VIBRATION SENSE AND FATIGUE

GEOFFREY KEIGHLEY, PH.D.[1]

IN the performance of many tasks, fatigue occurs although the amount of muscular effort is small. General fatigue of this character is attributed to fatigue of the central nervous system (1). It is difficult to evaluate. Examination of the responses to various stimuli is one of the ways which have been tried. It is not inconceivable that somewhere in the chain of functions from sense organ to response there is one which would be sensitive to fatigue, causing a change of the threshold, probably raising it. Vibration sensitivity is known to be altered by cold, (2,3) by increasing age (2,4,5), and by severe vitamin deficiencies (6,7). Roth (8) has said that during general fatigue the vibration sense diminished, and suggested that its measurement might be of importance in aviation medicine for the estimation of the fatigue level in flight personnel. He gives no figures showing such a decrease. The experiments reported in this paper were performed to test Roth's suggestion that vibration sensibility is diminished during fatigue, and to examine the simple quantitative method which he has devised.

The method which Roth described is not only simple but, as shown below, has a relatively small inherent error. He uses a 128 cycles per second (C.P.S.) tuning fork with a cross bar in the stem. To start it with the same amplitude of vibration each time, he strikes it against his hand with enough force to cause the two ends to click together. He suspends the fork between two of the subject's fingers; thus, hanging freely by the cross bar, the vibration is applied under constant pressure. He takes the time from the moment he strikes the fork until the subject no longer feels the vibration. The elapsed time is the threshold. With the standard fork, Roth found the threshold to be thirty-five seconds for normal young

[1] From the William G. Kerckhoff Laboratories of the Biological Sciences, California Institute of Technology, Pasadena.

people, with a range of three or four seconds. The thresholds are lower in other parts of the body. There is a decrease with age, and if the fingers are cold.

The pressure of the freely hanging fork is uniform. The time can be measured accurately with a stop-watch, started when the fork is struck against the hand, and held in the hand which is struck. There is the question of how uniformly the fork is started with this improved method. Tests of this uniformity were performed only after extensive practice had perfected technique.

Strain gauges were cemented to the outer sides of both tines of the fork near the stem (10). The wires of the gauges, running longitudinally, were alternately stretched and compressed as the fork vibrated, thus changing their resistance. The changes were recorded photographically with an oscillograph. The width of the trace on the record can be measured readily; it is proportional to the amplitude of vibration.

Several records were made. The beginnings of each trace varied somewhat, showing that even though the greatest care was taken in striking, the fork did not start with uniform strength. Roth recommends striking the mid-third of one prong against the hypothenar eminence with sufficient force to click the ends together. This method gave variations in amplitude of the order of ±9.0 per cent. If, instead of the mid-third the end of one prong is similarily struck, although the fork starts with somewhat less amplitude, the variations are of the order of only ±3.5 per cent. Consequently, in all the experiments reported further on, the fork was started by striking the end. No more force should be used than is enough to cause the easily heard click.

Variations in amplitude at the start mean that there are differences in the length of time the fork takes to drop to a level at which its vibration could no longer be perceived. It is necessary to convert the variations in amplitude into differences of time. The strain gauges cause some damping. The less damped vibrations, without the gauges, were measured with a microphone, amplifier, and output meter, by standing the vibrating fork upright on its stem on the back of the microphone, and taking readings of the output meter every five seconds. This is less accurate than using the strain gauges, but the mean of many runs gave a curve of the decay of amplitude with time which corresponds closely with the rate of decay when the fork is hanging from the fingers. Differences of amplitude between starts of ±3.5 per cent, from the strain gauge records, projected onto this curve, show differences of ±0.5 second in length of time taken to drop to a threshold amplitude.

This method of using a tuning fork is therefore sufficiently reliable and consistent to be used in making quantitative threshold measurements.

One of these 128 C.P.S. forks was used on three people to find the thresholds in the first two fingers, of right and left hands. Thresholds in both hands were determined once a day. Table 1 shows the comparisons; thresholds are given as the length of time in seconds the subjects felt the vibration. In one subject the mean thresholds of the two hands were equal, in the other two cases the differences were small, and not statistically significant.

The effects of fatigue were sought in the morning and afternoon

Table 1. Vibration threshold to tuning fork 128 cycles per second measured in seconds from time of striking to absence of sensation. Comparison of right and left hands.

Subject	No. of Times Tested	Thresholds in Seconds				Diff. of Means
		Right Hand		Left Hand		
		Mean	Standard Error of Mean	Mean	Standard Error of Mean	
J. J.	14	26.1	±0.7	26.1	±0.7	0.0
G. H.	19	36.9	±0.9	37.0	±0.7	0.1
J. D.	18	33.1	±1.0	35.1	±1.0	2.0

thresholds of a group of nine people (one male, J.D.). All were doing laboratory or secretarial work. Tests were made on the right hand only, twice a day for five or more days. Thresholds, from three or more trials with the fork hanging on the first two fingers, were measured in the morning starting at 9: a.m., and in the afternoon after 4: p.m. They are given in Table 2; all morning and afternoon thresholds are averaged for each subject.

If vibration thresholds were affected by fatigue, one might expect them to be consistently lower or higher at the end of a day's activities. They were not in the subjects tested. The differences, in seconds, between each subject's mean morning and afternoon thresholds, (D of the table), are not large. A ratio of the difference to the standard error of the difference (D/σ_D) of 2 or greater is commonly taken as significant. All the ratios are smaller than this. The changes are not even all in the same direction, eight out of the nine are positive, one negative.

There was no correlation between the results of the tests and subjective expression of fatigue which were volunteered or given in reply to occasional questions. It may be objected that, in spite of these subjective symptoms, the work these people were doing was

Table 2. Comparison of morning and afternoon vibration thresholds to tuning fork at 128 cycles per second, of nine people.

Subject	No. of Days	Mean Threshold—Seconds		D[1]	D^2/σ_D
		A. M.	P. M.		
F. A.	21	34.3	35.0	+0.7	0.7
M. K.	21	36.4	36.9	+0.5	0.5
V. B.	14	22.2	23.3	+1.1	1.3
J. W.	10	33.8	35.3	+1.5	0.6
H. R.	10	38.5	39.8	+1.3	0.8
G. H.	8	36.0	37.1	+1.1	0.6
J. D.	8	32.5	34.4	+1.9	1.2
J. J.	6	27.2	25.8	−1.4	0.9
M. E.	5	34.6	35.6	+1.0	0.4

[1] Difference between the mean thresholds.
[2] Ratio of the difference to the standard error of the difference.

not very hard, that they were accustomed to it, and that only moderate fatigue might be expected.

The results of a different experiment, summarized in Table 3, should meet these objections. The twenty-two men in this group went without sleep for four successive days. On two days before the experiment, and on each of the days without sleep they were tested each evening with the tuning fork. It was not practicable to repeat the test at the end, after they had had a night's sleep. The behavior and appearance of these men showed that they were under increasing stress, yet their vibration thresholds were not markedly changed. Their thresholds on the days without sleep differed from those on the days when they had had sleep, but the ratios of the differences to the standard errors of the differences are all less than 2, so the differences are not significant. Even though all the changes are positive they are too small to show any trend which can be associated with the increasing fatigue and strain.

In two experiments then, the first involving the fatigue brought on by the ordinary activities of a day's work, the second the cumulative fatigue of four days without sleep, the average thresholds before and after the fatiguing experience do not show any significant dif-

Table 3. Vibration thresholds to tuning fork at 128 cycles per second before and during four days without sleep for twenty-two men.

Day	Mean Threshold Seconds	D[1]	$\frac{D}{\sigma_D}$[2]
Five Days Before Start	27.9		
Day Experiment Started	28.3		
After the Following Number of Days Without Sleep			
1	29.8	+1.9	1.2
2	29.4	+1.5	1.0
3	28.2	+0.3	0.2
4	30.6	+2.7	1.9

[1] Difference of the mean threshold of each experimental day from the mean five days before of 27.9 seconds. If taken from the mean of 28.3 seconds the differences and the ratios $D/\sigma D$ are smaller.

[2] Ratio of the difference to the standard error of the difference.

ferences. Nor are individual changes reliable. The nine people in Table 2 were tested a total of 103 times; and their afternoon compared to their morning thresholds, were higher forty-eight times, lower forty-two times, and unchanged thirteen times; each of the nine had about an equal number of higher and lower afternoon thresholds. There was a similar random distribution of individual daily changes among the men who went four days without sleep.

These measurements at the fingers, made at 128 C.P.S., on two groups of people subjected to widely different degrees of stress, show that their vibration thresholds were not changed by the fatigue arising from the stress. Single day-by-day thresholds are unreliable for they may be raised or lowered. If the mean thresholds are taken of several people, or of one person over several days, the variations are less, though they may still not be consistently in one direction (*see* Table 2) and the differences are small and not significant (Tables 2 and 3).

Summary

The simple, quantitative method described by Roth for measuring vibration sense at one frequency has been examined for its inherent error, which is found to be relatively small.

This simple method was used on two groups of people undergoing widely different degrees of stress. No changes in vibration thresholds could be found as the result of these differently fatiguing experiences.

References

1. Simonson, Ernst: Industrial Physiology. *Annual Review of Physiology,* 1944, 6, pp. 543.

2. Keighley, Geoffrey: An Instrument for Measurement of Vibration Sensation in Man. The Milbank Memorial Fund *Quarterly,* January 1946, xxiv, No. 1, p. 36.

3. Weitz, Joseph: Vibratory Sensitivity as a Function of Skin Temperature. *Journal of Experimental Psychology,* 1941, 28, pp. 21.

4. Pearson, Gerald H. J.: Effect of Age on Vibratory Sensibility. *Archives of Neurology and Psychiatry,* 1928, 20, pp. 482.

5. Newman, Henry W. and Corbin, Kendall B.: Quantitative Determination of Vibratory Sensibility. *Proceedings of the Society for Experimental Biology and Medicine,* 1936, 35, pp. 273.

6. Fox, James C. Jr., and Klemperer, Wolfgang W.: Vibratory Sensibility, A Quantitative Study of Its Thresholds in Nervous Disorders. *Archives of Neurology and Psychiatry,* 1942, 48, pp. 622.

7. Shulack, Norman R. and Peters, Michael: Spinal Cord Changes in Avitaminosis. *Bulletin of the U. S. Army Medical Department,* 1945, No. 88, pp. 118.

8. Roth, Aaron: Measurement of Vibration Sense; A Method and a Means. *War Medicine,* 1943, 4, pp. 280.

9. Hathaway, Claude M.: Strain Analyzing and Recording Instruments. *Electronic Industries,* 1945, 4, pp. 74.