AN ANALYSIS OF AN INFLUENZA EPIDEMIC IN THE NEW ZEALAND DIVISION OF THE ROYAL NAVY.

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(With 8 Figures.)

CONTENTS.

1. Introduction.

During the winter of 1926 (May to September) influenza of a mild type was epidemic in New Zealand and some of the South Pacific Islands. Four out of the five ships stationed in these waters were attacked. I should like this report to be considered more in the nature of an exercise in epidemiological method than as a serious contribution to our knowledge of epidemic influenza. The number of cases was too small to be sure that the percentages and averages obtained from them were not in some instances due to chance, rather than to the reasons which are suggested in this paper. With this caution in mind it is however interesting to note that the results of this analysis confirmed all the main conclusions on the spread of infection which I have reported in previous publications[1].

On the New Zealand Station H.M. Cruisers *Dunedin*, *Diomede* and *Philomel* are under the New Zealand government, and are manned partly by New Zealand born men. In addition there are two sloops, the *Veronica* and *Laburnum*, whose crews are entirely British. Officers serving on this station, both medical and executive, are convinced that the New Zealanders have less stamina, and are more prone to infectious disease than the British ratings. Though this is undoubtedly the case, as is shown by the figures in the medical returns, yet the obvious reason for this, namely, that a New Zealander, all other things being equal, has less resistance than a Britisher is probably wrong.

[1] Dudley, S. F. (1919), *J. Roy. Nav. Med. Serv.* **5**, 359; (1921), *Proc. Roy. Soc. Med.* (War Section), **14**, **37**.

The incidence of disease is only higher among the naval New Zealanders because they include all the recruits and junior ratings on the station; and I have shown elsewhere[1] that the incidence of infectious disease in the naval training establishments at home is nine times as great as among seasoned men in sea-going ships. Exactly the same phenomenon occurs in the New Zealand navy: the *Philomel*, which is the naval recruiting depot for New Zealand, suffers from much more infectious disease than the sea-going cruisers.

The events to be described are chiefly interesting because they show that this generalisation on the distribution of infectious disease is applicable to epidemic influenza.

2. ONSET AND GENERAL INCIDENCE.

Table I gives some details of the influenza outbreak as it affected the different ships on the station. H.M.S. *Diomede* was the first ship attacked, on May 28th. She contracted the disease at Apia, or Pago-Pago, in Samoa, 20 days after leaving Auckland. It is just possible the ship may have been infected with the influenza virus at Auckland because the disease was epidemic there, whereas, at the time of the *Diomede's* visit, influenza had not attracted any attention in Samoa. If such was the case, it means that the infection remained hidden in the ship as a "carrier epidemic" until the ship arrived at Samoa. However, it is simpler and more reasonable to suppose that the *Diomede* was infected with influenza at Samoa. Cases that would be called influenza during an epidemic, but something else at other times, are always turning up at most places, and were probably present in Samoa.

The *Diomede* arrived at Suva, in the Fiji Islands, on June 3rd. By June 10th 24 men, or 6·3 per cent. of the ship's company, had contracted influenza. The outbreak then apparently ceased. But on June 18th, seven days later, influenza reappeared and during the next 11 days 42 (11 per cent.) more men went down with the disease. In this way the epidemic in the *Diomede* was separated into two distinct groups of cases or epidemic waves. Fig. 1 records the distribution in time of the *Diomede's* influenza and patients, and shows that the two waves of the epidemic were separated by a week during which no case was reported.

The next ship attacked was H.M.S. *Veronica*, which was lying alongside the wharf at Suva. Her first case was reported on June 1st. Undoubtedly the *Veronica* was infected from the shore, as her early cases appeared before the *Diomede* had arrived at Suva. The epidemic in the *Dunedin* started on June 7th, just as the first wave of the *Diomede's* outbreak was subsiding. It is much more likely the *Dunedin* was infected from the shore than from the *Diomede*, because the latter was in partial quarantine, also the type of influenza in the *Dunedin* resembled that prevalent ashore more than the *Diomede's* type of influenza. The epidemic in the *Dunedin* consisted of one wave only, and lasted

[1] Dudley, S. F. (1926), The spread of droplet infection, *Med. Res. Council, Special Report* (in press).

25 days, during which time 82 cases or 20 per cent. of the ship's company were attacked. Fig. 1 records the incidence to compare with the *Diomede*. The *Philomel*, which is the permanent depot ship at Auckland, was not infected

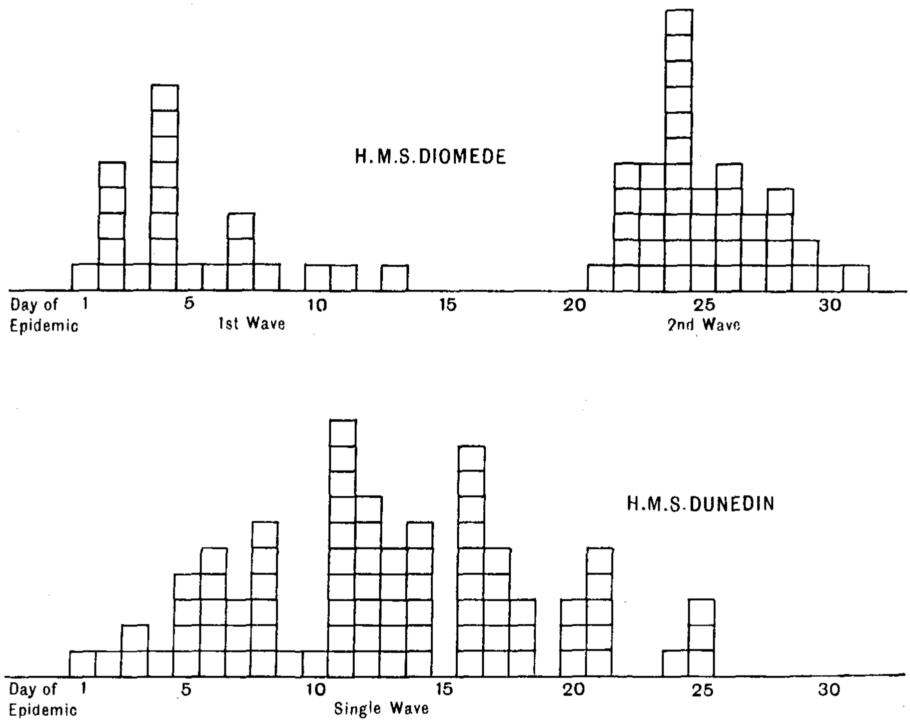

Fig. 1.

Note. Each square represents an influenza patient.

Table I. *Influenza in New Zealand Division.*

				Ship's complements					Influenza morbidity					
					British		New Zealand		Total		British		New Zealand	
Name of ship	Date of onset	Duration in days	Place where infected	Total No.	No.	%	No.	%	No.	%	No.	%	No.	%
Dunedin	7 June	25	Fiji	418	272	*65*	146	*35*	82	*20*	38	*14*	44	*30*
Diomede	28 May	32	{Samoa 1, Fiji 2}	383	285	*74*	98	*26*	66	*17*	42	*15*	24	*24*
Philomel	8 July	21	Auckland	164	107	*65*	57	*35*	34	*21*	6	*6*	28	*49*
Veronica	1 June	14	Fiji	101	101	*100*	0	*0*	7	*7*	7	*7*	0	*0*
Totals				1066	765	*72*	301	*28*	189	*18*	93	*12*	96	*32*

Note. The morbidity per cent. is in the case of the British and New Zealanders the incidence among the British and New Zealand groups in the ships, not of the total ship's company. In both instances the influenza cases of different birthplace formed 9 per cent. of the total naval population but the real incidence among New Zealanders was 2·5 times greater than among the British because there were 2·5 times as many British sailors in the squadron.

until July 8th, at a time when the other ships were away from the base. As Table I shows, the epidemic in the *Philomel* was practically confined to the New Zealand recruits; 21 per cent. of the ship's complement were attacked in

21 days. The remaining ship, H.M.S. *Laburnum*, escaped altogether, possibly because she was cruising among islands which were not apparently infected with influenza at the time. She did not touch Suva until the epidemic there was practically over.

3. INFECTIVITY.

When a word like infectivity is introduced into a discussion it is essential to explain what one means by it. Infectivity is used in this paper to denote an intrinsic character of a parasite whereby it is able to establish itself in a fresh host. Theoretically infectivity might be defined as the least weight of organisms required to infect a man of standard resistance under standard conditions. Practically therefore no actual number can be obtained to represent real infectivity. The apparent infectivity as distinct from an isolated attribute of a parasite, can be defined and estimated, as the number obtained when the attack rate per cent. is divided by the duration of an epidemic in days. Measured in this way apparent infectivity is the same thing as the average daily morbidity per cent. Apparent infectivity therefore depends as much on herd immunity (the degree of resistance of a population to the spread of disease), and on environmental conditions, as on the qualities of the infecting parasites. Hence in ships, because the type of population and the environment are very similar, apparent infectivities will probably be approximately proportional to the real infectivities of the biological agents responsible for epidemics.

For example, men on H.M.S. *Africa* and H.M.S. *Newcastle* were attacked by influenza under much the same climatic conditions.

The former ship had a morbidity of 75 per cent. in 13 days, the latter 51 per cent. in 14 days. The apparent infectivities were therefore 5·8 and 3·6 respectively. As all other factors were so similar it is legitimate to infer the infectivity of the virus responsible for the *Africa's* epidemic was greater than the infectivity of the *Newcastle's* influenza organisms. On the other hand, just because Greenwich school had 25 per cent. of boys attacked in 68 days, which is an apparent infectivity of 0·4, there is not a vestige of reason to suppose the organisms responsible for the influenza epidemic in H.M.S. *Africa* at Sierra Leone had a real infectivity 15 times as great as those which infected the Greenwich schoolboys—the type of population and conditions of living being so widely different. At Greenwich the infectivity relative to the *Africa* would be apparently increased since the former's type of population was more susceptible, but at the same time infectivity would be apparently decreased at Greenwich because the schoolboys slept in beds some distance apart, while in the *Africa* men slept in hammocks almost touching each other. In the New Zealand ships the apparent infectivities, estimated by dividing morbidity by duration, were: *Dunedin*, 0·8; *Diomede*, first wave 0·5, second wave 1·0; *Philomel*, 1·0; and *Veronica*, 0·5. Since infectivities up to 5 or more were common in ships during the big 1918 pandemic, the infective quality of the microbes must have greatly decreased, or the resistance of the population increased since 1918. For reasons that I cannot dwell on here the cause of the low apparent infectivity in 1926 as compared with 1918 is partly due to definite decrease in real microbic infectivity and partly to increase in herd immunity. The relative importance of these two factors is impossible to estimate. Like all epidemiological factors they must vary within wide limits for every complex of host, parasite and environment.

4. Relative Morbidity of New Zealand and British Sailors.

Table I (p. 134) shows that the attack rates among the New Zealanders in the ships which bore them were always larger than among the British ratings. Without further analysis these statistics might be used to support the belief that people born in New Zealand are more susceptible to influenza than English natives. But this will not explain another striking point in the table,

Table II. *Influenza in H.M.S.* Dunedin.

Group and ratings	Total ship's complements			British ratings			New Zealand ratings		
	Total No.	"Flu" cases No.	"Flu" cases %	Total No.	"Flu" cases No.	"Flu" cases %	Total No.	"Flu" cases No.	"Flu" cases %
Under 1 year at sea									
Boys	9	6	*67*	—	—	—	9	6	*67*
Ordinary seamen	18	11	*61*	—	—	—	18	11	*61*
R.N.R.	7	5	*71*	—	—	—	7	5	*71*
Total "Trainees"	34	22	*65*	—	—	—	34	22	*65*
Junior trained men									
Seamen	94	18	*19*	67	12	*18*	27	6	*23*
Stokers	56	9	*16*	31	2	*7*	25	7	*28*
Various	58	7	*12*	40	4	*10*	18	3	*18*
Total "Juniors"	208	34	*16*	138	18	*13*	70	16	*23*
Marines	40	5	*13*	40	5	*13*	—	—	—
"Seniors"									
P.O.'s and C.P.O.'s	114	17	*15*	72	11	*15*	42	6	*14*
Officers	22	4	*16*	22	4	*16*	—	—	—
Total ship's company	418	82	*20*	272	38	*14*	146	44	*30*

The italic figures give the attack rates among different groups of the ship's company. The table clearly indicates that immunity to influenza depended far more on seniority in the service than on place of birth or kind of employment.

namely, that the morbidity among New Zealanders in the *Philomel* was nearly twice as great as among those in the sea-going ships. This fact at once suggests that seniority, rather than place of birth in itself was the cause of the higher morbidity in New Zealand ratings because practically all the *Philomel's* New Zealanders were raw recruits, whereas the New Zealanders in the sea-going cruisers included many ratings of some years seniority. In order to see if seniority was more important than place of birth Table II was made. The Table shows that all the ratings in the *Dunedin* who had less than a year's experience of ship's life were New Zealanders, and that their morbidity was over four times as great as the rest of the ship's company—65 as against

15 per cent. Among junior ratings the New Zealanders had a morbidity of 23, as compared with 13 for English ratings. This was explained as being due to the fact that most of the younger seamen and stokers were New Zealanders, who had not been more than two years at sea; whereas all the Britishers in this group had spent at least three years or more at sea in the Royal Navy. When the most senior British and New Zealand ratings are compared, no significant difference in susceptibility, as indicated by the influenza attacks rates, is noticeable. These observations confirm a general rule which applies to all the infectious diseases on which I have been able to test it. In close sleeping quarters, such as prevail in ships, men are continually inhaling doses of all kinds of bacteria; these doses in most instances are too small to cause

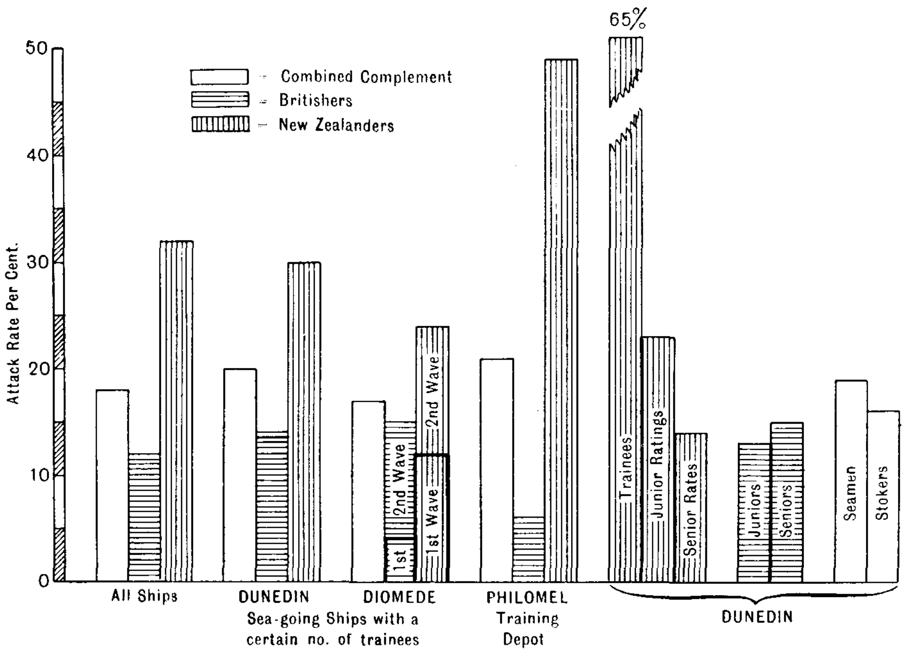

Fig. 2. Relative morbidities. Diagram demonstrating that New Zealand sailors were more susceptible to influenza because they had been less time in the Navy than the British sailors. The difference between 1st and 2nd waves of the epidemic in H.M.S. *Diomede* is also indicated.

symptoms of disease, but the tissues of those who inhale bacteria in sub-infective doses respond in the same way as they would to a prophylactic vaccine, introduced artificially with a hypodermic syringe. In this manner the resistance of the body to the subsequent invasion of the same, or similar microbes, is increased, so that when the doses of infection become larger, or the microbes themselves become more infective or more virulent, the "auto-vaccinated" or seasoned man is able to withstand their attack. The greater resistance of trained men, as compared with recruits, to disease and hardship is often attributed to the former's greater physical fitness. But physical fitness is probably of far less importance than adaptation to the masses of

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bacteria of all varieties and species which are always present in the sleeping quarters of ships and barracks. Athletically fit recruits, such as country farm hands or Scottish fishermen, often show less stamina under service conditions than weedy men from the London slums, because although the London slums are a better home than a battleship as regards the bacterial environment, yet towns have a denser pathogenic flora than country districts. Therefore adaptation to bacterial parasites will be more advanced in urban, than in rural, districts. Owing to many factors, especially mode of life, and even perhaps to comparative freedom from bacterial trauma, country recruits are physically fitter than town-bred ones. Here then is an interesting example of how incomplete knowledge of all the data can lead one astray: consider these two isolated observations and conclusions. First, among a body of recruits the morbidity was greater among the physically fit. Therefore physical fitness lowers resistance to disease.

Secondly, in a regiment it was found that recruits suffered more heavily than trained men from infectious disease. Therefore physical fitness increases resistance to disease. These diametrically opposite conclusions are shown to be false, while the observations which led to them are shown to be consistent with each other by the hypothesis that bacterial adaptation by previous auto-vaccination is a more important factor than physical fitness in determining relative morbidity. In fact physical fitness may be an almost negligible factor in such environments as ships (see also Section 6). Fig. 2 (p. 137) represents graphically some of the differences in incidence which have been discussed in the previous paragraphs.

5. The Effects of Admixture with Recruits on the Morbidity among Seasoned Men.

Recent work, by Topley[1] and his colleagues in England and by the staff of the Rockefeller Institute in America[2], has clearly demonstrated that one of the chief consequences of adding fresh mice to a mouse population which is recovering from an epidemic of mouse typhoid is a recrudescence of the epidemic—not only among the fresh susceptible mice, but also among those who have previously escaped, or recovered from, infection. My own observations at Greenwich suggested the same effect could be observed when boys were substituted for mice, and influenza for typhoid. The attack rates for the sea-going New Zealand ships are in accord with the above hypothesis. The morbidity among the seasoned ratings of the *Dunedin* and *Diomede*, who mixed freely with unseasoned recruits, was double the morbidity in the *Veronica*, who only carried seasoned British sailors (see p. 134, Table I). But, if this greater morbidity was due to the presence of recruits, how was it that the seasoned men of H.M.S. *Philomel* had the lowest attack rate shown in Table I, in spite of the fact that the *Philomel* contained the youngest and most

[1] Topley, W. W. C. (1926), *Lancet*, **1**, 477 (Milroy Lectures).

[2] Webster, L. T. (1924), *Amer. Journ. Hyg.* **4**, 134.

susceptible of the recruits? This anomaly may merely be a chance statistical variation due to the use of such small samples. But, on the other hand, the reason may lie in the fact that the *Philomel* is permanently at Auckland, and many of the seasoned ratings sleep ashore. Moreover, the *Philomel's* recruits are far more segregated from the seasoned men than are the trainees in the *Diomede* or *Dunedin*, who freely mix with the more senior ratings. The increase of morbidity among seasoned men caused by mixing with susceptible recruits is, after all, what might be expected. Most cases of infection will occur among the trainees of the ships which carry them but this very fact means that there will be an increase in the number of foci of infection, and that therefore the seasoned men in contact with recruits will be exposed more to chances of getting doses of bacteria sufficiently large to cause symptomatic infection than they would have been likely to have got if recruits had not been present. In other words, a decrease in herd immunity will be followed by an increase in the velocity of infection, which will enable a pathogenic parasite to produce symptoms in certain hosts, who otherwise would have either become carriers, or merely acquired increased resistance to the parasite by auto-vaccination.

6. DISTRIBUTION OF CASES IN H.M.S. *DUNEDIN*.

Fig. 3 is a diagrammatic plan of the living spaces in H.M.S. *Dunedin*. Except for the larger number of cases in the trainees' (boys and ordinary seamen) living space, the distribution of influenza cases was fairly even throughout the ship. However, should anyone still be inclined to believe the part of the ship itself was of more importance than its inhabitants' seniority in determining influenza morbidity, it may be pointed out that eight petty officers lived in the same place as the trainees in a screened-off mess of their own, and only one got symptoms of influenza. The type of employment also seems to have had little influence on a man's chances of escaping influenza. Table II (p. 136) shows that British stokers had a lower attack rate than the British upper-deck hands, whereas the New Zealand engine-room ratings had a greater morbidity than the seamen. Influenza attacked 19 per cent. of all seamen as against 16 per cent. of all stokers. The difference is not really significant but perhaps it might be suggested that the greater exposure of seamen to the inclemencies of the weather would tend to render them more prone to respiratory infections. It must, however, be remembered that this epidemic took place in the tropics, and one would have expected the stokers who worked in an engine room where the temperature was often over 100° F. to suffer most from infectious disease owing to the devitalising effect of the heat. The preceding observations provide an opportunity for a short digression. Again and again, during the last 20 years, evidence has been thrust upon me that natural or acquired *specific* resistance to a parasite is the main determining cause as to whether or not a man "catches" a disease. Though to me

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this seems an obvious fact, yet in text-books this factor is often scarcely noticed, while fatigue, exhaustion, malnutrition and hard living seem to attract far more attention than they deserve. That in many infections these latter factors may be important secondary causes is not doubted for a minute. But the minor degrees of such factors have probably far less effect than is

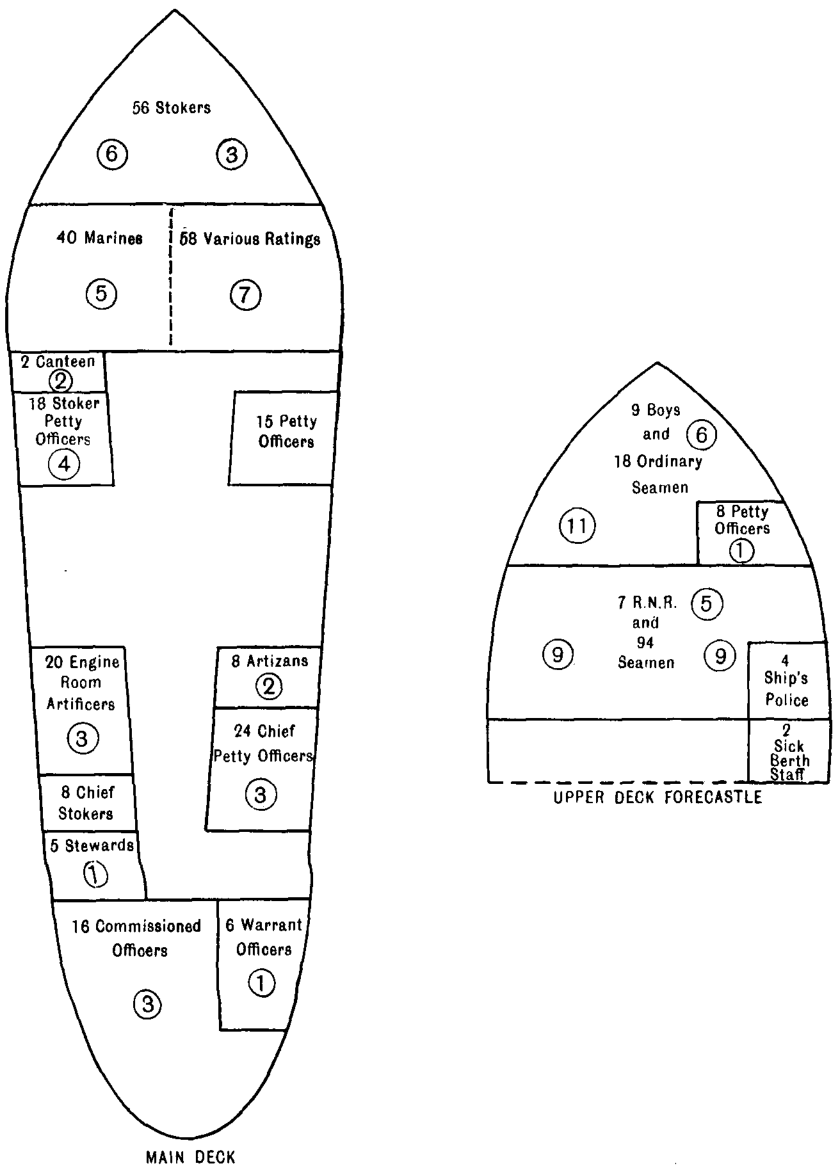

Fig. 3. H.M.S. *Dunedin*. Influenza outbreak 1926. Diagrammatic plan of living spaces on board. Enclosed areas represent mess decks or screened-in messes, with number and rating of men *inhabiting them. The larger numbers in circles record influenza cases occurring in the* corresponding areas.

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generally attributed to them. As regards guinea-pigs and rats Spaeth[1] has shown that preliminary exhaustion, or starvation, made the animals more resistant to infection with Type I pneumococci, provided that they were allowed to eat or sleep immediately after being inoculated. After all, no one has been overworked or underfed during peace time routine in the Royal Navy and yet where else will one find such large influenza attack rates. Therefore in the Navy at any rate malnutrition and exhaustion can only be very minor secondary factors. The determining factors of the large influenza morbidity in ships is the crowded environment which permits the dissemination of the infecting parasites in doses large enough to break down the specific defences of many individuals who could have resisted the usual doses of infection to be found in the average environment ashore.

7. VARIATIONS IN THE CLINICAL TYPE AND SEVERITY OF INFLUENZA OUTBREAKS.

Fig. 1 (p. 134) shows that influenza in the *Diomede* was divided into two distinct waves. I have already pointed out that the apparent infectivity of these two waves was different, being 0·5 in the first wave and 1·0 in the second. The patients' symptoms were also different in the two waves. In the first wave the temperature was in general higher and the pulse-temperature ratio lower than in the second wave. The victims of the first wave most commonly complained of severe frontal headache and post-orbital pain, and cough was rarely present, whereas in the second wave nearly every patient had an irritable cough and complained of a sore throat. Examination of the throat revealed nothing, or only a slight congestion. Headache was not a prevalent symptom of the second-wave cases. The symptomology of the *Dunedin's* single-wave outbreak was very similar to that of the *Diomede's* second wave. The infectivity of the *Dunedin's* single outbreak was 0·8—intermediate between the infectivities of the two waves in the *Diomede*. Therefore it would seem that the type of influenza which the *Diomede* contracted in Samoa was more severe, but less infectious, than the type the *Dunedin* contracted in Fiji; that when the *Diomede* arrived in Fiji she came in contact with a milder, but more infectious, type of influenza with the result that some men who had had sufficient resistance to resist the low infectivity of the Samoan influenza succumbed when attacked by the Fijian brand of the disease.

8. THE EFFECT OF ONE WAVE ON A SUBSEQUENT WAVE OF INFLUENZA.

If the incidence of influenza among the British and New Zealand ratings in each of the *Diomede's* outbreaks are compared, a peculiar phenomenon becomes apparent, as the following figures show:

Morbidity per cent.

1st wave	British	4	New Zealand	12
2nd ,,	,,	11	,,	12

[1] Spaeth, R. A. (1925), *Amer. Journ. Hyg.* 5, 839.

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During the first wave of the *Diomede* the susceptibility of the New Zealanders to attack by influenza was three times that of the British sailors. This is what would be expected from the study of the *Dunedin's* statistics, because the *Diomede* as well as the *Dunedin* carried unseasoned New Zealand trainees. But when the second wave arrived, apparently the susceptibility to attack had become practically equal in both groups. This apparent anomaly in the morbidity of the New Zealanders for the two waves can be explained as follows:

When a dense community on a ship is struck by a wave of influenza everyone becomes submerged in it; but those who have passed through a previous wave of infection, and have been able to profit by their experience, keep their feet with greater ease than those who have never been struck by a wave before. Those with no previous experience of waves of infection will be more numerous among the trainees than among the seasoned men. Hence the first wave will upset more trainees than seasoned men. But when a second larger (more infectious) wave arrives, all men will have had the chance of learning how to resist a wave of influenza. Only those who have been unable to profit by this chance, or too easily forgot their lesson, will be knocked over by the second wave. In other words the first wave turned the trainees into seasoned men. Thus when a second wave arrived the difference between the herd immunity of the trainees and trained men to a great extent was obliterated by the effect of the first wave, and the influenza morbidities became equal.

These *Diomede* figures are especially interesting because, in the absence of other facts, they would have suggested that the first wave of the epidemic had decreased, rather than increased, the resistance of the ship's company to influenza; seeing that the morbidity of the second was nearly twice that of the first wave. However, such a view becomes untenable when it is known that in the *Dunedin* the Fijian infection caused a 20 per cent. attack rate, whereas Fijian influenza was only responsible for an 11 per cent. rate in her sister ship, the *Diomede*; therefore the herd immunity of the *Diomede* had been considerably augmented by the previous wave of Samoan influenza. That the Samoan infection had increased the herd immunity of the *Diomede* is also hinted at by the fact that her combined attack rates for the two epidemic waves was less than that for the single wave of the *Dunedin*. The same phenomenon was noted during the great pandemic of 1918, namely, that ships which escaped the mild spring influenza of 1918 more often suffered a greater total morbidity if infected in the autumn or winter than the ships which suffered from both epidemic waves.

The fact that the New Zealanders in H.M.S. *Diomede* suffered no more than the British when exposed to the Fijian brand of influenza, whereas in the *Dunedin* the New Zealanders had an attack rate more than double that of the British sailors when exposed to the Fijian infection, is to my mind very strong evidence that the New Zealand sailors' herd immunity had been brought up to the same level as that of the British by passage through the Samoan wave of infection. These clues would lead us too far afield to be discussed further here but are introduced to show the extreme caution needed in interpreting epidemiological statistics. However, I am convinced it is only by studying and comparing carefully collected statistics and observations in which as many conditions as possible are constant, or known, and then devising the simplest hypothesis possible to explain the observed sequence of events that we can ever hope to control the spread of epidemics in space and time. But at the same time the mind must be always kept as free as possible from all bias, and when, as so frequently happens, fresh facts turn up which will not fit a theory one must never hesitate for a moment to modify, or even to discard for good, the most ingenious hypothesis or the most cherished of medical traditions.

9. ON MEASURING THE "SEVERITY" OF EPIDEMICS.

In any comparison between two or more groups of events, it is better if possible to choose some definite criterion which does not depend on individual judgments. For example, as previously noted, most of the early influenza patients in the *Diomede* differed from those in the *Dunedin* in complaining of headache but not cough. A vague statement like that covers about 90 per cent. of what one reads in the literature of clinical medicine. To make any real progress in epidemiology figures must be given in order to convey a quantitative as well as a qualitative idea of the differences between various groups of cases. The fatality rate is useful in so far as it does not depend in any way on the personal equation of different observers. But death rates are of only limited application, because in many epidemics no deaths occur. One epidemic may have very severe cases on the average, but few deaths. In another epidemic although deaths may be frequent yet the average case may be mild. One of the most useful measures in comparing the "severity" of outbreaks of disease is the average number of days each victim of an epidemic is off duty. In the services this number is always easy to obtain. Note that "severity" needs defining. As used above it means "incapacity caused by." It is a matter of opinion or definition, whether an all but fatal attack of cholera, which only keeps a man off duty for a month, is a more severe illness than an attack of undulant fever which, while giving no ultimate cause for anxiety, may incapacitate a man for a year or more.

In the New Zealand influenza outbreak the average days off duty were: *Diomede*, first wave 7·0, second wave 4·3; *Dunedin* 4·6; *Philomel* 6·0. This is another point in which the *Dunedin* outbreak was similar to the second wave of the *Diomede*. The average of days of sickness is, however, to some extent also affected by the personal equation, because medical officers will always vary in their opinion as to when a man is fit for duty. Even the same medical officer may have days when he feels inclined to send any patient who can walk back to duty, and other days when he keeps everybody in bed on the least possible excuse. I also found the average days off duty did not give a fine enough distinction when used to compare groups of cases between which the difference in "severity" was small. After some trials I came to the conclusion that a method based on average temperatures would be very free from personal equation, and at the same time give a fine distinction between groups of similar cases. The results of the initial trial of average temperatures are given below. They suggest that in the future this method might prove to be a useful instrument in epidemiology if it is employed with more accurate and fuller data. That is to say, all the temperatures should be taken four hourly and at the same time of day. Also at least four daily temperatures instead of one should be used for making "epidemic temperature charts." Since the epidemic temperature chart was not devised until the epidemic I first applied it to was over, the figures given in the subsequent paragraphs can only be rough approximations because a single daily temperature, taken at any time of day, was used in their compilation.

10. Epidemic Temperature Charts.

The charts depicted in Figs. 4 to 7 were made as follows. The highest temperature recorded each day for every case of a group was taken. Then the average of all the temperatures on the first day of illness was calculated and placed on the chart, and so on with the subsequent days of illness. Fig. 4 *A* gives the epidemic temperature curves of the first and second waves in H.M.S. *Diomede* and the single wave of H.M.S. *Dunedin*. The chart confirms the previously made impression that the early group of cases in the *Diomede* were more severe than those of the subsequent group. The average temperature of the latter cases was on each day nearly a degree below that of the earlier ones. The temperatures in the *Diomede's* second epidemic wave were even lower than those of the *Dunedin's* single wave; perhaps this was due to the immunising effect of the previous wave, which was non-existent in the *Dunedin*. There is another point worth noting in Fig. 4 *A*. First, the average temperatures of the *Dunedin's* cases did not fall until the second day of illness, whereas in both of the *Diomede's* waves the temperature was a degree higher on the first day than in the second. This parallelism between the *Diomede's* two temperature curves just hints that the later wave may possibly have been of the same type of influenza as the first, only modified by the immunising influence of the earlier outbreak. However, all the other evidence is in favour of a fresh type of influenza being introduced at Fiji, after the Samoan type had worn itself out. In many diseases it has been noticed that the severity of the symptoms seem to fall off as the epidemic approaches its end. The temperature charts given indicate that this was true of the New Zealand epidemic. In Fig. 4 *B* the curves in Fig. 4 *A* have each been broken in half. The broken lines represent the temperatures of the last half of each group of influenza patients. In each instance the broken are completely below the unbroken lines, which are the average temperatures of the first half of the whole groups given in Fig. 4 *A*. The milder nature of the second half of the *Dunedin's* epidemic is also indicated by the temperature dropping straight away from the first day of illness, whereas in the early cases it usually rose on the second day. The mildness of some cases towards the end of an epidemic is most rationally explained by supposing that, during the early stages of the epidemic, some men got partly immunised by inhaling subinfective doses of the causative microbes. Later on pure chance, or an increase in the number of infective

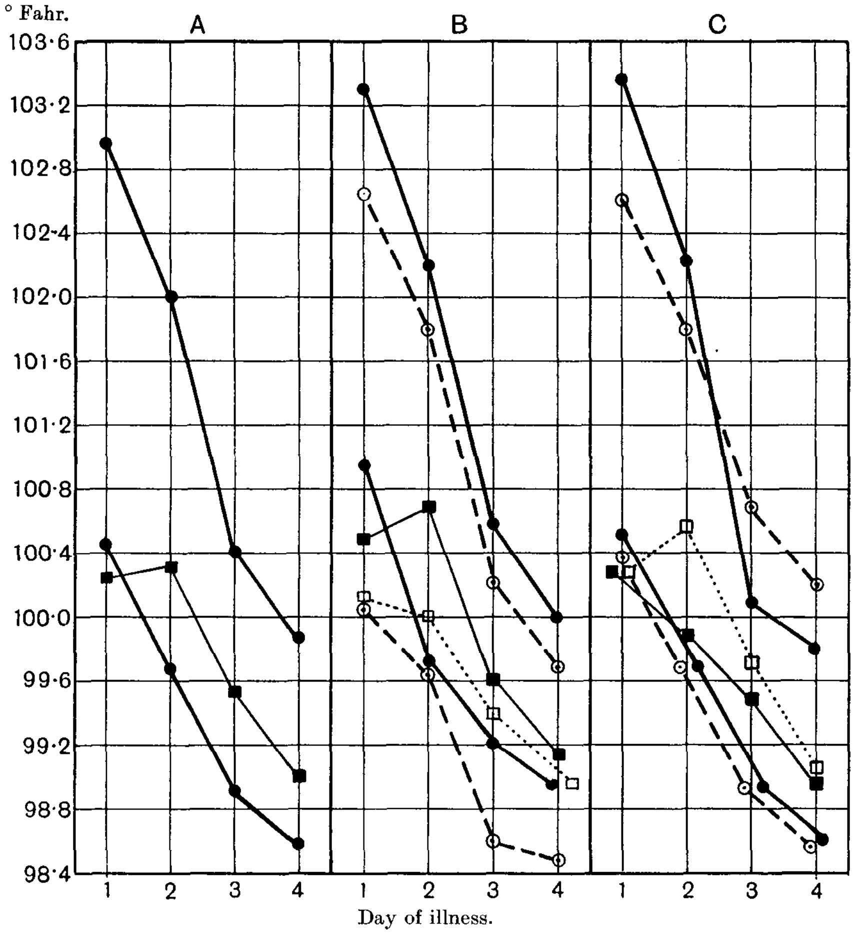
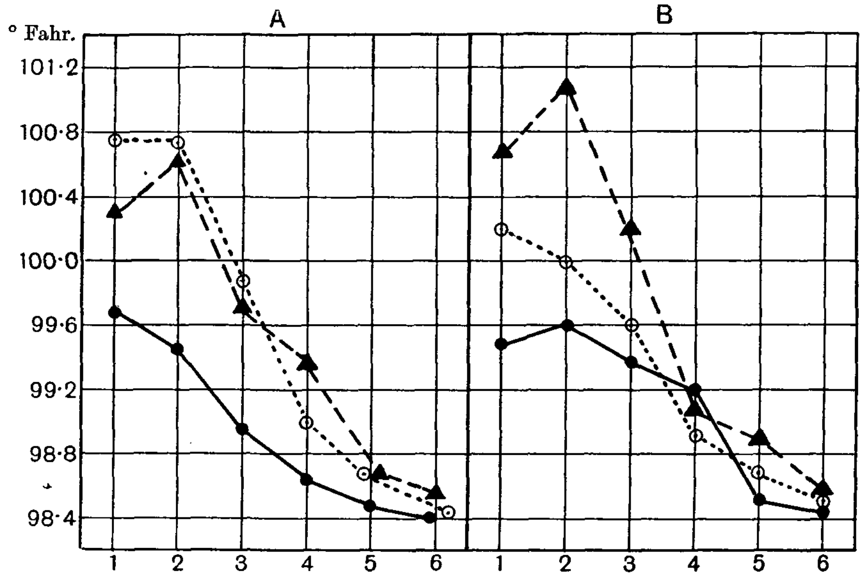


Fig. 4. Thick lines: *Diomede*; upper, 1st wave; lower, 2nd wave. Thin lines: *Dunedin's* epidemic. *A*. Total cases each group. *B*. Continuous lines first, and dotted lines second, half each group. *C*. Continuous lines, British; dotted, New Zealand ratings.

foci in the environment, increases the size of the infective doses received and accelerates the velocity of infection[1]. These men now succumb to a symptomatic infection which is however milder than usual owing to the increase of resistance produced by exposure to the earlier stages of the epidemic. In Fig. 4 *C* the average temperatures of the New Zealand are compared with those of the British ratings. In the *Diomede* the average temperatures of the

[1] Dudley, S. F. (1924), *Lancet*, 1, 1141.

two groups showed little difference. In the British affected by the first wave, the onset was apparently more severe than among the New Zealanders. The more acute onset was however counterbalanced by the more rapid fall of the temperature among British ratings. In the second wave the British and New Zealand temperatures coincided, which is of interest because the British and New Zealand morbidities were also nearly equal for this wave (see above). In the *Dunedin* the average New Zealander had a higher temperature than the average Britisher; also his temperature went up on the second day, whereas with the British the average temperature on the second was lower than on the first day. It is interesting to notice that, so far as the evidence goes, in both ships the New Zealanders (because they formed the bulk of the



Day of illness.

Fig. 5. H.M.S. *Dunedin*.

1st 27 cases = Broken line = 20 Trainees
2nd 27 cases = Dotted line = 34 Junior ratings
3rd 28 cases = Continuous line = 17 Senior ratings

A. Drop in heat production at end of epidemic. *B*. Heat production greatest in recruits and least in most experienced sailors.

junior and younger men) were more susceptible to attack, but once attacked it is only in the *Dunedin* that there is any indication that the symptoms were more severe than those of the more senior British ratings. I will not waste time in speculating on the cause of this difference, but would point out that observations of this sort afford useful hints as what to be on the look-out for when another opportunity occurs for studying a similar outbreak (*i.e.* one of the chief objects of studying one epidemic is to gain knowledge that may be useful for collecting data in the next). Figs. 5 to 7 were based on different samples of men in H.M.S. *Dunedin*; each sample was divided into three groups (except Fig. 5 *B*) according as the men reported sick during the periods in which the 1st, 2nd and 3rd group of cases of the whole epidemic arose. Fig. 5 *A* shows that the severity of attack did not fall till the last third of the epidemic. It may be mentioned that the first 27 cases were reported in 10 days, the next 27 in 5 days and the last 28 in 10 days. Therefore the middle third of the epidemic, measured by the number of cases, occupied only the middle fifth of the duration. Fig. 5 *B* shows that in the *Dunedin* severity of attack was correlated with seniority in the service. Fig. 6 compares the senior ratings *B*

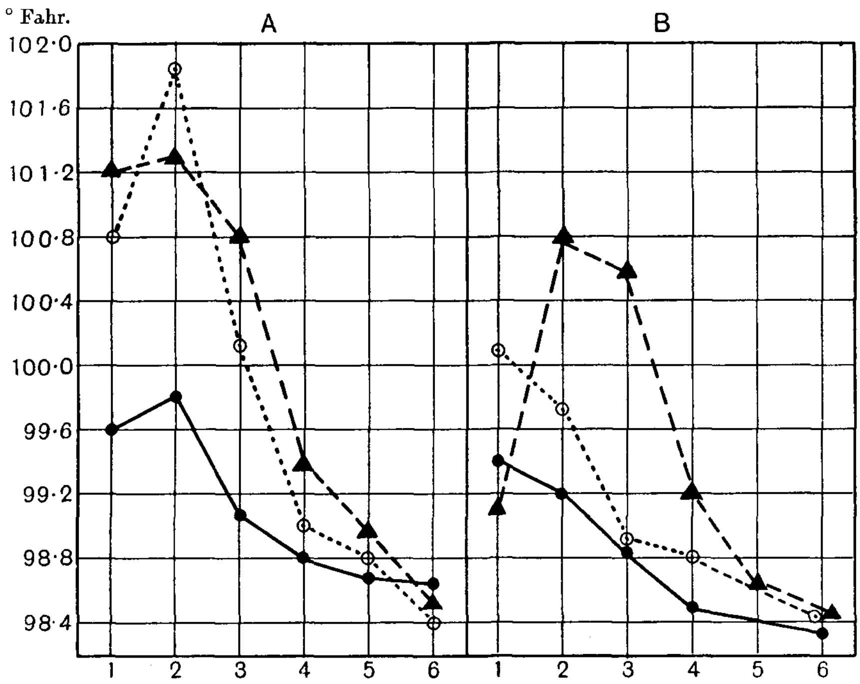
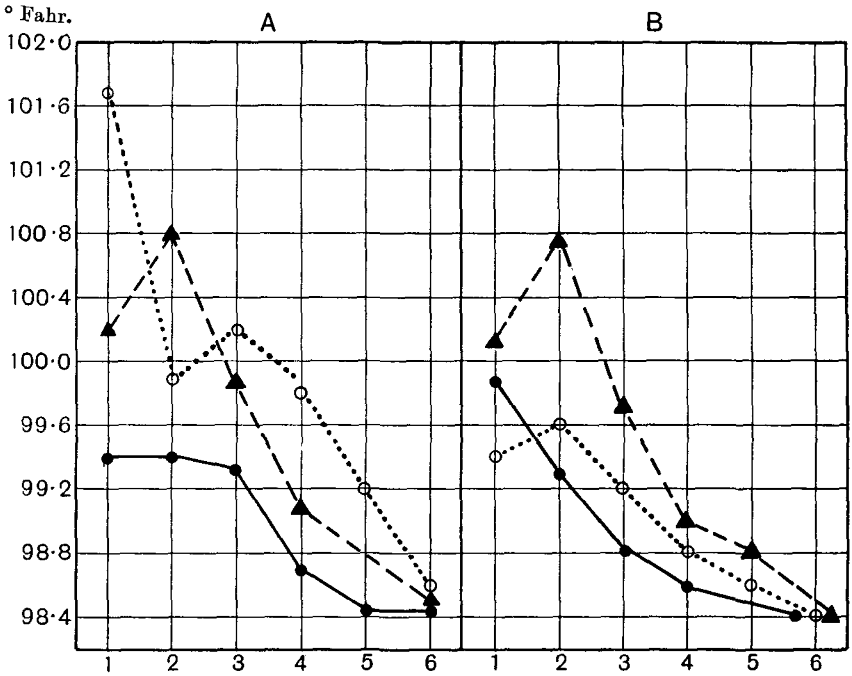


Fig. 6. H.M.S. *Dunedin*. Average temperature charts.

1st third of epidemic 9 = Broken line = 5
Mid third of epidemic 7 = Dotted line = 4
Last third of epidemic 6 = Continuous line = 8
A. Trainees. *B*. Senior ratings.

with the trainees *A*. The junior ratings of every period suffered more than the corresponding senior group. The exceptional temperature curve for the first period of the senior ratings is due to the fact that the small sample from which it was made by chance contained two of the more severe atypical cases of the epidemic. Though the numbers and differences are very small yet, before leaving Fig. 6, it is instructive to notice that the largest number of trainees were infected in the first group but the largest number of senior ratings in the last part of the epidemic. This phenomenon was seen to occur with both influenza and diphtheria among Greenwich schoolboys (Dudley, 1926, in press). When an epidemic attacks a community the most susceptible, who are generally the most junior, go down first. As the epidemic grows the amount of infective material increases, and senior members whose resistance to attack had been sufficient to save them in the earlier stages of the epidemic are now overpowered. Fig. 7 compares British (*A*) with New Zealand (*B*) junior trained men. If anything the British in this group seem to have suffered more severely than the New Zealanders but the samples from which the curves are calculated are very small and the differences are not statistically significant.



Day of illness.

Fig. 7. H.M.S. *Dunedin*. Epidemic temperatures.

1st third of epidemic 5	= Broken line	= 6
Mid third of epidemic 7	= Dotted line	= 6
Last third of epidemic 6	= Continuous line	= 4

British = Junior ratings = New Zealand

11. Heat Production as an Index of "Severity."

When the temperature of a man rises above normal it means that he is expending extra energy in the production of extra heat. The specific heat of man is somewhat less than that of water, but when allowance is made for the extra loss of heat due to convection, radiation, and evaporation, while the temperature is rising, it will not be far wrong to say that the energy expended in raising the temperature of 150 pounds of man through 2·0° F., say from 98·4° to 100·4°, is at least 300 pound-Fahrenheit calories. The energy thus expended is roughly equivalent to the work done in lifting 40 tons off the deck and placing it on a table 2·5 feet high (*i.e.* 100 foot-tons). Once the temperature is raised extra energy is required to maintain it. The amount will vary considerably with many factors such as the sweating of the patient, the weight of the bedclothes and physical conditions of the surrounding atmosphere. These fundamental facts are rarely in mind when one reads a clinical thermometer. However they are worth a moment's meditation because they help to explain the exhausting effect of fever, and the amount of work done in resisting microbic assaults. Also it would seem that the amount of heat production, or rather a figure proportional to it, would give a useful index for comparing the relative severity of febrile illnesses. If the temperature curve on an ordinary chart is presumed to be a continuous record then the area enclosed by the curve and its projection on the normal temperature line (98·4°) will be proportional to the amount of extra heat produced by the pyrexia.

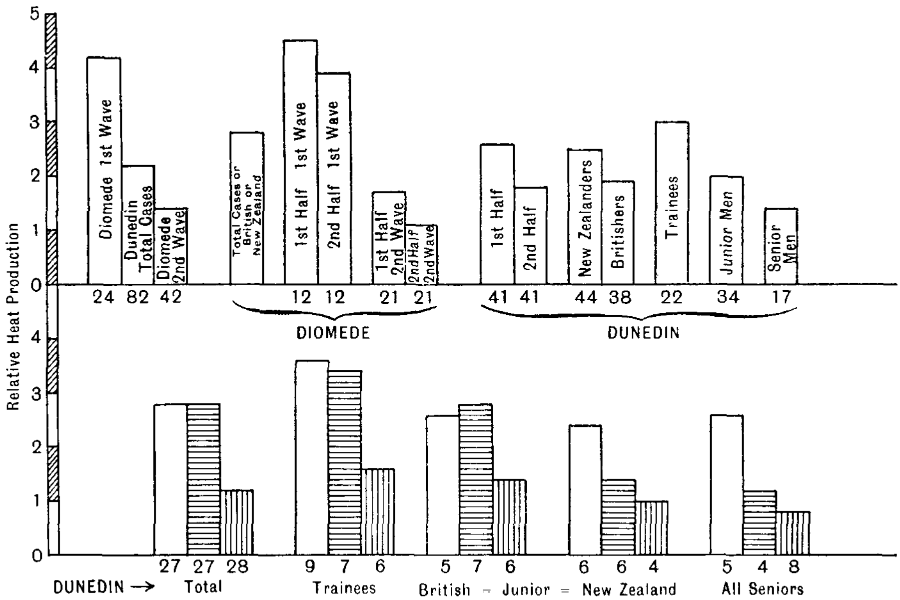


Fig. 8. Relative heat production. Height of columns = Heat production index first four days of illness. Figures at bases of columns give No. of men in each sample. (*Note.* Marines and officers are only included in first of lower five groups.)

Approximate values for these areas can be obtained by counting the squares enclosed between the 98·4° line and the charted temperature. Fig. 8 gives a series of columns whose heights indicate the relative amount of extra heat produced by the average man in the groups of influenza cases they refer to. Only the first four days of illness were used to calculate these "indices of heat production." The chief points worth noticing are that the average man in the first wave of the *Diomede's* outbreak produced about three times as much extra heat as a second-wave patient and about twice as much as a *Dunedin* case. That in the *Dunedin* epidemic the average heat production of the last

28 cases was half the average of the first 54. In all the groups the production of heat in the terminal epidemic cases was much less than that produced by the early cases. Finally these figures do not suggest that the morbidity of a group is always inversely correlated with the heat production of those who are attacked in the group. In the *Diomede* the morbidity of the New Zealanders was 24 per cent. as compared with British 15 per cent., while the heat production was the same. In the *Dunedin*, on the other hand, both the attack rate and average temperature were higher among the New Zealand ratings.

12. Summary.

The analysis of an epidemic of influenza in the New Zealand division of the Royal Navy confirms the following hypotheses which were suggested by previous studies of the same and other diseases.

(1) The type of influenza in different places, especially if they are more or less isolated areas, such as islands or ships, tends to assume special characters as regards infectivity, virulence, and clinical type[1]. In this respect the influenza virus, or viruses, are only following a well-known biological "law," namely, that isolation tends to encourage the evolution of new varieties and species. A classical example of this "law" is found in Darwin's reference to the fact that each island of the Galapagos Archipelago has its own special flora and fauna—similar to but yet different from that of the other islands.

(2) One wave of influenza, even if of a different type, will confer considerable immunity to a subsequent wave not only on the victims attacked, but also on those who apparently escaped infection during the first wave.

(3) The brunt of the morbidity of influenza (and other infections) is borne by recruits and junior ratings, not because they are, on the whole, younger, but because they have had less time than the senior men to adapt themselves, by means of auto-vaccination, to the bacterial environment of crowded ships or barracks.

The effect of bacterial adaptation to environment is often overlooked. Hence other factors, such as physical fitness, are often given more credit than they deserve as preservers of the public health.

(4) Senior ratings mixed with recruits suffer a higher morbidity from infectious disease than they do under similar circumstances in the absence of recruits. This statement, if true, should have a most important practical bearing on military medical administration. The phenomenon is probably due to increased velocities of infection (due to the higher infectibility of the recruits) breaking down the herd immunity of the senior men.

(5) In this epidemic New Zealanders suffered more from influenza than the British sailors not, as usually supposed, because of the mere fact of being

[1] Reference may also be made to the discussion of epidemics in ships contained on pp. 57–65 of the Ministry of Health's *Report on the Pandemic of Influenza*, 1918–19. Chapter 6 of the same report bears upon the problem of immunity. (Editor.)

born in New Zealand, but because all the recruits and the bulk of the junior ratings were New Zealanders.

The problems which this influenza epidemic presented suggested that a method, as free as possible from personal bias, would be useful for the purpose of comparing the relative severity of symptoms in different groups of individuals taken together. The procedure finally adopted consisted in averaging the temperatures for the same number of days of all the patients of a given sample and roughly estimating the relative amount of extra heat produced by this hypothetical average patient.

The preliminary application of this method seemed encouraging enough to warrant further careful trials of it should a suitable opportunity arise in the future.

In conclusion I must thank Surgeon-Commander G. D. Macintosh, M.B., R.N., for his courtesy and trouble in supplying me with the details of the *Diomede* cases.

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