THE CONSTRUCT OF FATIGUE: A MODEL FOR AVIATION

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ABSTRACT

Data gathered from the aviation community during the last 5 years substantiates an existing difficulty in defining human fatigue. Four choices of the definition of fatigue that emphasized the mental processes were provided to 206 survey respondents; 13% chose not to answer the item, although 40% did agree upon the definition provided by a sleep expert. Fatigue in man has been an ill-defined phenomenon since the late 19th century. During the 20th century, numerous reviews and studies have been inconclusive as to the definition of fatigue. A graduate seminar during the summer of 2000 produced a model depicting the construct of fatigue as applicable within aviation human factors (AHF). Although generalized fatigue has shared the adjectives chronic, muscular, nervous, combat-related, temperature-related, and a variety of others, today's aviation environment is primarily concerned with the reduction of human errors of a cognitive nature. A principal AHF, situation awareness, requires mental alertness on the part of the operators. Thus, the design of this fatigue model was focused on the multi-facets and complexity of cognitive fatigue across AHF. The model consists of three columns under the headings "manifestations," "degradations," and "innovations." (Interactivity between the columns and all elements is implicit, and no interactive arrows have been utilized in the model.) The subheadings chosen for depiction under manifestations are cognitive, physiological, and psychological. Similarly, alertness, situation awareness, and crew resource management are listed under degradations. Innovations call for changes in philosophy, policies, and practices; the individual and the culture of the operation are two of the key determinants for human fatigue. For the 21st century, an exemplar has been provided for one individual's treatment of the model. The exemplar is indicative of the individual tailoring that would occur within the three columns and their subheadings. Similar tailoring of the model is an implication for other modes of transportation and other industries.

RECENT DATA

There have been 206 respondents to a survey developed in 1996 for U.S. aviation curricula (Weitzel, 1997). For purposes of comparison, and with adult education as the setting, these respondents have been classified in three groups. A group consisting of 58 instructor pilots from the COMAIR Academy and 22 graduate students from Embry-Riddle Aeronautical University (80 total) has been labeled "Developing Learners." A group of 68 Air Line Pilots Association captains with U.S. major airlines (none employed by the same airline as one of the authors) has been labeled "Mature Learners." A group of 35 educators from aviation higher education and 23 individuals involved with air carrier training (58 total) have been labeled "Aviation Educators," in unity with praxis (a continual process of activity) and the adult content of AHF (Knowles, 1980).

Two tables summarize the demographics of the three groups and their preferences for a definition of fatigue. Table 1 is a group means comparison, with parenthesized standard deviations, of four demographic variables: (a) chronological age in years, (b) formal education in years, (c) total flight time hours, and (d) aviation experience in years. Cases that had missing values for any of the four variables were omitted (listwise deletion).

A definite lack of consensus as to the definition of fatigue throughout the years resulted in the provision of four choices from late 20th century sources for item 1, to provide a framework for the following 21 opinion items of the survey. The preferred definition (39.8% of the 206 respondents), provided by a sleep expert, for fatigue was:

> A condition characterized by increasing difficulty sustaining a high level of performance output, caused by an interaction of a number of neurobiological (sleep need, circadian rhythm) and neurobehavioral (sustained vigilance, workload) factors, which may be reflected in a variety of subjective states (e.g., fatigue, sleepiness, lethargy). (David F. Dinges, personal communication, November 12, 1996)

Table 2 is a cross tabulation (expected frequencies parenthesized) of the three groups' preferences for the definition of fatigue. It is interesting to note that within Table 2, 13.6% of the respondents chose not to answer this item. A possible explanation for the missing data is the adult learning trait of self-direction that involves different degrees of autonomy and empowerment. As advocated by Brookfield (1988), education involving fatigue (and other AHF) should probably plan for some degree of this adult learner independence.

TABLE 1
Means Comparison of Four Demographic Variables

Categorical Groups	Chronological Age In Years	Formal Education In Years	Total Flight Time Hours	Aviation Experience In Years
Developing Learners (*n*=80)	28.75 (6.33)	15.99 (1.52)	725.81 (989.57)	6.70 (5.15)
Mature Learners (*n*=68)	42.73 (8.86)	15.51 (1.56)	12,377.98 (5,292.90)	21.90 (8.48)
Aviation Educators (*n*=58)	46.40 (8.34)	18.61 (1.91)	4,770.96 (4,973.56)	21.81 (7.72)

TABLE 2
Cross Tabulations of the Preferred Definitions of Fatigue

Categorical Groups	Choice *a*	Choice *b*	Choice *c*	Choice *d*	No Choice	Row Total
Developing Learners	14 (10.9)	11 (7.4)	20 (19.0)	26 (31.8)	9 (10.9)	(*n*=80) 38.8%
Mature Learners	7 (9.2)	4 (6.3)	15 (16.2)	29 (27.1)	13 (9.2)	(*n*=68) 33.0%
Aviation Educators	7 (7.9)	4 (5.3)	14 (13.8)	27 (23.1)	6 (7.9)	(*n*=58) 28.2%
Column Total	28 13.6%	19 9.2%	49 23.8%	82 39.8%	28 13.6%	206 100.0%

Without an analysis of variance, the differences for the variables in Table 1 are obvious, and as would be expected:

1. The developing learner group is the youngest and least experienced.
2. The mature learners group possesses the most experience.
3. The aviation educators group is the oldest, with the greatest amount of formal education.

Within Table 2, the distribution within the cells was such that a chi-square goodness-of-fit test was utilized for the analysis of the choices for the definition of fatigue. Table 2 has 8 degrees of freedom, and at alpha=.05, the critical chi-square was found to be 15.51. The calculated chi-square (8) of 8.795, *p*=.360, was indicative of no significant differences between the three groups in their preferences for the definition of human fatigue.

THE LITERATURE

The recent data for the definition of fatigue is in concert with what knowledge of the construct has existed for more than 100 years. A late 19th century explanation of “general” fatigue by Vivian Poore, a London physician, was: "There is a disability for performing either mental or physical work . . . first in work requiring attention or sustained effort . . . symptoms of general fatigue are referable to the brain and nervous system" (1875, p. 163). In 1887, the Italian physiologist Ugolino Mosso raised the question whether the day-night rhythm of rectal temperature (today, a most common biological marker for body core temperature) could be inverted by working at night and sleeping during the day. Utilizing self-measurements, Mosso arrived at the conclusion that there was "une courbe fondamentale de variations automatiques de la température," and that by shifting his sleep time by 12 hours, he only had "superposer une nouvelle courbe à la première, et à obtenir une courbe résultante de deux phenomènes qui procèdent en direction opposée" (p. 183). Loosely translated, Mosso had anticipated the existence of what is currently referred to as endogenous rhythm, and the two properties of this rhythm -- rigidity and plasticity. MacDougall (1899) made the distinction between subjective and objective fatigue; and further concluded that there were measurement difficulties.

In 20th century England, the formation of an Industrial Fatigue Board resulted in a suggestion "That the term *fatigue* be absolutely banished from precise scientific discussion, and consequently that attempts to obtain a fatigue *test* be abandoned" (Muscio, 1921, p. 45). During the 1970s and 1980s, researchers typically supplied their own meaning of the "human fatigue" term, as difficulty with its measurement and definition was acknowledged (Broadbent, 1979; Dodge, 1982). Federal Aviation Administration (FAA) investigators at the Civil Aeromedical Institute discussed fatigue as:

> The undesirable state produced by effort -- either the physical or mental effort of doing work or the effort of maintaining vigilance when there is no physical work to be done. Fatigue is an undesirable state because it causes people to commit errors; fatigue can adversely affect not only the accuracy but also the timeliness of performance. (Higgins et al., 1982)

In 1980, the U.S. National Aeronautics and Space Administration (NASA) sponsored a workshop on pilot fatigue and circadian desynchronosis, in response to a Congressional request to determine whether "the circadian rhythm phenomenon, also called jet lag, is of concern" (NASA, 1981, p. 1). A rather diverse group of aviation experts attended the workshop. Scientists from academe, federal agencies, and the military services were joined with the representatives of airline pilots and management. The first day's summary statements indicated that ". . . most did not perceive a major problem relating to pilot fatigue or to circadian desynchronosis as factors in air safety. As the participants received additional information from their colleagues, these views began to change . . ." (p. 4). After 3 days of discussions it was determined that pilot performance degradation as a result of fatigue was a problem that should concern the aeronautical community; and that perhaps similar workshops should be held on a regular basis.

Despite the enlightened awareness displayed by many of the workshop attendees, there appeared to be a reluctance on the part of pilots, airline management, and the FAA to admit that fatigue in the cockpit was a problem negatively impacting the safety of flight. Some of the participants felt that "it was neither fair nor correct to imply that pilot fatigue (or pilot performance degradation) was a cause of accidents, since the number of airline accidents is relatively small" (NASA, 1981, pp. 4-5). Nevertheless, a program was established that pursued three goals:

1. Determination of the extent of fatigue, sleep loss, and circadian disruption in air transport operations.
2. Determination of the effect of these factors on flight crew performance.
3. Countermeasures development and evaluation to reduce the adverse effects of these factors and to maximize flight crew performance and alertness.

A series of scientific studies and publications by NASA resulted in the 1991 label, the NASA Ames Fatigue Countermeasures Program. A 1999 outcome of the Program was the comprehensive Education and Training Module (Rosekind, Gander, Connell, and Co). A model depicted within the Module utilized interactive arrows to focus on the fatigue factors of sleep loss and circadian disruption.

In 1995, the NASA Fatigue Countermeasures Program and the U.S. National Transportation Safety Board (NTSB) jointly sponsored an international fatigue symposium. Mr. Jim Hall, then Chairman of the NTSB, opened the symposium by remarking that fatigue is one of the major hazards of transportation, and that during the 23 year period from 1972 to 1995, the NTSB issued nearly 80 fatigue-related safety recommendations. Jim Danaher, then Chief of the NTSB Operation Factors Division, added that:

> In its investigation of numerous accidents in all transportation modes, the Safety Board has identified serious and continuing problems concerning the far-reaching effects of fatigue, sleepiness, sleep disorders, and circadian factors in transportation system safety. We have seen repeated instances of poor

> scheduling of work and rest periods in all transportation modes that have or might have affected adversely the performance of operating personnel. (NTSB, 1996, p. 11)

Few aircraft accident investigators have named fatigue as the probable cause (or even a causal factor) of an accident. In support of the noted reluctance to classify fatigue as causative, fatigue has been very difficult to measure even in advanced laboratories (Broadbent, 1979); and nearly impossible to precisely measure after an accident (Barlay, 1990). A French accident investigator once stated:

> Our lack of knowledge about fatigue may well prove to be the chief explanation of those accidents which are now put down to “pilot error” or “the human factor” simply because we don't quite understand what makes well-qualified, conscientious specialists, like pilots, commit almost unbelievably stupid mistakes. (Barlay, 1970, p. 322)

Although the body of knowledge concerning fatigue has grown substantially, accident investigators today typically consider the flight crew's duty, flight, and rest schedule for the preceding 72 hours. However, a detailed analysis of a deceased crew’s schedule has generally not been sufficient to determine the impact of fatigue on flight crew performance.

MODELING THE CONSTRUCT

The terms used in the Dinges definition of fatigue included performance, sleepiness, circadian rhythms, vigilance, workload, lethargy, etc. to characterize a human state or condition. The NASA Education and Training Module mentioned a “variety of different subjective experiences” (Rosekind et al., 1999, p.8). In the public, the workplace, and the sciences, the adjectives associated with a state of human fatigue have included chronic, muscular, nervous, combat-related, temperature-related, and a variety of others. During the summer of 2000, a graduate seminar chose to delimit its content (human fatigue in air carrier operations) to that of a cognitive nature.

Recognition of the multi-facets of fatigue, the broad impact on AHF, and the associated complexity resulted in an adult teaching model. The graduate exchange of ideas determined that human fatigue was a construct that should be modeled comprehensively and simplistically for teaching and application across a variety of curricular settings. A developmental consideration was that a probable and necessary tailoring of the model to individuals within different aviation settings, additional modes of transportation, across numerous industries, and all levels of adult learning should not restrict the treatment of fatigue to its cognitive nature.

Accordingly, three headings were developed for three columns, or classifications of another type (e.g., triangular points modeling the human as the center): “manifestations,” “degradations,” and “innovations.” Interactivity between the columns was implicit, and the usage of arrows was not deemed necessary. Within the columns, subheadings were utilized; each individual was encouraged to apply his/her treatment to discussion of each subheading. The subheadings under manifestations were cognitive, physiological, and psychological; under degradations, the list was alertness, situation awareness, and crew resource management; and those listed under innovations were philosophy, policies, and practices.

One adult learner’s application from the model’s presentation within the graduate seminar can be summarized as an exemplar. For this individual’s setting, the physiological manifestations were more important than the cognitive or psychological. (Of course, it has been generally acknowledged that self-evaluation of cognitive performance or psychological state is not always accurate.) Anecdotally, colleagues in the same state were observed to behave differently, displaying individual reactions. The sleep deprivation and circadian desynchronosis consequences of a 24-hour aviation world were long term.

Among the degradations, a decrement in alertness for this individual was caused by advanced cockpit automation that resulted in monotony and a state of boredom. Increased crew input to the system was suggested, combined with more stringent duty/rest provisions associated with the individual operations. The individual culture would be responsible for the innovations concerning the philosophy, the policies, and the practices that produced human fatigue.

The individual and the culture of the operating environment remain two of the key determinants for human fatigue. Organizational innovations have been researched, but need to be practiced. The philosophy, the policies, and the procedures require change and application. The solution to problems associated with fatigue is most probably the application of adult learning principles tailored to individuals and their settings. The simplistic, though comprehensive model advocated within this paper appears to satisfy this suggestion.

IMPLICATIONS

The technological advances throughout the world have resulted in a society that cannot always be governed by humans' internal and external clocks. The resultant human fatigue and its consequences are a complex problem, but understanding and solutions can be taught as a construct. During the 21st century, adults within aviation, all modes of transportation, and throughout many industries should be educated with respect to the manifestations of human fatigue, the degradations associated with human fatigue, and the innovations required on an individual basis within specific settings.

The specific settings include institutions of higher learning and industry. Regulatory bodies govern most individuals throughout the 24-hour world to some degree, but probably do not need to develop catchall requirements for fatigue education and application of its outcomes.

The model currently exists as a framework. The developmental stages of the fatigue model as an educational tool are planned to continue in the near future. For example, expansion and refinement of the model might include some classification of the literature in conjunction with the headings and subheadings. Adult learners utilizing the model will probably suggest additional enhancements. Usage of the model within the aviation community can be tailored to traditional training, however, the construct of fatigue is best treated as an educative issue within the information-rich aviation world.

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