ENVIRONMENTAL FACTORS INFLUENCING HEALTH AND EFFICIENCY IN WARSHIPS*

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When the designers plan the allocation of space and the installation of equipment in warships they have to effect a satisfactory compromise between many requirements, including those for providing in one ship an optimum number of useful weapons and detecting devices, high-powered engines for achieving high speeds, armoured protection against bombs or shells, watertight compartments to enable damaged ships to remain afloat, and, lastly, living and working conditions under which men may remain healthy and work efficiently.

It is one of the tasks of the Royal Naval Medical Service to advise the Staff when this balance of conflicting interests may act unfavourably towards the men and impose adverse effects on their health or efficiency. It will be seen that in the past the acceptance of standards which fell short of those required by the highest dictates of environmental hygiene was unavoidable at times; but the circumstances were such that the alternative would have been unacceptable loss of fighting efficiency in other ways, or a reduction of the safety factor.

In recent years the attention of those responsible for the efficiency of the armies, navies, and air forces of the World Powers has been drawn repeatedly to the fact that the power of modern weapons and the efficiency of fighting machines may be reduced because of neglect to consider sufficiently the characteristics of the men concerned with their operation. This has led to a renewed stiffening of opinion concerning the relative importance of human factors in the design of equipment. These factors may be examined broadly in relation to the physical or psychological ability of the men to carry out their various tasks, or in relation to limitations imposed on them by the nature of their environment. In practice these considerations are usually merged together, and to study one it is necessary to have a good working knowledge of the other.

When war was declared in 1939 the Navy had not for 130 years conducted a major campaign which entailed ships remaining continuously at sea in tropical waters, and the constructional features and design of ventilating arrangements were mainly based on experience gained in operating in temperate or subtropical waters. Although the ill effects of nutritional deficiency and infectious disease, which had ravaged the fleets in the past, were rarely seen, warships were still desperately crowded when they carried their full war complements, and the enormous power generated by their machinery produced great quantities of heat below decks which were hard to control by normal ventilating methods.

The efficiency of ships' ventilation systems was determined until recently by measurement of their ability to keep the level of carbon dioxide in the air of occupied compartments below 7 parts in 10,000. Compartments ventilated to accord with this standard were found, however, to be uncomfortably warm in the Tropics, and in 1937 the decision was made that ventilation arrangements would be designed thenceforward with the aim of maintaining an equable thermal environment under the climatic conditions generally imposed on warships, a decision easy to make but difficult to carry out.

The early years of the war saw a tightening up of precautions for increasing the watertightness of ships damaged in action by increasing compartmentation and reducing communications between compartments, such as those afforded by ventilation trunking deemed to be unessential. These developments, combined with the "black-out," further complicated the task of those who had to provide satisfactory living and working conditions.

While the main activity lay in home and northern waters the increasing warmth in ships did not hamper operations, but the early Mediterranean campaigns gave warning that when the Fleet operated in the Tropics conditions incompatible with reasonable efficiency might be encountered in certain situations. Thus in 1944, when the Japanese campaign became imminent, the Royal Naval Personnel Research Committee of the Medical Research Council, which had previously devoted its attentions to problems of operational divers, anti-aircraft defence, cold-weather clothing and body protection, was directed to examine the environment of men in warships in the Tropics and to report on the probable effect on fighting efficiency.

This direction was expanded later to include more general problems, conditions in submarines, and problems of the thermal environment in temperate and northern waters. The specialized problems of the naval airman in the air were dealt with by the Flying Personnel Research Committee of the Air Ministry and will not be discussed here. Much of the work subsequently carried out has been reported or is to be reported elsewhere; other studies are not yet complete. It is therefore possible to refer only to the interim conclusions of these investigations.

Surface Ships

It is convenient to consider the various living and working spaces of warships in separate groups according to the activities of the men who occupy them, and the complexity of the problem is indicated by the varying nature of the average thermal conditions. The observations described below were made during a four-month period in 1944 in eleven ships of the Eastern Fleet, including battleships, aircraft carriers, cruisers, and destroyers.

Thermal Environment

The thermal conditions below decks were measured in accordance with the recommendations of Bedford (1946), and were described in terms of the "normal" effective temperature as well as the more conventional dry- and wet-bulb temperatures. The effective temperature may be derived simply, if the air movement and dry- and wet-bulb temperatures of the air are known, from the charts constructed by Houghten and Yaglou (1923) in the United States. This scale of warmth expresses as a single figure the summated effects on the comfort of lightly clothed human beings of air temperature, humidity, and air movement. At the higher ranges of warmth it does not afford an accurate index of the physiological effects of the possible combinations of these three factors, and the practicability of replacing this scale with a concept based more closely on the physiological and psychological reactions of individuals is being examined. During the war effective temperature was the most suitable common index available, and over the range of conditions generally encountered it was satisfactory for our purpose.

Houghten and Yaglou also constructed a "basic" effective temperature chart which referred to the comfort sensations of men stripped to the waist. Warship crews in action, however, generally wear overalls and anti-flash hoods and gloves to protect them against flash burns. The normal effective temperature chart was therefore used in describing the measurements made on this survey.

*The basis of a paper given to the Society of Medical Officers of Health (Services Hygiene Group) on Nov. 28, 1947.

Allowance was made for the effects of radiant heat where these were important by making globe-thermometer measurements also and computing the mean radiant temperature of the surroundings; or, alternatively, by applying a correction to the effective temperature scale by substituting the globe-thermometer readings for those of the dry-bulb thermometer when reading the chart.

Bedford (1948) has pointed out that recent American studies on the effects of radiant heat on rectal temperature showed that "corrected effective temperature" fitted the experimental findings when the average rectal temperature of the subjects of the experiments was 100° F. (37.8° C.), over-corrected for radiation under more severe thermal conditions and under-corrected for it when the environment was less severe. The concept of corrected effective temperature may be used, therefore, only to give an approximation of the added strain imposed if heat radiation is added to the other thermal factors of a man's environment.

The standards provisionally accepted by the Admiralty since 1944 in planning warship ventilation for the Tropics state that 80° F. (26.7° C.) effective temperature (or corrected effective temperature if radiant heat is a factor) is the upper desirable limit for thermal conditions in spaces where men must live and work, and that 86° F. (30° C.) effective temperature (or corrected effective temperature) is the upper acceptable limit.

It is necessary to interpret these standards with considerable latitude in considering different compartments. The severity of thermal conditions should be assessed in relation to the energy expended by the men exposed, to the complexity of their mental tasks, and to the clothing they must wear. Thus men handling ammunition for the heavy guns would become inefficient in a less severe environment than would engine-room watch-keepers, whose physical tasks might be light in comparison; or a radar operator watching for the faint signals on the display might fail to observe the presence of a ship or aircraft in the vicinity, although an engine-room watch-keeper observing the more plainly displayed dials and indicators in the engine-room under similar thermal conditions would be less liable to make an error; or, again, submarine crews stripped to the waist when submerged in the Tropics could sustain without loss of efficiency severer thermal conditions than the more heavily clothed crews of surface ships in action.

TABLE I.—*Average Thermal Conditions in Living and Working Compartments in Surface Ships of the Eastern Fleet (1944)*

	Normal Effective Temperature	Dry-bulb Temperature	Wet-bulb Temperature	Air Movement per Minute	Relative Humidity	No. of Observations
Mess decks	84·0° F. (28·9° C.)	90·0° F. (32·2° C.)	82·0° F. (27·77° C.)	100 ft. (30·48 m.)	71%	947
Machinery spaces	88·7° F. (31·5° C.)	102·7° F. (39·27° C.)	87·7° F. (30·94° C.)	468 ft. (142·65 m.)	55%	359
Gunnery control compartments	86·5° F. (30·28° C.)	95·5° F. (35·28° C.)	84·2° F. (29° C.)	172 ft. (52·42 m.)	61%	364
Gun-turret lower quarters	86·6° F. (30·33° C.)	91·9° F. (33·28° C.)	84·9° F. (29·39° C.)	60 ft. (18·29 m.)	75%	125
Radar offices	86·9° F. (30·5° C.)	97·7° F. (36·5° C.)	83·8° F. (28·77° C.)	160 ft. (48·77 m.)	56%	59
Electrical spaces	89·5° F. (31·95° C.)	104·7° F. (40·4° C.)	82·6° F. (28·11° C.)	147 ft. (44·8 m.)	39%	81
Workshops	87·5° F. (30·83° C.)	100·3° F. (37·33° C.)	83·7° F. (28·66° C.)	193 ft. (53·83 m.)	51%	55
Sick bays	83·0° F. (28·33° C.)	90·9° F. (32·72° C.)	82·1° F. (27·77° C.)	239 ft. (72·85 m.)	68%	82
Communication offices	85·8° F. (29·88° C.)	95·9° F. (35·5° C.)	83·9° F. (28·83° C.)	163 ft. (49·68 m.)	61%	168
Galleys	87·4° F. (30·77° C.)	97·5° F. (36·39° C.)	84·2° F. (29° C.)	192 ft. (58·5 m.)	58%	168

The average dry-bulb temperature on deck was 83° F. (28.3° C.) and the average wet-bulb temperature 77° F. (20° C.) when these measurements were made. The sea temperature varied between 82 and 88° F. (27.8 and 31.1° C.). In the living compartments (mess-decks) the average wet-bulb temperature was 82° F. and the average effective temperature 84° F. (28.9° C.). In the main working spaces of these ships, and in some of the compartments which were especially important in action, the average effective temperature varied from 85 to 90° F. (29.3 to 32.2° C.). In certain spaces, such as machinery compartments, galleys, and workshops, it was found that for nearly 800 measurements made the mean radiant temperature of the surroundings lay between 90 and 120° F. (32.2 and 48.9° C.) for 66%, and between 120 and 150° F. (48.9 and 65.6° C.) for 24%; and "corrected" effective temperatures between 95 and 100° F. (35 and 37.8° C.) were encountered at times.

The thermal conditions in ships in temperate waters gave less cause for concern. In northern waters men below decks were generally able to carry on with their work without loss of efficiency, and remained healthy. The men on deck were reliant on carefully designed clothing for protection against cold, wet, and wind. The thermal environment here was apparently less critical than in the Tropics, but the effects of conditions in the Arctic regions have not been the subject of detailed investigation in recent years.

Accommodation

Sir Sheldon Dudley, in his preface to *Environmental Warmth and its Measurement* (Bedford, 1946), stated: "The problem to be solved by research and experiment can be stated briefly, thus—What is the ratio of the space allocated to the human element, to the space allotted to the mechanical element of the total fighting machine (ship plus ship's company) which will make the most efficient engine of war?"

A review of the space available for a community of nearly 8,000 men who were living on the mess decks of two battleships, four cruisers, an aircraft carrier, and an escort carrier in the Eastern Fleet showed that less than 150 cu. ft. (4.25 $m.^3$) of space per man was provided on the mess decks for 69% of these men and their belongings and less than 200 cu. ft. (5.66 $m.^3$) for 92%. The height of the deckhead is usually about 8 ft. (2.4 m.) in warships. Thus the majority of ratings were entitled to a floor area of less than 19 sq. ft. (1.76 $m.^2$). It is interesting to note that Dudley (1928) reported similar arrangements for the crew in H.M.S. *Dunedin.* Satisfactory air hygiene was obtainable under these congested conditions by high ventilation rates below decks achieved by powerful fans for supplying fresh air to compartments and others for drawing stale air away from them.

The above figures may be compared with wartime standards in naval barracks ashore, which allowed a minimum of 45 sq. ft. (4.18 $m.^2$) of floor space per man and an "austerity" standard of 30 sq. ft. (2.79 $m.^2$) if double-tiered bunks were used for sleeping (Dudley, 1943). The men slept in hammocks in temperate waters, but in the Tropics many found these too hot, and light camp-beds were issued as well, so that up to 70% of ships' companies slept in the open air on the upper deck.

Chemical Factors

The powerful ventilation systems of modern warships prevent undesirable accumulation of products of respiration such as carbon dioxide. Chemical factors are not therefore generally of importance. Reference has been made elsewhere (Ellis, 1944, 1947b) to circumstances which may result in casualties when, as a result of explosions or faults in machinery, contamination of the air of compartments, by nitrous fumes, carbon monoxide, and certain volatile chemicals used as refrigerants and in fire extinguishers, may occur without the knowledge of the occupants.

There is one exception to the above generalization. The magazines and ammunition-handling spaces of ships in action are hermetically sealed to prevent the flash of explosions blowing up their dangerous contents. In war these compartments may be heavily manned for many hours, or even days, and after a period (10 to 15 hours) without ventilation it becomes necessary to guard against undesirably high accumulations of carbon dioxide. The rate of accumulation varies with the size of the compartments, the number of occupants, and the energy expended by them. At an earlier time complaints may be made of headaches and general malaise due to inhaling the volatile decomposition products of cordite. These effects have been studied by Thomson and Weiner (1947), who have shown that men handling cordite charges are more severely affected in hot humid atmospheres. The gun-crews were clothed in overalls, fabric hoods, and long gloves to protect them against flash-burns. Ammunition compartments were also critically warm and humid in the Tropics (Table I). It may be concluded that ammunition handlers carried out their arduous tasks in the face of considerable difficulties.

Bacterial Factors

The increasing use of air-conditioning equipment in warships led to proposals for economizing in the weight and and size of ventilation trunking by effecting considerable reductions in the volumes of fresh air to be supplied to air-conditioned compartments; for the former lavish supplies were based on the need for limiting the thermal conditions, which would now be controlled by refrigeration. It was asked, therefore, if decreasing fresh air supplies and increasing air recirculation would cause undesirable additions to the bacterial content of the air of compartments.

Several serious epidemics of upper respiratory tract diseases which had occurred in ships at critical stages of the war, and the annual rate for pulmonary tuberculosis in the Navy, which had been double that in the other Services for many years (Dudley, 1941), were additional reasons for examining these proposals to reduce fresh air supplies with some precision.

A preliminary survey of conditions in a newly built cruiser and a submarine (M.R.C. Special Report Ser., No. 262) provided interesting data which permitted a comparison to be made between the bacterial environment of naval ratings and that of the civil community. About 600 "two-minute" samples of air were taken with a slit sampler (Bourdillon, Lidwell, and Thomas, 1941) in the cruiser during several days at sea under action conditions and while lying in Scapa Flow.

Previous studies by the Medical Research Council had suggested that under ordinary domestic or working conditions bacterial counts made in this way should not exceed 50 bacteria-carrying particles per cubic foot (0.028 m.^{3}) of air, although much lower levels were desirable in hospital wards, dressing-stations, or operating theatres. It was found that when men were engaged in quiet occupations on the mess decks the above level was not usually exceeded, but it was when there was much activity, such as sweeping up after meals, turning out of hammocks in the early morning, and crowding into the bathrooms before breakfast. These findings indicated a need for making improvements, but did not compare unfavourably with similarly crowded situations ashore. In the critical action-compartments, such as the crowded gunnery-control positions beneath the armoured deck, surprisingly high standards of air hygiene were achieved by the ventilation provided.

In the air-conditioned compartments investigated recirculation of the air did not lead to a build-up of bacteria during two-hour periods. This aspect requires further investigation, and it is also desirable to repeat in the Tropics the general study in ships.

Submarines

Although the first submarine is said to have been navigated in the Thames in the time of James II, they were not developed as naval weapons until the twentieth century, when in two wars they nearly proved to be decisive weapons in the hands of our enemies. British submarines were also a most effective naval weapon, and, in view of the small numbers of men employed, an economical one too. In the Mediterranean alone a total force which rarely exceeded 1,000 men—or the ship's company of a single cruiser—sank between one and two million tons of Axis shipping and paved the way for the success of the Eighth Army by disrupting enemy supply lines. The Germans were late in appreciating that the effectiveness of a submarine on long patrols depended on the provision of an optimum environment for the crew. These environmental problems differ in certain important respects from those of surface ships.

Thermal Environment

When a submarine is submerged and propelled by the electric motors the conditions are ideal for securing a high degree of control of the thermal environment by insulating the pressure hull to prevent large heat transfers between the sea water and the internal surface of the pressure hull, and by using refrigerating machinery for cooling and dehumidifying the air in the Tropics and heating elements and radiators for warming it in the Arctic.

A series of observations made just after the end of the war in a submarine carrying out an Arctic and tropical cruise showed that, even when pressure-hull insulation was only partially fitted, satisfactory control of the thermal environment could be achieved during a diving patrol in tropical conditions off the Orinoco, where the upper desirable thermal level of 80° F. (26.7° C.) effective temperature was rarely exceeded.

When a submarine is on the surface the main engines draw large amounts of air down the conning-tower hatch and aft to the engine-room. In northern waters the crew are probably colder than they would be in surface ships in the same area, while in the Tropics the introduction of so much fresh air reduces the effectiveness of the air-conditioning plant. In rough seas and foul weather the added inconveniences of motion sickness and exposure to cold and wet which handicap many of the crew on surface patrols are practically eliminated when the submarine is submerged.

Accommodation

The cubic space allocated for sleeping and living quarters in large submarines varies from just above to just below 100 cu. ft. (2.83 m.^{3}) per man. Thus the average space available for a man and his belongings is rather less than in surface ships; but the separate messes are divided from each other only by curtains or light partitions, and when the ventilation fans are circulating the air it is more reasonable to consider the entire submarine as a single compartment. It is then found that the volume of breathable air available for each man when the submarine is submerged will lie somewhere between 300 and 500 cu. ft. (8.49 and 14.16 m.^{3}) in different classes of submarine, and, provided the sleeping billets are separated by adequate intervals, this will be more important for providing satisfactory air hygiene than the amount of space actually allocated to each man in each mess.

The best use is made of the space available by ingenious designs of fittings and furniture, and the degree of comfort obtainable is surprisingly high under the circumstances.

Chemical Factors

When a submarine is submerged carbon dioxide will accumulate in the air, which will at the same time be depleted of oxygen by the respiratory requirements of the crew. The rate at which these changes occur will vary with the volume of air available in the different types of submarine, the numbers of the crew, and the energy expenditure of the latter in the duties they must perform.

The careful control of both these factors is essential. The features of oxygen lack are said to include deterioration in visual acuity when the percentage at one atmosphere falls below 19% and, at lower concentrations, impairment of judgment and reasoning faculties, possibly associated with confident unawareness of the dangers involved and a feeling of well-being. Narcotic effects may also result from breathing atmospheres with a high content of carbon dioxide (5 to 10%), and varying degrees of headache and malaise occur in some people after breathing lower concentrations for a few hours. In addition, after regaining fresh air, unpleasant "after-effects" of this type may be experienced.

The time factor is of considerable importance. Past standards for achieving satisfactory air purification have been based on the assumption that periods submerged would not usually extend beyond one to two days at the outside and were usually less than 24 hours. In the event of more prolonged exposure these physiological effects will require re-examination. In the control of these factors reliance is laid on devices for absorbing carbon dioxide and generating oxygen, and on indicators which keep the commanding officer informed of the chemical composition of the air.

Atmospheric hazards, which occasionally may cause casualties in submarines, include poisoning by carbon monoxide evolved from torpedoes which "run hot" in the torpedo-tubes, battery gases such as chlorine, and volatile chemicals used as refrigerants or in fire extinguishers. The breathing apparatus provided to enable men to escape from sunken submarines is an excellent ready-to-hand self-contained breathing apparatus for rescue or repair work in compartments containing these gases. The refrigerant "freon" (dichlorodifluoromethane) which is generally used in submarines is innocuous if inhaled. Such accidents are uncommon nowadays.

Pressure Changes

During long periods submerged, leaking high-pressure air, and ballast adjustments concerned with maintaining the ship on a level keel, may lead to considerable increases in atmospheric pressure. The physiological effects are not important provided that the partial pressures of oxygen and carbon dioxide are known and suitable precautions are taken before opening the conning-tower hatch.

TABLE II.—*Common Causes of Ill-health in the Tropics: Case Incidence per 100 Man-months*

	British Pacific Fleet (March–May, July–August, 1945)				Eastern Fleet (February–September, 1944)			
	Warships (58)	Depot Ships (19)	All Ships (77)	Shore Estabs. (9)	Warships (23)	Depot Ships (5)	All Ships (29)	Shore Estabs. (7)
Man-months available	83,206	43,570	126,776	37,720	128,194	28,863	157,057	131,700
Heat exhaustion	0·14	0·20	0·16	0·01	0·24	1·23	0·42	0·04
Skin diseases*	**8·43**	**10·16**	**9·02**	**3·62**	**9·39**	**10·96**	**9·68**	**5·75**
Otitis externa	1·80	2·16	1·93	0·47	1·84	3·01	2·05	0·99
Malaria	0·02	0·01	0·02	0·01	0·09	0·04	0·08	0·76
Dysentery	0·37	0·70	0·48	0·45	2·31	4·08	2·63	1·83
Psychoneurosis	0·06	0·07	0·06	0·08	0·05	0·11	0·06	0·11
Dyspepsia	0·19	0·18	0·19	0·17	0·25	0·24	0·25	0·15
Bronchitis	0·17	0·22	0·19	0·12	0·20	0·40	0·24	0·29
Common cold	1·26	1·61	1·38	1·39	1·45	2·02	1·56	1·17
Sore throat	1·00	1·34	1·12	1·03	0·78	0·93	0·81	0·91
Fever (P.U.O.)	0·07	0·07	0·07	0·01	0·13	0·04	0·11	0·12
Pulmonary tuberculosis	0·01	0·02	0·01	0·02	0·02	0·02	0·02	0·02
Minor injuries	**3·27**	**4·15**	**3·57**	**2·11**	**3·79**	**5·99**	**4·20**	**2·09**
Totals	16·79	20·89	18·20	9·49	20·54	29·07	22·11	14·23

*Excluding prickly heat.

In 1944 and 1945 the Germans fitted to their submarines a device developed by the Netherlands Navy which they called a "Schnorkel." This consisted of a hollow mast which could be raised above the surface to provide air supplies for the interior while the main hull of the submarine remained submerged. The schnorkel supply duct was a relatively narrow tube, and the demands of the engines for air were heavy, so the pressure within these submarines was generally depressed to varying degrees below one atmosphere, and in a choppy sea the intermittent occlusion of the air inlet by a valve fitted to prevent flooding would cause fluctuations of the internal pressure. By the use of this device U-boat commanders remained continually submerged for many weeks while avoiding detection, and it would appear that, provided the machinery was suitably designed and the device was wisely used, ill-effects on the personnel did not result.

Bacterial Factors

During the survey of air-borne bacteria described above 80 two-minute samples of air were collected in a submarine during a day at sea off the Orkneys. It had been suggested previously that the difficulties of ventilating submerged submarines might lead to undesirably high bacterial contamination of the air, although it had often been observed that on long patrols submarine crews were unaffected by serious epidemics of upper respiratory tract infections.

It was found that, under a wide variety of probable operating conditions, the upper desirable level of 50 bacteria-carrying particles per cubic foot of air was exceeded only when there was considerable human activity near to the slit sampler. This excellent state of affairs was attributed to the good ventilation obtainable on the surface and to the recirculation of the submarine air through the engine-room when submerged, where the bacteria-carrying particles adhered to the oily bulkheads and machinery.

The Effect on Health

The health of men serving in home and northern waters did not give rise to undue concern during the earlier years of the war, but when the majority of ships were transferred to the Indian Ocean and the Pacific in 1944, before the Japanese campaign, it was considered desirable to obtain an overall picture of the reaction of the men to their new environment. Reports were requested from the medical officers of the ships in the Eastern Fleet and later in the British Pacific Fleet. Their examination showed remarkable similarity in the state of health of the men in the two Fleets.

In the Eastern Fleet it was found that on the average each month, for every 100 men in ships afloat, 29 attended the sick bay as out-patients and 5 were made unfit for duty because of ill-health. In the British Pacific Fleet the corresponding figures were 28.6 and 4.6. The more common conditions which caused the men to report at the sick bay are shown in Table II.

The amount of ill-health in ships was very much greater than in naval barracks and establishments ashore, mainly because of the predominance in ships of skin diseases (including boils, fungus infections, septic prickly heat, and tropical pemphigus) and other infections of the epidermis such as otitis externa, and also because of the relatively greater incidence of minor injuries. Uncomplicated prickly heat was almost universal in many ships, and the monthly incidence of heat exhaustion in ships of the Eastern Fleet (0.42) represented a rate of 1 man in every 20 per year.

On the credit side the incidence of infectious diseases and malaria remained at a low level. Respiratory tract infections were the most prevalent infective condition in both Fleets. Dysentery, however, accounted for increased ill-health in the Eastern Fleet. Dyspepsia was not a common complaint, and neuro-psychiatric disorders were relatively infrequent. Cruises out of the Tropics to South Africa or Australia were always associated with a great decrease in minor sickness, and the significant role of hot humid atmospheres in the causation of ill-health in the Tropics was undoubted.

Comparable wartime figures are not available for the Home Fleet. Reports from ships made during the first twelve-month period after the Japanese War ended, which gave the numbers of men on the sick-list or attending as out-patients at midnight each Wednesday, have been analysed by Dr. J. A. Fraser Roberts. These show that the average sickness for the period under review was approximately twice as great for ships serving in the Tropics as for those in the Home Fleet, and the figure for ships in the Mediterranean lay between these two extremes. Few ships were serving in northern waters at this time. The increase in the Tropics was found again to be due to skin diseases and minor injuries, and again the ships' companies of depot ships and repair ships were the least healthy in the Fleets.

The Effect on Efficiency

The adverse influence on efficiency imposed by this widespread increase of skin disease and heat illness in the Tropics was unquestionable. It was found that air-crew in a fleet aircraft carrier lost more than three times the number of flying days in three months in the Tropics than did a larger number of air-crew in the same ship in a previous quarter when operating off the coast of Norway. In addition to ill-health the warm environment in itself reduced the efficiency of the men. Work took longer to do, and was not so well done as in cooler climates. Heavy operations, such as "bombing-up" a wing of 24 aircraft, took half as long again as in home waters.

Observations on men working in gun turrets (Ellis, 1947a) showed that the ammunition parties were working under conditions which brought them near to the limits of physical endurance. Submarine crews were prevented by heat and humidity from carrying out full-length tropical patrols until air-conditioning plant was fitted.

The view that the prevailing warmth in ships was detrimental to efficiency was given further support by work at the climatic laboratories of the Medical Research Council by Professor F. C. Bartlett and Dr. N. H. Mackworth at Cambridge and by Dr. E. A. Carmichael and Dr. B. McArdle and their colleagues in London. This work confirmed the main conclusions of Eichna *et al.* (1945) and of Robinson *et al.* (1945) in the United States of America that men could carry on with heavy physical tasks for short periods without collapsing when the prevailing level of warmth was greater than that generally encountered in the Eastern Fleet except in gun turrets in action and certain machinery compartments. The efficiency of wireless operators, however, was found to fall off between effective temperatures of 83 and 87.5° F. (28.3 and 30.8° C.) which were commonly experienced in the Eastern Fleet; and the examination of the effects of warmth on other activities of importance in warships confirmed the conclusion that accuracy, judgment, and concentration over short periods (four hours) were reduced in quality before ability to continue to perform simple but strenuous physical tasks.

Many of the principles of man's reaction to excessive warmth have been examined in the United Kingdom, although the effects of heat radiation require further elucidation. It is now desirable to discover whether men acclimatized by living in ships stationed in tropical waters will show similar reactions to the conditions of the above experiments.

This survey of conditions in ships, similar observations by Royal Air Force observers in aircraft in the Eastern Theatre, precise observations on the effects of desert heat on soldiers by Ladell, Waterlow, and Hudson (1944), research in climatic chambers, and parallel studies in the United States have provided much information on the environmental factors which limit the efficiency of military forces in hot climates. In general this supports the standards which are now used in designing ships' ventilation systems for tropical service.

It is generally agreed that to afford men periodic respite from the heat by the selective application of air-conditioning to certain offices, work-places, and recreational and living spaces offers the best chance of improving the thermal environment of men in warships in the Tropics, but much can be done with soundly designed and operated ventilation systems, and by keeping the air moving with ceiling or bracket fans. More generous application of air-conditioning is desirable for those smaller ships which must patrol in the desert-locked waters of the Red Sea and the Persian Gulf, where the severity of the climate far exceeds that normally encountered in the Indian Ocean.

Less is known about the effects of extreme cold on efficiency. There is no sound index for indicating simply the effect of varying low temperatures, humidities, and air velocities on physiological and psychological functions, and information about the optimum levels of warmth to be maintained in ships by artificial heating is incomplete. There is thus a need for further examination of the human factors related to operations under extremely cold conditions, to make available the fundamental facts without which the design of equipment for the Arctic and Antarctic will continue to depend on empirical methods.

Conclusion

Considerable research is being devoted to ways of securing optimum arrangements of working equipment, machinery, and seating, to the designing of instrument controls and displays to enable simple and efficient operation, to anthropometry, and to time-studies for reducing delay or saving man-hours in processes involving several operators or teams of workers. Other investigations are concerned with the definition of optimum lighting intensities and the most favourable siting of sources of illumination for various types of work. The influence of background noise or unexpected sounds on the performance of auditory or non-auditory tasks, and more abstract considerations such as the effects of monotony or repetitive tasks on overall efficiency, are being reviewed.

It is not possible here to consider many other factors which affect working efficiency. Little reference has been made to clothing or the psychological aspects of life in warships, the present knowledge of which was reviewed by Critchley (1945), or to less common environmental problems such as those associated with escape from sunken submarines.

From this brief survey it will be seen that the structural features of warships are closely bound up with the requirements of the men. The acute space limitations, the need for securing watertight subdivisions of ships, the heat generated by machinery, and the limitations in the Tropics of ventilating procedures designed for temperate climates make it necessary to secure a sound compromise between meeting these requirements and building efficient fighting ships. We have reached a stage when satisfactory design can proceed only if precise and accurate data are available on the human requirements and limitations and if these can be translated simply into terms appreciated by engineers and designers.

The rapid strides in aircraft construction, shipbuilding, underground engineering, and under-sea activities, and the economic need for providing optimal conditions for workmen in many spheres, have shown that many of the environmental problems which beset the fighting services in war differ little from those of the civil community at peace.

It would seem appropriate that men with a medical education should play a large part in these studies, and in particular that the medical services of the Army, Navy, and Air Force should play a leading part in integrating the results of research work in the medical and physiological fields in the plans of those responsible for equipment design or concerned with maintaining operational efficiency.

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PERMANENT HOMONYMOUS QUADRANTANOPIA AFTER MIGRAINE

BY

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Migraine with visual hallucinations is reported often enough in the literature to need no further amplification. That it can have a permanent effect on vision is not. A case is here described of permanent homonymous quadrantanopia following 20 years of migrainous headaches.

Case History

The patient, a married woman aged 32, has had headaches since she first began to menstruate at about the age of 12. There is some relationship to her periods, but it is not absolute. The headaches have been getting worse during the past two or three years. They always develop in the same way: first there are "flashing lights," and as these fade a "haze" appears on the right side and spreads from above downwards and to the left. With the haze, or soon after, the headache ensues, beginning in front and radiating to the back of the head, becoming most intense occipitally. The patient recently noticed that the "haze" was permanently present wherever she looked and whether she had a headache or not. When I first saw her she had had this shadow in each eye, above and to the right, for about two years. She has been married 14 years and has two children (girls, aged 13 and 7); there have been no miscarriages. She was very thin up to the birth of the younger child, but during the next two years her weight rose from 7 st. 6 lb. (47 kg.) to over 10 st. (63.5 kg.), where it has remained for the past four or five years. Her periods are normal and regular. There is no polyuria or polydipsia.

On examination she was seen to be a well-nourished, placid, intelligent, and apparently healthy young woman. Eye examination revealed: R.V. 6/5, J. 1; L.V. 6/5, J. 1; emmetropic; orthophoric; pupils active to light, both direct and consensual, and to accommodation-convergence, equal and well sustained; Wernicke's hemianopic reaction could not be obtained; tension (digitally) normal; media and fundus of each eye normal and healthy. The blood pressure was 128/68. Night and morning specimens of urine were normal. The Wassermann reaction and gonococcus-fixation test were negative. *X*-ray examination of the skull showed that the pituitary fossa was exceedingly small, with ossification of the petro-clinoid ligaments. The only other abnormalities discovered were:

Peripheral Field.—1/330 mm. white was full and normal in each eye, except for a small absolute scotoma, homonymous and quadrantic in shape and less than 30 degrees, which was more satisfactorily plotted with the Bjerrum screen. Those for red, green, and blue were similar. Only the white is illustrated (Figs. 1 and 2).

Bjerrum Screen.—5/2000 mm. white, red, blue, and green were taken, but only that for white is illustrated (Figs. 3 and 4). The points to be noted are: sparing of the macula; the clean-cut edge along the 90 degrees vertical and 180 degrees horizontal meridians, and between these the absolute scotoma from 1 to 18 degrees; the relative scotoma for a further 5 degrees where the colour faded; its quadrantic shape, homonymous in character, and almost complete congruity. The colours followed an almost identical pattern.

Discussion

Migraine is usually considered to result from vascular instability, the headache being due to spasm of the arteries supplying the occipital cortex, or of the scalp and dura mater, or to irritation of the meningeal arteries following an initial dilatation which produces the sense of well-being. In the present case, however, there is just the possibility of friction on the left optic tract due to calcification of the clinoid ligament; but this seems somewhat unlikely, for the patient was re-examined at three-monthly intervals during the ensuing six months and no change was found.

Traquair (1933, 1942) states that the characteristic feature of optic tract lesions is incongruity, that the fixation area is more often affected when the lesion is in the anterior part of the suprachiasmal path, that homonymous quadrantanopia is found in damage to the calcarine fissure or to the radiation, that sparing of the fixation area of usually less than 5 degrees is almost constant in occipital hemianopias, and that isolated hemianopia is so rarely due to optic radiation and so frequently to occipital lesions that the latter position should be assumed as the site of the lesion unless there is other and stronger evidence, such as a wound, to implicate the former. While Peter (1938) states that perimetry definitely locates ophthalmic migraine in the visual cortex and that migraine is probably due to spasm of the small vessels in the cuneus and where the scotomata—quadrantic or hemianopic, always bilateral and homonymous—have become permanent, the repeated attacks of spasm in these vessels during the migrainous attacks have resulted in permanent occlusion of the vessel, with softening of the brain tissue, the functional now becoming organic.

It may therefore be safely assumed that in my case this is what has happened rather than the problematical suggestion of friction from an ossified clinoid ligament damaging the optic tract.

Review of the Literature

That there is a connexion between idiopathic migraine, epilepsy, and subarachnoid haemorrhage has been mentioned before. It is not the purpose here to discuss this, but to draw attention to the much greater frequency of hemianopias associated with migrainous headaches either of established or, most probably, vascular origin, irrespective of the age of the patient, and those associated, as in the case described, with idiopathic migraine in which the possibility of vascular origin other than vasomotor instability is most unlikely. Ormond (1913), quoting from his own and other observers' cases, mentioned nine in all, six of which,