leg, but the aircraft did not respond as expected. The pilot then put in additional left wheel and used full power to execute his turn and maintain height. The aircraft lost considerable height and it was later determined from the FDR readout that the aircraft was close to the trees before the aircraft straightened out to land. While Eastern Provincial initially suspected that the maneuvers were caused by an apparent lateral control malfunction, the FDR showed that when the pilot applied 40 to 50 degrees of left wheel he had also applied 15 degrees of right rudder. Less extreme cross-control inputs continued until the airplane landed.

- On March 8, 1994 Sahara India Airlines conducted a 737-200 training flight in New Delhi. On this occasion, Sahara was training its first officers. As the aircraft was completing a touch and go, the Instructor Pilot initiated an unannounced and unbriefed engine inoperative training experiment, in which he slowly retarded the left engine thrust lever at takeoff. The FDR and CVR indicate to Boeing that the trainee first officer responded to the asymmetric thrust by applying right wheel followed by left rudder. The Instructor Pilot apparently took over the controls and applied right rudder before the airplane crashed.

- Most flight crew training programs call for the Instructor Pilot to block or guard the rudder pedals during certain training exercises (e.g., engine inoperative training) that call for rudder input. This precaution prevents a pilot, who may rarely use rudder, from making an incorrect rudder input.

The NTSB should address the following questions:

(a) Did the Flight 427 flight crew respond to the rolling moments experienced in the wake turbulence upset by applying and maintaining left rudder?

(b) Did the captain and first officer receive training and accumulate flight hours in other aircraft in which they would have used rudder to offset roll?

(c) Are there any training records of the captain or first officer misapplying the flight controls?

3. <u>Control Column Issues</u>

The crew responded after autopilot disconnect at FDR Time 139.4 by pulling the control column as far back as possible.

(a) Was this appropriate?

(b) What role did the control column inputs have in the crew's ability to control and recover the aircraft?

(c) If the crew made inappropriate control column inputs, is it also likely that the crew responded with inappropriate usage of rudder?

4. <u>Cockpit Resource Management Issues</u>

A thorough analysis should be made of the manner in which the captain and first officer performed and communicated with each other during the upset.

Specific questions that need to be addressed are:

(a) What cockpit resource management training had the crew received in terms of responding to sudden and unexpected events and emergencies; interacting during an upset; diagnosing problems; and transferring command?

(b) Were there incidents or experiences that contributed to the decision by USAir to add written guidance about "transfer of control" to the forthcoming revision of the Flight Operations Manual (NTSB Public Hearing, Exhibit 2A, page 19)?

(c) Are there other accidents in which it has been found that both pilots were attempting to fly the airplane? Is there evidence in this accident that both pilots had their hands on the wheel?

CAUSES OF AIRCREW ERROR IN THE ROYAL AIR FORCE

J. W. Chappelow

R.A.F. Institute of Aviation Medicine
Farnborough
Hants. GU14 6SZ
U.K.

SUMMARY

One hundred and forty nine military flying accidents were investigated by psychologists. Inspection of the data collected revealed that nearly half of the accidents involved inadequacies in equipment design, training or administration. Cognitive failure was a major cause of aircrew error and was more often associated with underarousal than with overarousal. Overarousal made a significant contribution to aircrew error, but largely as a secondary factor, i.e. it was generally a consequence of mechanical problems, disorientation, or prior mishandling of the aircraft. Personality factors also made a significant contribution, and the data suggest two distinct types of problem. Life stress and high workload appeared not to play a major part in stress-related accidents. Fatigue was not a major factor, but was closely associated with cognitive failure.

INTRODUCTION

It is widely accepted that flying, particularly military flying, is a stressful occupation. The real significance of the stresses involved in flying is, however, not easily explicated. There are several reasons for this. First, the role of stress is equivocal. Some aviators at least are attracted by the challenge of operating under pressure of whatever kind. And the effects of stress may, under the right conditions, be beneficial. Although the inverted 'U' relationship between arousal and performance, first proposed by Yerkes and Dodson (1) eighty years ago, is by no means a full description of the complexities of stress, it is, nevertheless, a useful reminder of some salient facts: Some stressors raise arousal level, and some depress it, and either action can, at times, improve performance. In addition the experimental investigation of the effects of stress is restricted by obvious ethical and practical difficulties. As a result, the effects of relatively benign stressors in mild doses (eg fatigue, noise, hypoxia) have received attention in the laboratory and, to a lesser extent in simulations and flight tests, but one is left with the suspicion that stressors of great operational significance (particularly varieties of threat) have not yet been adequately investigated in a realistic context, despite some remarkable efforts (2).

The study of aircraft accidents offers the prospect of obtaining some clues to the operational impact of stressors and their relative importance. One may assume, perhaps with little justification but as a useful starting point, that whatever factors are found to be major causes of accidents are also likely to have a deleterious effect on operational effectiveness - perhaps in proportion to their significance in the aetiology of accidents. This gives the investigation of accidents a significance in addition to that derived from the enormous cost of individual accidents. Clues may be sought as to the origins of stress in flying, the nature of the effects of stress, and the relative importance of stress in comparison with other human factors problems.

In 1972 the Royal Air Force started a scheme allowing psychologists to conduct independent investigations of aircraft accidents in conjunction with the established Boards of Inquiry. The data discussed here were collected in the course of these investigations.

METHODS

By the summer of 1988, 149 military flying accidents had been investigated. A few involved Royal Navy or Army aircraft; the majority were RAF accidents. The investigations drew on several sources of information:

- Confidential interviews with survivors and others.
- The personal records of those involved in the accidents.
- Eyewitness reports.
- Analysis of flight data recorder tapes, recordings of radar traces, radio transmissions etc..
- Examination of cockpit equipment, regulations, manuals and other documents.

Data on each accident were recorded in a simple computer data base. In addition to information on aircraft type, phase of flight in which the accident happened, etc., the human factors which contributed to the accident are recorded as 'possible', 'minor' or 'major' influences.

RESULTS

More than thirty human factors categories have been used in coding the accidents. Some form natural subgroups and have been combined into generic terms in the list in Table 1. The full list is in Appendix A. It is intuitively obvious that the factors do not all have the same logical status: Some are enabling conditions or predispositions, rather than direct causes; others describe the way in which an error occurs. An arbitrary division of the factors has been imposed on Table 1 reflecting this consideration. The three groups are: Aircrew Factors - predisposing conditions some of which are under the control of the aircrew, others being more or less natural or innate; System Factors - enabling conditions engendered by high workload, inadequacies of equipment design or training, etc.; and Modes of Failure - essentially descriptions of types of error. Table 1 shows those factors cited as at least possible contributory causes in more than 10% of the accidents. Most accident investigations revealed three or four human factors problems; some revealed ten or more.

Table 1: The major human factors

AIRCREW FACTORS	
personality	23%
inexperience	20%
life stress	11%
SYSTEM FACTORS	
ergonomics	23%
training and briefing	19%
administration	17%
high workload	14%
MODES OF FAILURE	
overarousal	26%
cognitive failure	17%
distraction	16%
inappropriate model	13%
disorientation	13%
visual illusion	12%

A few of the terms in Table 1 require some explanation:

- Overarousal: The term 'stress' is commonly used in a variety of ways to describe both stressors and the response to them. For convenience 'overarousal' is used here to describe a non-adaptive response to stressors of an exciting or alarming nature. Similarly, 'underarousal' denotes performance degradation due to depression of arousal level.

- Life stress: Any personal or domestic events believed to have a worrying, anxiety provoking or exciting effect on an individual. The personal events may include some arising in the course of professional duties, but not, usually, short term episodes directly connected with flying.

- Administration: This term covers the content of manuals, pilot's guides, instructions and orders, and also features of chains of communication.

- Cognitive failure: A type of error in which actions fail to match intentions, usually because an intended action is omitted or because an unintended action is committed. Such failures are commonly attributed, in lay-man's terms, to 'absent-mindedness'.

- Inappropriate model: This term covers errors due to the formulation of intentions on the basis of incorrect information or assumptions.

The early accidents in the database were selected for their obvious human factors interest. The terms of reference of the scheme have changed, and now an attempt is made to investigate any accident in which aircrew error is considered to be a possible contributory cause. There are grounds, therefore, for expecting a change in the pattern of results obtained over the years. The data do not, however, fulfill this expectation. A comparison of early and late investigations reveals no significant trends.

Origins and effects of overarousal

Table 2 summarizes a classification of the factors chiefly responsible for a state of overarousal in the aircrew involved in the accidents, and of the effects of that overarousal on their performance. The classification was by no means easy to impose on essentially narrative data describing accidents with complex causes. It is entirely possible that some categories, such as 'disorganised response', are inflated as a result of this difficulty and that of the original investigators, who had to deal with the survivors' understandably confused recollections of alarming events. Nevertheless, the classification allows some broad distinctions to be made.

Of the 39 accidents for which overarousal was cited as a contributory factor, 19 involved a mechanical problem (such as engine failure, hydraulic or electrical failure, bird strike, lightning strike, fire or low fuel state) which was regarded as the stimulus for overarousal. In fourteen of these cases, the emergency was considered to have been in some degree mishandled, thereby increasing the danger. Precipitate and inappropriate action accounted for four cases and disorganised or slow responses for seven. Overarousal was not the only cause of mishandling of emergencies; five other cases were due to a variety of factors other than overarousal.

Table 2: Origin and effects of acute overarousal

Origins of overarousal:	
Mechanical problems	19[1]
Mishandling	6
Disorientation	5[1]
Anxiety or other personality factor	4
Supervisory defects	3
Cognitive failure	2
High workload	1
Effects of overarousal:	
Disorganised response	12
Narrowing of attention	7[2]
Cognitive failure	5[2]
Slow response or inactivity	4
Precipitate action	4
Minor or undetermined effects	9

[1] One accident included in both these categories
[2] Two accidents included in both these categories

In six accidents, overarousal followed mishandling of the aircraft. Limited talent was a predisposing factor in at least half of these.

Five accidents involved overarousal arising from disorientation. All five resulted in the loss of the aircraft. In three instances in which the pilot was killed, it is fair to say that overarousal was assumed to have been a likely concomitant of the disorientation that was believed to be the cause of the accident.

In twelve overarousal-related accidents, a crewmember's personality was thought to have been a contributory factor. Usually, (eight of the twelve) this was due to a lower than average tolerance for stress (see the section on Personality). In four accidents a predisposing personality factor was the cause of overarousal. In three of these, the origins of the overarousal lay in a crewmember's predisposition to anxiety - in one case about test sorties; in another about the possible effects of high intensity radio sources; and in a third, a general unease about fast jet flying may have been heightened and focussed on the possibility of control restrictions. The effects of overarousal in these cases were: a focussing of attention which resulted in the omission of an important action; and, in two cases, precipitate and probably unnecessary ejections.

In two accidents supervisory failings resulted directly in pilots facing novel situations with which they were ill-equipped to deal. In both cases the pilots made errors leading to their losing control of the aircraft. A third accident was similar, except that the overarousal followed the loss of control and hindered recovery; again the necessary enabling conditions included a supervisory factor.

In two accidents, problems arising from a cognitive failure caused overarousal which impeded resolution of the problems. In a further five accidents, cognitive failure appears to have been a result rather than a cause of overarousal.

Other sources of stress

Life stress:

In seventeen investigations it was thought relevant to record details of personal and domestic events that might have been a source stress for the aircrew involved. In eight cases overarousal was also considered to be a factor contributing to the accident. In general, however, it was not possible to make any direct link between the life stress recorded and the causes of the accident. In only two cases could personal events be viewed as having a direct causal bearing on the accident: One involved recent experience under fire, which may have caused the pilot to emphasise tactical considerations at the expense of safety; the other involved a terminated engagement to marry and subsequent rather cavalier use of an aircraft. Most of the remaining instances fall into the following groups:

- Domestic problems - five cases: deaths, illness or health problems in the family; intensive and tiring domestic activity immediately preceding the accident (two cases, also listed under fatigue).

- Marital problems - two cases: specifically worries about infidelity or incompatibility.

- Work problems - five cases (two also involve domestic stress): excessive executive responsibilities or secondary duties; conflict between domestic and professional demands.

The mode of failure for five accidents in which life stress was cited as a possible contributory factor was cognitive failure; in three cases a deliberate disregard for rules was a major factor in the accident.

Fatigue:

Although fatigue does not appear in Table 1 as a major cause of accidents, thirteen investigations (9%) did reveal fatigue as a possible contributory factor. Four accidents occurred during night flying, three of them after relatively long periods on duty. In one case night flying over the previous three nights was thought possibly to have caused fatigue on the day of the accident. In five case the fatigue originated at least partly in social or domestic activities. Cognitive failure was the main associated mode of failure (six cases); there were also two cases of apparently controlled flight into the sea, two of failure to avoid rising ground and one mid-air collision.

High workload:

Although 21 accidents implicated high workload as a contributory factor, only seven of these were associated with evidence of overarousal. Four of the seven involved mishandled emergencies, the excess workload arising from mechanical problems. Two of the remainder involved training in demanding operational conditions, which may, of themselves, have generated a degree of excitement. It is not possible to determine whether the high workload or the overarousal made the greater contribution to any of these accidents, but it may be reasonable to assume, in the four cases involving mechanical problems, that the high workload was not itself the primary cause of the overarousal.

Other causes of accidents

Personality:

In 34 investigations the personality of a crewmember or other relevant person was considered a possible contributory factor. Twenty cases fall into one or other of two definable sub-groups, nine in one, eleven in the other. The smaller group is characterised by comments in the subject's personal records such as: "underconfident", "nervous", "prone to over-react". Six of the nine cases involved mishandling of an emergency; one probably involved over-reaction to a mis-identified emergency. The larger group is identified by the following descriptors: "over-confident", "reckless", "disregards rules". The results of this attitude included deliberate excitement seeking (eg illegal low flying) and exhibitionism, as well as pressing on into difficulties without much thought. Two mid-air collisions and four collisions with obstructions, the ground or the sea resulted.

Supervision and ergonomics:

Poor display design accounted for 14 of the 34 accidents in which ergonomic deficiencies played a part. Nine were ascribed to poor cockpit layout and eleven to poor control design. Combining the two supervisory categories (training and briefing and administration) with the ergonomic category reveals that 65 accidents (44%) involved enabling factors generated by the system rather than by the aircrew themselves.

Cognitive failure:

Cognitive failure was a primary or contributory cause of 26 accidents. Nine of these involved actions omitted by the crew, usually from a very familiar drill; 19 involved substitution of inappropriate actions for those intended. In seven cases, distraction provoked or enabled the cognitive failure to happen. In ten cases fatigue or underarousal was considered a predisposing condition. Eight cases of cognitive failure were also associated with life stress. The most common result of cognitive failure was a wheels-up landing - ten cases in all.

DISCUSSION

Overarousal:

The origins of acute overarousal appear to fall into several subgroups. About half of the overarousal related accidents (13% of the total sample) involved mechanical failure, sometimes as a result of operating hazards such as birdstrikes or lightning strikes. Another important subgroup is overarousal due to disorientation. Other specific causes were problems arising from mishandling, cognitive failure or supervisory failings. Overall the first impression is of specific, single causes of overarousal, usually with a sudden onset, rather than a gradual accumulation of several minor stresses. Specific remedies might, therefore, be found in improvements in simulator training - to improve responses to emergencies - and in better presentation of attitude information. Attitude displays that address the ambient visual system rather than central vision could be of real benefit in reducing the probability of disorientation (3).

Life stress and personality:

Indications that specific, single causes of stress do not constitute the whole picture come from the data associating personality characteristics and life stress with aircrew error. Life stress has commonly been assumed to contribute to stress-related errors and has been the subject of some attention in recent years. Alkov and Borowsky (4) and Alkov et al (5) found a number of life events to be associated with involvement in aircrew error accidents. These included:

- Recent engagement to be married.
- Recent loss of a friend or relation through death.
- Marital problems.
- Recent major career decision.
- Recent trouble with peers, subordinates or senior officers.

Some additional factors seemed to be more descriptive of personality characteristics than life events:

- Lacking in maturity or stability.
- Lacking in a sense of humour concerning self.
- Experiencing difficulty with interpersonal relationships.
- Slow to assess potentially troublesome situations.
- Lacking professionalism in flying.

It is possible to interpret two of the five life events listed above (marital problems, trouble with other officers) as also reflecting immaturity or inadequacy in coping with interpersonal relations. In fact, Alkov et al interpret the findings of the two studies as indicating that social maladjustment may be a good predictor of aircrew error and they place little weight on the remaining life events. What, then, is the role of life stress? As indicated above, in only two of the 17 cases where life stress was recorded as a possibly relevant background variable was it possible to see a direct relationship between the life events and the behaviour that caused the accidents. These may be regarded as rather special cases. It is, of course, inevitable that any sizeable sample of aircrew should carry a burden of some marital disharmony, some illness, domestic upheavals and problems at work. Without a control group, it is impossible to know whether these problems are over-represented in our sample of accident victims. For the moment, the case for life stress as a direct contributor to aircrew error is, at best, not proven, and must be regarded with some suspicion until more substantial evidence becomes available. McCarron and Haakonson (6) came to a similar conclusion after surveying life events among Canadian pilots. This would probably represent the attitude of many aircrew themselves. For many the cockpit of a high performance aircraft provides a welcome refuge from down-to-earth pressures and annoyances.

The role of personality in aircrew error accidents appears to have at least two discernible aspects which account for 20 out of the 34 personality-related accidents. One aspect has a bearing on stress. Some individuals previously described by their supervisors as underconfident or nervous failed to cope when presented with emergencies or unusually demanding conditions. Precipitate, inappropriate action was a common style of error. The second group, described as overconfident or reckless, either sought excitement in unauthorised ways, or was oblivious of or slow to recognise risks. Levine et al (7) found that questionnaire items concerned with adventurousness or risk taking were associated with accident occurrences among U.S. Navy aviators. However, in a review of personality studies, Farmer (8) found that despite the existence of some evidence implicating extraversion and neuroticism, overall the evidence was inconclusive and contradictory. The two studies by Sanders and Hoffman (9) and Sanders et al (10) provide an instructive example of the difficulty of obtaining stable correlations between personality data and accident statistics. If the data presented here are any guide, it seems likely that both unstable introverts and unstable extraverts have their own idiosyncratic risks. This would certainly make it harder to demonstrate a simple correlation between extraversion/introversion, as measured by personality tests, and accident-proneness. There seems little prospect of identifying the high risk personalities with a useful degree of validity at the selection stage. However, given that supervisors are already demonstrating some awareness of relevant personality characteristics, it may be worthwhile attempting to supplement their observations with formal personality tests. These could provide the basis both of guidance for supervisors and of counselling for individuals.

Fatigue and workload:

Fatigue and high workload were both associated with relatively few stress-related accidents. It is no surprise that nearly 40% of the fatigue-related accidents involved night flying. Perhaps more interesting is the fact that domestic activities contributed to fatigue in a similar number of accidents. Both sources of fatigue should be controllable by suitable supervisory action.

Cognitive failure:

The largest homogeneous class of immediate causes of accidents appears to be cognitive failure (17%). This represents a peculiarly difficult problem to tackle, because, to a large extent, being well trained and experienced is a requirement for this type of error. Reason and Mycielska (11) found that people reporting cognitive failures were more often preoccupied (at the time of the mistake) than not, and also tended to be tired or sleepy rather than emotional or excited. There are parallels in the present data. Ten out of 26 cognitive failures were associated with fatigue or underarousal (five resulted from overarousal); eight were associated with life stress - a possible source of preoccupation. There is a more complicated link between cognitive failure and life stress, however, and one that takes account of the intuitively obvious fact that individuals differ in their response to life stress.

Broadbent et al (12) showed that proneness to cognitive failure is a relatively stable trait and that those who are prone to cognitive failure are more likely to develop minor symptoms in response to stress than those who are not. Broadbent later argued (Broadbent et al (13)) that the basis of the trait lay in differences in cognitive style, those with a more obsessional style being both less vulnerable to chronic stress and less subject to cognitive failure. He also suggested that cognitive styles become more extreme under stress. Thus, although the evidence for life stress as a direct cause of accidents is doubtful, it may have a relevance in identifying those who are most liable to cognitive failure, and, possibly, their times of highest risk. Some piecemeal remedies for cognitive failure, involving redesign of equipment, are possible. There is also a clear need for a valid, objective test of liability to cognitive failure, and for techniques of remedial training in cognitive style.

System factors:

It is a truism that complex systems, like aviation, can never be free of human error. The present data indicate that, in a substantial proportion of accidents (44%). significant errors were made by people remote from the critical events. These errors included design of equipment, inadequacies in training and briefing and administrative failures. Often the errors were not obscure or complex. Many of them were surely identifiable as potential hazards before they caused an accident. The only practical remedy for system errors of this type requires aviators to take a closer interest in the way their system operates and, perhaps more important, the relevant authorities should encourage a questioning attitude and be prepared to support changes to the system in the interests of flight safety.

CONCLUSIONS

Although overarousal makes a significant contribution to aircrew error accidents, it appears, in general, to result less from generally high levels of stress or the cumulative effects of small stressors than from specific, provocative events. Mechanical failure and disorientation are two significant classes of provocation. Specific remedies in the form of improved simulator training and enhanced presentation of attitude information are at least conceptually feasible.

The role of life stress in accidents appears ill-defined. It seems unlikely to be a direct causal agent, and whatever significance it has may be related to some aspects of personality (social maladjustment) or cognitive style. Fatigue made a small contribution to the accidents investigated, largely in connection with night flying and, interestingly, tiring domestic activities. Nearly half the accidents involving fatigue were due to cognitive failure.

Two distinct classes of personality problem are discernible in the data. One involves overarousal in response to emergencies or other demanding circumstances, and appears to be the province of unstable introverts. The other involves excitement seeking and disregard of risks by unstable extraverts. The use of personality tests to provide guidance for supervisors and counselling for aircrew is a possible remedy.

A major cause of aircrew error was cognitive failure. Although some cognitive failures occurred in stressful conditions, they were more likely to happen in normal, undemanding circumstances, or when the aircrew were fatigued or underaroused. General remedies for this type of failure are not available and should be a priority for future research.

Nearly half of all the aircrew error accidents involved some contribution from design deficiencies, inadequacies in training or briefing, or administrative failures. Such errors represent a significant challenge for both designers of equipment and those authorities responsible for the training of aircrew and the control of flying activities.

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Appendix A: Human factors classification

AIRCREW FACTORS

alcohol
disregard for rules
excess of zeal
fatigue
hypoglycaemia
inexperience
joie de vol (unnecessarily spirited or adventurous manoeuvring)
lack of airmanship
lack of talent
life stress (exciting or worrying personal or domestic events)
low morale
personality
QFI checking another QFI; reluctance to take control
sensory limitations - visual
social factors/crew co-ordination
underarousal

SYSTEM FACTORS

aircraft handling characteristics
ergonomics - displays
ergonomics - cockpit layout
ergonomics - controls
logic errors in automatic systems
noise/communication
operational pressures
time pressure
training/briefing
administration
physiological stress (usually heat)
high workload
under fire

MODES OF FAILURE

cognitive failure - inappropriate action
cognitive failure - omission
disorientation
distraction
'giant hand' experience
inappropriate decision
inappropriate model
inappropriate spatial model
overarousal
slow response
stress
unawareness episode
visual illusion

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Human Behaviour in High Stress Situations in Aerospace Operations

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PERFORMANCE RECOVERY FOLLOWING STARTLE: A LABORATORY APPROACH TO THE STUDY OF BEHAVIORAL RESPONSE TO SUDDEN AIRCRAFT EMERGENCIES

Richard I. Thackray, Ph.D.
Civil Aeromedical Institute
Federal Aviation Administration
P.O. Box 25082
Oklahoma City, Oklahoma, 73125
USA

SUMMARY

This paper deals with the use of response/recovery to auditory startle as a laboratory technique for simulating some of the principal aspects of the initial shock phase of sudden emergency situations. It is submitted that auditory startle, with its unexpectedness, pronounced autonomic reaction, fear-like subjective experience, and frequent behavioral disruption, approximates the response pattern to be expected in the initial shock phase of sudden traumatic emergencies, and that by studying the time course of performance recovery following startle, as well as individual differences in response/recovery, we may gain a better understanding of some of the variables related to extreme reactions displayed by individuals in real-life emergency situations. Research studies conducted in our laboratory and in others on performance impairment/recovery following startle are reviewed. These studies include those dealing with initial reaction time to the startle stimulus itself, disruption and recovery rate of perceptual-motor (tracking) performance following startle, and the time-course of performance recovery in information processing tasks after exposure to startle. Data are also presented showing a relationship of several individual difference variables to performance response/recovery following startle. These variables include autonomic response to the startle stimulus and level of task proficiency prior to startle.

INTRODUCTION

Aircraft emergencies often occur without prior warning and require rapid response. Although it is commonly accepted that response times to unexpected events generally exceed those to comparable events that are anticipated, actual data on response times to unexpected stimuli or events occurring infrequently in real-life settings are surprisingly sparse. In one of the few studies in which such data were obtained, Warrick, Kibler, and Topmiller (1965) examined the time that it took secretaries to press a button located 9.5 in from their typewriters when the stimulus (buzzer) was sounded without warning once or twice a week over a 6-month period. Relative to alerted conditions, the increase in response times when the buzzer was unannounced was surprisingly small. During the first month, unalerted response times (Mdn=.8 sec) were about 33 percent longer than response times under alerted conditions. By the end of the 6-month period, the median unalerted time was .6 sec, representing only a 22-percent increase over alerted times.

Other studies of response times to unexpected events have been conducted by investigators concerned with driver reactions to simulated emergencies. Muto and Wierwille (1982), for example, found that braking time to an unexpected event, presented after prolonged driving, averaged about 1.64 sec when the event first occurred. By the time the fourth "emergency" occurred, response times were about equal to baseline response times (approximately 1.40 sec). Thus, unexpectedness resulted in braking times that were 23 percent longer, at most, than braking times when the events were anticipated. In a somewhat similar study, Johansson and Rumar (1971) also compared braking response times to expected and unexpected situations. On the average, braking time to unexpected situations averaged .73 sec; this decreased to .54 sec when the events were anticipated. Unexpectedness, thus, resulted in response times that were approximately 35% longer than response times for anticipated events.

A few reported studies have dealt with simulated nuclear power plant emergencies. In these studies, process operators in nuclear control rooms were instructed to respond as rapidly as possible to simulated emergencies signaled by audible alarms and visual indicators. With signal rates of 1.35 to .35 per hour, response times (estimated from the data given) ranged from less than 1 sec to approximately 2.5 sec (Lees and Sayers, 1976).

Of the studies just discussed, those that have compared response times to both expected and unexpected stimuli are relatively consistent in their findings. Maximum percent increase in response time due to the factor of unexpectedness has been found to range from 22 to 35 percent. When the influence of repetition has been examined, reduction in uncertainty caused response times to approximate baseline (alerted) conditions. Such findings lend support to the conclusion reached by Warrick, Kibler, and Topmiller that one may be able to extrapolate to unalerted conditions from data collected under comparable alerted conditions.

In many types of emergency situations, however, one has not only the factor of unexpectedness to contend with, but also the additional and potentially disruptive factor of intense emotional arousal. Actual data with regard to response time to traumatic emergency events, to say nothing of the time-course of behavioral recovery following such experiences, are virtually nonexistent. Part of this is clearly due to the extreme difficulty of creating under controlled, experimental conditions the particular perceptual/cognitive events that, because of their meaning or significance to the individual, are the usual triggers for the emotional reactions associated with real-life emergencies.

RATIONALE FOR THE USE OF STARTLE

A possible technique for circumventing this dilemma involves the use of startle. Before considering this approach, however, a brief review of the startle response is warranted. In essence, the startle reflex is primarily a muscular response where the complete reaction consists of a series of involuntary contractions beginning at the head with the eyeblink and rapidly progressing to the legs. It is typically evoked by impulsive auditory stimuli (e.g., a pistol shot), although other, and generally less effective stimuli, such as a jet of ice water, photoflash, and electric shock have also been found to elicit it (Landis and Hunt, 1939). It always begins within 100 msec of the eliciting stimulus, and may have a duration of .3 sec for a mild but complete response to approximately 1 to 1.5 sec for an intense reaction (Ekman, Friesen, and Simons, 1985; Landis and Hunt, 1939). Although the muscle reflex, described in detail by Landis and Hunt (1939), is often considered to define the startle pattern in its entirety, the total pattern includes physiological as well as subjective components. The physiological response consists of a pronounced, generalized increase in autonomic and central nervous system activity and has been described in detail by Sternbach (1960a). This pattern of physiological response, when compared with autonomic response patterns produced by exercise, the cold pressor test, and injections of epinephrine and norepinephrine, has been found to closely resemble the pattern produced by epinephrine injection (Sternbach, 1960b).

The feeling state evoked by startle is more difficult to classify. While often considered to be related to the emotion of surprise (Ekman, Friesen, and Simons, 1985), others have identified it not only with surprise, but with fear and anger as well (Blatz, 1925; Landis and Hunt, 1939; Skaggs, 1926). Interestingly enough, the epinephrine-like physiological pattern to startle that was noted above is also the characteristic pattern found to be produced by fear-inducing situations (Ax, 1953; Schachter, 1957). Although agreeing that the feeling state associated with startle appears closest to fear and anger, Landis and Hunt (1939) consider that it may be best to define startle as preemotional. They note that "It does not stand in the same group of phenomena as the major emotions, yet it seems to be closely related to them and to belong generically in the same field. It is an immediate reflex response to sudden, intense stimulation which demands some out-of-the-ordinary treatment by the organism. As such it partakes of the nature of an emergency reaction, but it is a rapid, transitory response much more simple in its organization and expression than the so-called 'emotions'" (Landis and Hunt, 1939, p. 153).

In a study concerned with the question of why some individuals seem to "freeze," while others appear to react almost instantaneously in emergency situations, Sternbach (1960a) reasoned that startle resulting from a loud auditory stimulus might be used to approximate the principal components (surprise, fear, intense physiological arousal, and temporary behavioral disruption) that are common to many types of sudden emergencies and hence provide a technique for studying behavioral recovery following traumatic events under laboratory conditions. It is generally accepted that sudden emergencies frequently, if not typically, elicit feelings of fear or anxiety, and, as we have just noted, a number of studies have demonstrated that startle does evoke an experience, albeit rather transitory, that has been identified not only with surprise, but with fear as well. Further, the physiological response to startle, when compared with the autonomic response patterns produced by a number of other stressors, has been found to closely resemble the epinephrine pattern associated with fear-inducing situations. Taken in conjunction with the Landis and Hunt (1939) belief that the total startle pattern resembles that of an emergency reaction, it would not seem unreasonable to believe that studies of response to startle might provide a useful laboratory approach to the study of human behavior in sudden stress situations. The present paper adopts this position and reviews research findings relevant to performance recovery from startle. No attempt is made here to document the methodological considerations (e.g., stimulus parameters, modifying variables, differentiation of startle from orienting and defensive reflexes, measurement requirements) that must be recognized in carrying out research in this area. Relevant methodological considerations are reviewed or described by Graham, 1979; Landis and Hunt, 1939; Ekman, Friesen, and Simons, 1985; Raskin, Kotses, and Bever, 1969, and Thackray, 1972.

RESPONSE TIME TO STARTLE

Using a pistol shot as the stimulus for a required button press response, Sternbach (1965a) found that voluntary response times to startle stimulation ranged from 128 to 3,262 msec with a mean (estimated from the data) of 950 msec. Sternbach's primary concern, however, was not with establishing the actual range or limits of response time to startling events, but rather with investigating psychophysiological correlates of individual differences in time to respond. In this regard, he examined physiological resting and response levels of the 10 fastest and slowest reactors to startle. While there was no meaningful relationship of resting physiological levels to reaction time, fast and slow reactors differed significantly in their physiological response to startle on a number of variables; slow reactors showed a significantly greater increase in systolic blood pressure, pulse pressure, palmar skin conductance, and heart rate than did fast reactors. In addition to greater autonomic response, informal statements made by slow reactors (e.g., "I knew I was supposed to do something, but I couldn't think of it at first." "I thought I pressed it at first, then I realized I hadn't." "It took me a moment to realize what I had to do.") suggested greater cognitive disruption as well; no such statements were made by the group of fast reactors.

A subsequent study by Thackray (1965) extended the Sternbach study by including a comparison of response times to high-intensity, startling stimuli with reaction times to nonstartling auditory stimuli. The principal intent of this investigation was to provide baseline data that might be used to estimate pilot response times to potentially critical situations, such as unexpected clear air turbulence or a sudden failure in an automatic control system. Subjects were instructed to respond to any auditory stimulus by moving a control stick as rapidly as possible to the left and simultaneously flipping back a response button located on top of the stick. The first stimulus consisted of an unexpectedly loud burst of 120-db noise; this was followed by a series of 50 low-intensity auditory stimuli at constant 15 sec intervals and a final 120-db stimulus. The mean (893 msec) and range (356 to 1800 msec) of response times to the initial high-intensity stimulus were similar to those obtained by Sternbach. Like Sternbach, autonomic reactivity to startle was found to be positively correlated with response time to startle. The second high-intensity stimulus presented 15 sec after the series of low-intensity stimuli, and with no indication that anything other than another low-intensity stimulus would occur, yielded a mean (416 msec) and range (167 to 1550 msec) of response times that were considerably lower than that obtained to the first high-intensity stimulus. Interestingly enough, autonomic response to the second loud stimulus was found to be inversely related to response time. Thus, while magnitude of autonomic response to the initial high-intensity sound was directly related to performance disruption, autonomic response to the second, and subjectively less startling sound, was associated with performance facilitation. One might hypothesize that, in accordance with the predictions of activation theory (Malmo, 1959), arousal level to the initial startle was sufficiently high to disrupt performance, while the lower arousal associated with the second startle acted to facilitate performance.

Although positive correlations were found between reaction times to the low-intensity sounds (Mn=358 msec) and response times to the high-intensity, startling stimuli, the most interesting aspect of this finding was that startle appeared to magnify differences between individuals in their reaction times to the low-intensity, nonstartling tones; i.e., slow responders tended to respond even more slowly, while the fast responded more rapidly to startle stimulation.

RESPONSE/RECOVERY OF CONTINUOUS PSYCHOMOTOR PERFORMANCE FOLLOWING STARTLE

While the studies described above provide basic information on the time required to make a discrete, voluntary response to startle, they fail to indicate whether this time frame encompasses all of the disruptive effects of startle or whether some disruption may extend beyond this period. Since the reflex muscle response to startle, depending upon the intensity of the reaction, may last from .3 to 1.5 sec (Landis and Hunt, 1939), it is evident that a major portion of the time required to complete a voluntary response following startle is a direct result of this reflex interference. To provide information on possible disruptive effects of startle beyond this period, Thackray and Touchstone (1970) studied the recovery rate of continuous psychomotor performance following startle. In this study, subjects performed a compensatory tracking task continuously during a 30-min period. A 115-db burst of white noise occurred unexpectedly 2 min into the session and again at the middle of the session. Tracking error during the first minute following the initial startle stimulus is shown in Figure 1. Also shown in this figure are the response/recovery curves for heart rate and skin conductance. Although maximum performance disruption occurred during the first 5-sec measurement period following stimulation, significant ($p<.05$) impairment was still present 10 sec after startle.

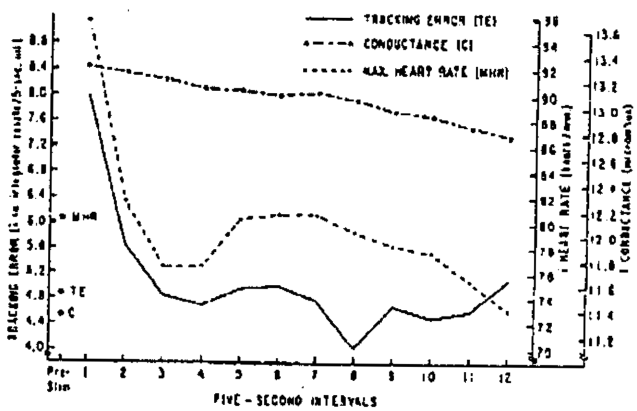

Figure 1. Mean tracking error, maximum heart rate, and conductance level during successive 5-sec intervals following startle. Also shown are pre-startle values for each variable.

The disruption in tracking performance, persisting into the 10-sec period following startle stimulation, clearly extended beyond the initial disruption caused by the reflex response itself and would appear to be a manifestation of a longer lasting, more general physiological/emotional response to the unexpected noise stimulation. Support for this view is suggested by the apparent covariation of heart rate with performance that is shown in Figure 1 and that appears to extend at least into the first 30 sec following stimulation. (Incidently, it is of interest to note in this figure that significant performance improvement occurred during the 8th 5-sec interval following startle; facilitation at this same location also occurred following the second startle stimulus. Since neither of the autonomic measures showed any corresponding change during this time period, some central nervous system facilitory process is suggested.)

The pattern of performance change and physiological response to the second of the two startle stimuli, although of somewhat lower magnitude, was quite similar to that shown in Figure 1. Of interest was the finding that magnitude of tracking error to the two startle stimuli was significantly correlated ($r=.60$, $p<.01$). This enabled us to form two subgroups of subjects whose tracking error following both startle events placed them in either the top third (high impairment) or bottom third (low impairment) of the combined distributions. Relative to prestartle tracking performance, it was found that the high-impairment group almost doubled in their tracking error scores immediately following startle; the low-impairment group showed little difference between their prestartle and poststartle levels of tracking error. With regard to physiological response to startle, the high-impairment group showed significantly greater heart rate acceleration, but the groups did not differ significantly ($p>.05$) in conductance change.

A study by Vlasak (1969) likewise evaluated individual differences in psychomotor disruption to startle stimulation. Using a simple line-tracing task, Vlasak studied differences in performance disruption to an unexpected 100-db sound from a Klaxon horn. His findings were similar to those of Thackray and Touchstone (1970); performance impairment following startle was related to prior task proficiency, with less proficient subjects being considerably more disrupted by startle. As noted earlier, Thackray (1965) also found evidence to suggest that, with the particular reaction time task employed, startle tended to exaggerate preexisting differences between individuals in their nonstartle response time; i.e. the slow became slower and the fast responded with even shorter latencies to startle. Taken together, the results of these three studies suggest the general hypothesis that the extent of disruption following startle is dependent upon prestartle level of performance, with the greatest impairment occurring among those who are either slowest or least proficient prior to startle.

Before concluding this section it should be noted that both Vlasak and a subsequent study by May and Rice (1971) found the total duration of tracking impairment following startle to be only 2 to 3 sec, which is considerably less than that found in the Thackray and Touchstone study. In a reexamination of their data, Thackray and Touchstone likewise found maximum impairment to occur within this same time period and concluded that at least some of the disruption that takes place within the 5-sec period following startle is attributable to direct mechanical effects of the muscle reflex on motor control. However, the fact that Thackray and Touchstone found tracking performance to be significantly impaired for up to 10 sec following startle clearly demonstrates that disruptive effects transcend the time period that one might reasonably attribute to mechanical effects of the startle reflex. The longer period of disruption found by Thackray and Touchstone may have been due to the use of a more difficult tracking task and/or the use of a more refined measure of tracking error than was used in either the Vlasak or the May and Rice study.

RECOVERY OF COGNITIVE FUNCTIONING FOLLOWING STARTLE

Although perceptual-motor recovery following startle appears to be quite rapid, there is evidence that tasks involving decision making or information processing may be impaired for a longer period of time. Thus, Vlasak (1969) studied the effects of startle on continuous mental subtraction and found performance to be significantly impaired during the first 30 sec following stimulation. A similar period of impairment was found by Woodhead (1959, 1969), who obtained decrements on a continuous symbol-matching task lasting from 17 to 31 sec after startle. The fact that impairment on some tasks following startle may last for at least 30 sec lends further support to our belief that startle effects may extend considerably beyond the initial period of motor disruption produced by the reflex response itself.

In all of the startle studies just reviewed, however, performance recovery effects were studied only during some portion of the first 60 sec following stimulation. While it is certainly possible that performance impairment does not extend beyond this time period, startle is known to be accompanied by rather pronounced autonomic (especially cardiovascular) changes (e.g., Thackray and Touchstone, 1970, 1983), and it is conceivable that such changes could have more lasting effects on performance. Thus, a pronounced discharge of the autonomic nervous system might have a long-term activating effect leading to performance facilitation, or, conversely, it might produce a period of parasympathetic overcompensation resulting in eventual drowsiness and impaired performance.

In our most recent study (Thackray and Touchstone, 1983), we used monitoring and information processing tasks to examine both short- and long-term performance recovery effects following a simulated emergency situation (a radar failure) that was accompanied by either a startling or a nonstartling auditory signal. The subject's primary task was to monitor a simulated air traffic control (ATC) radar display. One hour into the session a radar failure occurred that was accompanied by either a loud (104 db) or low level (67 db) burst of white noise acting as an alarm signal. Subjects were then required to turn in the chair and begin performing a simple information processing (serial reaction) task. (The serial reaction task consisted of a self-paced, four-choice reaction time task in which the subject pressed one of four keys in response to a centrally displayed number.) Five minutes of performance on this task was followed by a return to radar monitoring. In addition to performance, physiological and subjective measures of startle and arousal were also obtained. It was hypothesized that performance following the high-intensity alarm signal (expected to elicit a startle reflex) would be significantly impaired relative to performance following the low intensity signal (expected to elicit an orienting-type response).

Heart rate response and subjective ratings of startle were consistent in demonstrating that the high-intensity signal was clearly startling to subjects in this group. Conversely, the group exposed to the low-intensity signal did not rate the signal as startling, and the slight heart rate deceleration that occurred immediately following stimulation was consistent with the expectation that this level of noise would produce only an orienting or surprise reaction (Graham, 1979). In spite of these differences, however, both groups showed almost identical patterns of performance change during the first minute following noise stimulation. Relative to prestimulus levels, mean response times on the serial reaction (SR) task were significantly elevated only during the first 6 sec following noise; thereafter, performance returned to prestimulus levels for the remainder of the 60-sec period. A comparison of the response patterns obtained for the two groups is shown in Figure 2.

At first glance, this lack of any difference between the startled and nonstartled groups in mean performance during the first 6 sec following stimulation would appear to be inconsistent with the findings of our previous studies and those of others reviewed earlier. Since these results were not expected, response times during the first 6-sec period were examined more closely. The time from the onset of the noise signal to the first SR response was obtained for each subject. These initial SR response times, which encompass the time required to transition from the radar to the SR task, were plotted on log probability paper and are shown in Figure 3. Although mean time to make this initial response (designated task transition time) did not differ among the two groups (2.91 and 2.84 for the means of the high- and low-intensity groups respectively), Figure 3 clearly suggests a difference between the groups in range or variability of transition times. An F test of the variances of the two groups revealed the startled group to be significantly more variable ($F(14/14)=2.61$, $p<.05$) in the time required

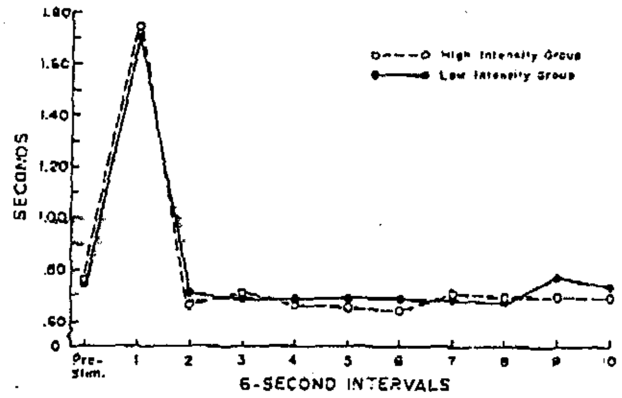

Figure 2. Mean response time for SR performance during successive 6-sec intervals of the first minute following noise stimulation. Also shown are prestimulus values.

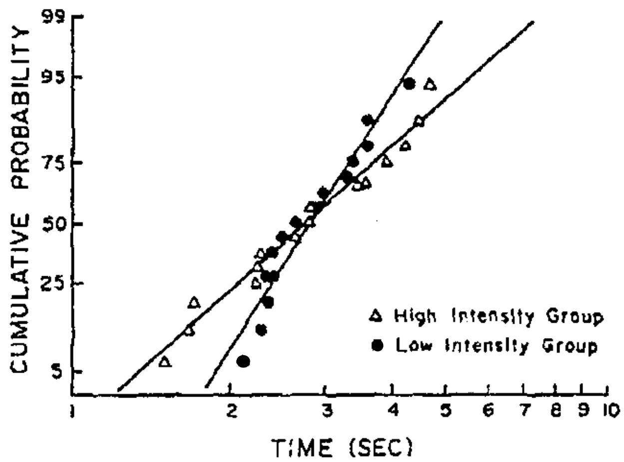

Figure 3. Task transition times for the two groups.

to make this initial response. An examination of variability of responses on the SR task subsequent to this first response, but still within the first 6-sec period following stimulation, revealed variances of .2869 and .1272 for the high- and low-intensity groups respectively. These values, although in the same direction as the transition time variances, failed to reach significance ($F(14/14)=2.25$, $p>.05$). The difference between groups in response variability was thus confined to task transition time.

Analyses of the video-taped recordings taken during noise stimulation clarified these findings. In the group receiving the nonstartling noise signal, behavior following stimulation was extremely uniform; subjects slowly turned in the chair and began performing the SR task. In the high-intensity (startle) group, there were pronounced individual differences following stimulation with some subjects appearing dazed and confused by the noise while others recovered almost immediately and rapidly began performing the task. The disruptive effect of the loud sound for some subjects combined with the rapid recovery shown by others apparently balanced the generally uniform response of the low-intensity group. This also explained the difference in the variance of response times of the two groups. The increased range or variability of initial response to startle that was found in this study is clearly similar to that discussed earlier in the context of both voluntary reaction time to startle and tracking performance following startle.

Unlike response times which, except for the initial task transition time, were largely unaffected by startle, the frequency of incorrect responses (representing errors in information processing) was found to be significantly greater in the startled than in the nonstartled group during the first minute following stimulation. This finding is in general agreement with the findings of Vlasak (1969) and Woodhead (1959, 1969) mentioned earlier, that information processing may be impaired during recovery from startle for periods ranging from 17 sec to over 30 sec. Woodhead (1969) has noted that 30 to 60 sec is the period that it generally takes for autonomic responses such as heart rate to recover to approximate prestimulus levels following startle and that it may not be mere coincidence that this corresponds to the recovery period of cognitive performance.

There was no evidence that startle affected frequency of errors or mean performance on either the SR task or on the radar task subsequent to the first minute following stimulation. Since neither heart rate nor conductance level differed among the groups during these subsequent periods of SR and radar performance, it may be concluded that both the physiological and performance effects of startle are largely confined to the initial 1-min period following startle stimulation.

FIELD STUDIES OF RESPONSE/RECOVERY TO STARTLE

It would be desirable to compare laboratory findings of performance recovery from startle with the findings of comparable studies conducted in the field. Unfortunately, such comparisons are few because of the paucity of published findings. In one of the few field studies of which I am aware that specifically investigated the effects of startle on performance, Ziperman and Smith (1975) compared the extent of disruption of driving behavior produced by unexpected air-bag deployment with that resulting from hood fly-up. Fifty-one male and female drivers ranging in age from 19 to 74 years were tested. Although air-bag deployment, accompanied by a shot-like sound, was experienced as being considerably more startling than hood fly-up, both types of events produced similar, marked changes in heart rate, blood pressure, and skin conductance. In spite of pronounced subjective and physiological evidence of startle, drivers apparently retained control of the test vehicle and were reported to be lucid on questioning less than 10 seconds after cushion deployment. As stated in their paper, "The average steering-wheel rotation was 85 degrees during hood fly-up and 72 degrees during cushion deployment. This degree of steering-wheel rotation would correspond to approximately 3 to 4 degrees at the tire. In combination with the lateral-deviation data, it shows that adequate steering control can be and is maintained in the startle modes tested" (p. 439). Although the effects of these startling events might appear to be less than one might have expected, it should be noted that the actual time-course of performance recovery cannot be determined from the data as reported in this study. There is no indication, however, that the duration of performance disruption found by Ziperman and Smith would differ appreciably from that found in our laboratory studies.

CONCLUSIONS

If we combine the results of all studies considered thus far, certain generalizations concerning response/recovery following startling events can be made:

1. Simple, voluntary responses to startling stimuli or events can generally be made within 1 to 3 sec following stimulation (Sternbach, 1960a; Thackray, 1965; Thackray and Touchstone, 1983). In this regard, mean time to respond to a startling stimulus may not differ appreciably from mean time to respond to an unexpected event or stimulus that is simply surprising. It is likely, however, that the <u>range</u> of response times to the former type of event will significantly exceed the range of response times to the latter type of event (Thackray, 1965; Thackray and Touchstone, 1983).

2. More complex perceptual-motor behavior, such as that requiring continuous psychomotor control, is likely to show maximum disruption during this same 1- to 3-sec period (May and Rice, 1971; Thackray and Touchstone, 1970, 1983; Vlasak, 1969; Ziperman and Smith, 1975), although significant, but lesser, disruption may still be present for up to 10 sec following stimulation (Thackray and Touchstone, 1970).

3. Evidence from several studies suggests that the ability to process information may be impaired for 17 to 60 sec following the occurrence of a startling event (Thackray and Touchstone, 1983; Vlasak, 1969; Woodhead, 1959, 1969).

4. Individual differences in the magnitude of performance impairment following startle appear (a) directly related to physiological reactivity to startle (Sternbach, 1960a; Thackray, 1965; Thackray and Touchstone, 1970) and (b) inversely related to level of prestartle task proficiency (Thackray, 1965; Thackray and Touchstone, 1970; Vlasak, 1969).

In order to evaluate the relevance of the above laboratory and field findings of response/recovery following startle to behavioral response following real-life emergencies, it is important to recognize that unexpected and traumatic emergency situations in real life probably involve at least two phases. The first phase, which could be termed a "shock phase," constitutes the initial reaction. In this phase, the individual attempts to respond with immediate behaviors that are intended to cope with or rectify the unexpected event. While the behaviors employed may appear to be irrational and actually worsen the situation, this is clearly not the intent. With some individuals, behavior seems to become suspended (affective immobility or "freezing"), although numerous studies of response to disaster (e.g., Singer, 1982) suggest that this type of response is the exception rather than the rule. When it does occur, it appears to be a rather temporary or momentary response. In some emergencies, the shock phase is followed by a second phase which could be termed an "evaluative phase." This phase occurs if the emergency situation has not been resolved during the intial shock phase and is characterized by an emerging perception or evaluation of the situation in terms of the individual's ability, or lack of ability, to cope with the emergency. It is during this phase that panic, if no solution or escape seems possible, may occur. However, panic, like affective immobility, also appears to be a relatively infrequent form of disaster response (Singer, 1982).

If one is willing to accept that the emotional/physiological response to startle can serve to at least approximate the initial shock phase of traumatic, real-life emergencies, then findings of laboratory studies of performance recovery following startle may have relevance in predicting the time course of behavioral recovery following such events and may assist in our understanding of some of the extreme reactions displayed by individuals in real-life emergency situations. As we have noted, laboratory studies have isolated several individual difference variables (autonomic reactivity and level of prior task proficiency) that appear to be correlated with performance recovery from startle. The first of these, autonomic reactivity, suggests that inherent, constitutional factors undoubtedly play some role in startle recovery; the second variable, task proficiency or skill level, would suggest that some of the performance disruption following startle may be amenable to training. Research is needed, however, to determine the extent to which individual differences in response/recovery found in laboratory studies of startle can serve as useful predictors of disruption/recovery following simulated emergencies that closely approximate real-life situations.

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