

The Scale Method as a Spectral Analysis for Accommodative Fluctuation

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ABSTRACT

A scale method of computer analysis was developed as an automatic spectral analysis system of the accommodative fluctuations. The scale approach employed a computer to identify wave peaks. Using this new system, spectral analysis of the fluctuations in accommodation measured by an infrared optometer was performed. Both the power spectrum method and the scale method were used to perform a spectral analysis and a wave form analysis. The spectrum peaks obtained by both methods were virtually coincidental. Twenty sec was adequate for the measuring time examined from the viewpoint of data stability. Fluctuations in accommodation were measured in 17 adult males. The mean peak frequency band range in 18 eyes of the young group was 2.5–3.15 Hz, in contrast to 1.25–1.6 Hz in 16 eyes of the middle-aged group. The newly developed system was considered effective as a criterion for visual load in VDT (visual display terminal) work and other high-level visual tasks.

Key Words: Fluctuations of Accommodation, Spectral Analysis, Infrared Optometer, Scale Method, VDT, Visual Load, Power Spectrum

INTRODUCTION

Present workplace conditions are undergoing rather sudden changes with the advance in modern microelectronics. Heavy physical work is on the wane, and work using the upper extremities, sensory organs, and sophisticated visual functions are on the increase. With this change in overall working conditions, a new examination method is needed which can determine objectively and easily the effects on visual functioning. The items measured in relation to visual work load included amplitude of accommodation, accommodative near point, accommodative far point, accommodation time, critical flicker fusion frequency, blinking, accommodative fluctuation of the crystalline lens, and convergence, among others. The accommodation-related measurement is likely the most promising method¹⁾. As the result of efforts to obtain an objective measuring procedure, two methods have been developed: one is the observation of the accommodative wave form measured by infrared optometer, from which it was noted that frequency lowered with fatigue²⁾. The other is a new method to measure objectively the accommodation time using a dynamic refractometer³⁾. Both of these approaches can be said to measure the feedback function of the accommodation system via

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the ciliary muscle. The former method by the infrared optometer is to assess the accommodative capability in the static condition, whereas the latter method is a measurement of dynamic accommodative capability. Thus, in the latter method, the subject must make a conscious effort to make the accommodative focus as fast as possible; this effort must be greater than in the static method. The present study focuses on the former analytical method dealing with accommodative fluctuation.

In evaluation of the results of measurement of accommodative fluctuation, the lowering of frequency has been measured by visual monitoring⁴⁾ as a conventional approach (i.e., a specialist observes the accommodative fluctuation, checks the wave forms visually, and measures peak-to-peak distance of the periodic oscillation with a scale). However, this visual method of evaluating depends heavily upon the specialist's experience and subjective judgment. The present authors have developed a new method for automatic abstraction of characteristics of the wave forms in accommodative fluctuation. A computer was employed to analyze frequency spectrum and wave forms by the scale method. This report presented the scale method of analysis of accommodative fluctuation as a new spectral analysis.

MATERIALS AND METHODS

1. Outline of System for Computer Analysis of Accommodative Fluctuation by Scale Method

1-1. Device for Measuring Accommodative Fluctuation

For the realization of spatial or kinetic vision, the curvature of the crystalline lens must be constantly changed for the accommodative oscillation. Campbell and Robson⁵⁾ developed the infrared optometer and made it possible to measure this oscillation peculiar to the accommodative function. The accommodative oscillations measured by this device have been called fluctuations of accommodation. Campbell and Robson indicated that their visual monitoring of the waves showed the constant presence of a rhythmical component with a frequency of about 1–2 Hz.

Using an infrared optometer (Kowa Optoron-2), the present investigators measured these fluctuations in accommodation.

1-2. Principle of Analysis of Fluctuations in Accommodation

The present authors employed the scale method for spectral analysis of the fluctuations in accommodation. As shown in Fig. 1, the scale method relied upon changes in slope and constriction of the triangular type configuration in determining the peaks. The analytical procedure using the scale method may be summarized as follows:

- 1) The downward point when the slope changes from negative to positive is considered the point of the wave trough (the valley of the wave). These are, in fact, $T_1 - T_{12}$ in Fig. 1(a).
- 2) Between two neighboring wave trough points, we seek to obtain the maximum level point as the peak P . For example, the peak between T_1 and T_2 is P_1 . Similarly, the peak is P_i between T_i and T_{i+1} . Figure 1(a) presents the initial processing stage. Within the wave interval between troughs there are no other wave trough points, so all hook-type intervals are taken to be single waves and their periods are measured. All of these measured periods are computed for separate band ranges, and the distribution is considered to be Scale 1.
- 3) All primary wave trough points are conjoined in order by a line. For the wave involved, the point at which the slope changes from negative to positive is considered a new wave trough point. In Fig. 1(b), the new wave trough points are $T_1, T_3, T_5, T_7, T_9,$ and T_{12} .
- 4) The point reflecting the highest level within the wave interval between these new troughs is considered the peak point. The peak points in Fig. 1(b) are $P_1, P_3, P_5, P_7,$ and P_9 . Using the

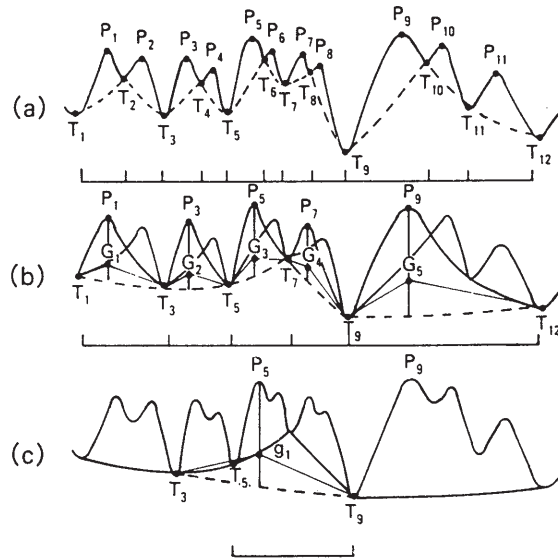


Fig. 1 Analytical procedure using the scale method.
 (a): Original wave and analysis as Scale 1.
 (b): Analysis as Scale 2.
 (c): Analysis as Scale 3.

center-of-gravity search system, the single and superimposed waves are distinguished. Thus, we obtain the center of gravity for the triangle formed by the two new adjoining wave trough points and the new peak point. For example, G_1 is the center of gravity between T_1 and T_3 . In relation to the line (T_1/G_1 and G_1/T_3) conjoining the center of gravity (G_1) and both end points (T_1 and T_3), it must be determined whether the other points of the wave are above the line in the intervals. In the interval between T_1 and T_3 , the other trough point T_2 is above the lines T_1/G_1 and G_1/T_3 , so the interval between T_1 and T_3 is a single wave interval.

In this way, all of the troughs and their intervals are investigated in Fig. 1(b), and single wave intervals are shown in the lower part of Fig. 1(b). Their periods are measured in separate band ranges, and the distribution in combination with Scale 1 is termed Scale 2.

- 5) Next, the wave trough points T_1 , T_3 , T_5 , T_7 , T_9 , and T_{12} are conjoined in order by a line. As with 3) above, as shown in Fig. 1(c), T_3 and T_9 are calculated as new wave trough points. Between T_3 and T_9 , the center of gravity is g_1 . It must then be determined whether other points of the wave are above the lines T_3/g_1 and g_1/T_9 . In the case of Fig. 1(c) the wave trough point T_5 is below the line T_3/g_1 , so the T_3 to T_9 interval is not considered a single wave interval. The T_5/T_9 interval, however, is a single wave interval. Its period is measured for separate band ranges, and combined with Scale 2 it is termed Scale 3.
- 6) Then the processing of the T_5/T_9 interval is undertaken, but completed because no new superimposed wave interval exists.

We developed the above scale method programming and programmed it into a personal computer (NEC PC-9801F2) to which we added a high-speed analog-digital converter module (Contec PC-Module AD12-16-98). The A-D conversion was done at a resolving power of 12 bits with a full voltage scale of $\pm 5V$ sampling period, at 50Hz.

2. *Actual Measuring Procedure*

2-1. *Actual Measurement and Analysis of Fluctuations in Accommodation*

In measuring fluctuations in accommodation by infrared optometer, there was output by means of voltage fluctuations. Signals were so weak that a preamplifier (Toyota KI-1) was needed to amplify them. The effective frequency range of the preamplifier and optometer was from 0.5 Hz to 48 Hz. The signals were monitored by oscilloscope, and at the same time recorded by a data recorder (Teac R-70A) on cassette tape. The data were entered into the computer after playback by the data recorder and following A-D conversion.

The scale method of computer analysis was used with "percent time" for the quantitative evaluation unit. The percentage was calculated by adding the cumulative peak-to-peak time for each frequency band in terms of measuring time (usually 20 sec).

The 0.5 Hz–4.0 Hz frequency was analyzed and, based upon the 1/3 octave band, divided into 9 band ranges: 0.5 Hz–0.63 Hz, 0.63 Hz–0.8 Hz, 0.8 Hz–1.0 Hz, 1.0 Hz–1.25 Hz, 1.25 Hz–1.6 Hz, 1.6 Hz–2.0 Hz, 2.0 Hz–2.5 Hz, 2.5 Hz–3.15 Hz, 3.15 Hz–4.0 Hz.

In the accommodative fluctuations, waves with short peak-to-peak time were initially analyzed on Scale 1, followed by individual waves with long peak-to-peak time. In this way, analyses were performed in order until individual waves of over 0.5 Hz could no longer be identified.

2-2. *Analysis of Same Wave by Both Scale Method and Power Spectrum Approach*

A young female (18 yrs) was made the subject of an analysis of the fluctuations in accommodation. Her right eye was fixed for 20 sec on a target 1 D inside from the far point. The testing room was sufficiently curtained off to result in appropriate pupil enlargement, and the fluctuations in accommodation were measured in the interim by infrared optometer.

The wave forms recorded by the data recorder were played back twice, and they were respectively analyzed by the scale method and by the power spectrum approach. The wave forms of both analyses were the same.

2-3 *Measuring Time*

The same measurement of the fluctuations as in 2-2 above was undertaken on a 19-year-old female subject. The data were stored in the computer memory and repeatedly analyzed from the same starting point. The scale method was employed for analysis of three lengths: 10, 15 and 20 sec, respectively.

3. *Measurement and Analysis of Accommodative Fluctuation in Adult Males*

Seventeen healthy adult males (34 eyes) were used as the subjects to measure the fluctuations in accommodation while at rest. Fixation was on a target positioned 1 D inside from the far point (20 sec, one eye). The measurements were made on each eye, and the data were analyzed by the scale method.

The subjects were split into 2 groups: 1) young men from 20 to 38 years of age; 2) middle-aged males ranging in age from 41 to 55 years. The first group consisted of 9 subjects (18 eyes), the second of 8 subjects (16 eyes). Mean age in the first group was 28.7 ± 6.8 years, against 50.6 ± 4.2 years in the second (mean \pm S.D.). The mean percent time of distribution was totaled for each of the two groups in terms of the respective frequency band range.

RESULTS

1. *Analysis of Same Wave with Both Scale Method and Power Spectrum Approach*

Figure 2 presented the results of analysis with the scale method and power spectrum approach, respectively, of the fluctuations in accommodation of the right eye of the 18-year-old female subject.

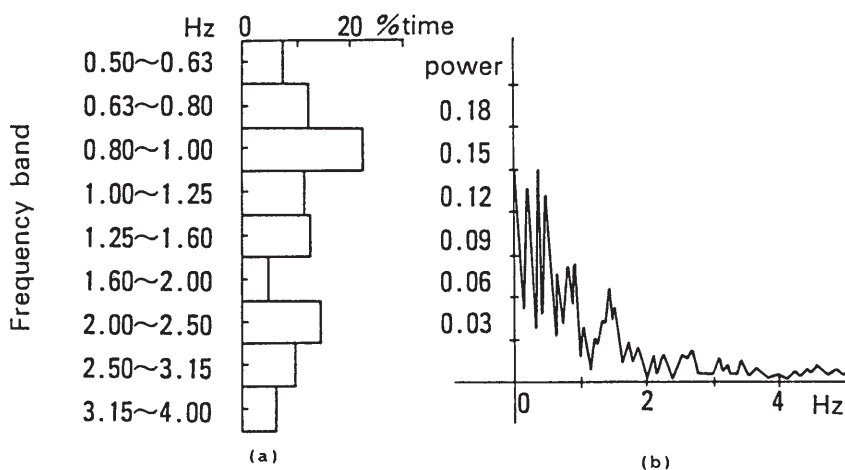


Fig. 2 Analysis of same wave by both scale method and power spectrum approach.

(a): Scale method.

(b): Power spectrum approach.

The peak frequency band range in the scale method was 0.8–1.0 Hz, and the peaks were found in the same ranges using the power spectrum approach. Although it was not clear from use of the power spectrum method, there were several small peaks in the 2.0–2.7 Hz range vicinity. In the power spectrum procedure, an extremely high value was noted in a remarkably low frequency band range (under 0.5 Hz), but this range below 0.5 Hz was outside of the scale method capability.

2. Measuring Time

Measurements of 20 sec were made of the healthy young woman's accommodative fluctuations. As seen from Fig. 3, the scale method analysis was conducted for the lengths of 10, 15, and 20 sec from the data's same starting point. As a result, in the 10-sec analysis, a sharp peak was noted between 0.8 and 1.0 Hz. A peak was always found around 2 Hz, no matter how long the analysis was, but there was a peak below 2 Hz in the 10-sec analysis, and another at over 2 Hz in the 15- and 20-sec analyses. The distribution was similar on the basis of the analyses.

3. Measurement and Analysis of Accommodative Fluctuation in Adult Males

The scale method analysis was used on measurements of fluctuations in accommodation in male subjects. Figure 4 indicated the mean percent time distribution for the respective frequency band range in the two groups (i.e., Group 1: 9 young males, 18 eyes; Group 2: 8 middle-aged males, 16 eyes). The peak frequency band range in the younger group was 2.5 to 3.15 Hz, against 1.25 to 1.6 Hz in the middle-aged group. Comparison of their peak frequency band ranges revealed that the older group had a significantly lower frequency ($P < 0.01$, Mann-Whitney's U-test).

DISCUSSION

Numerous attempts have been made to pinpoint objective criteria for asthenopia. These may be roughly divided into two methods which measure the accommodation function, refractive power, and other visual functions, and those methods such as error rate measurements which are based on performance. The fluctuations in accommodation under consideration here were studied using a

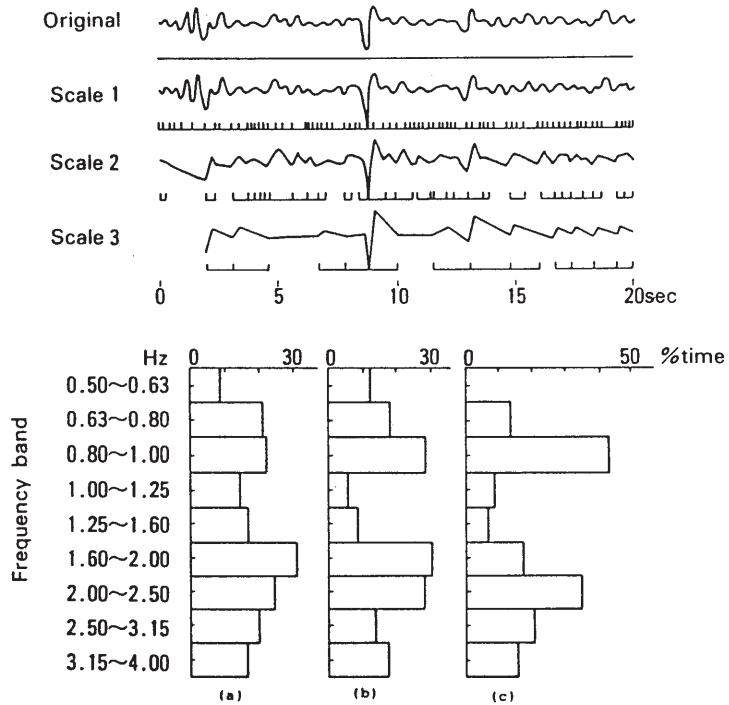


Fig. 3 Length of analysis time and scale method.
 Upper: Original wave for 20 seconds and scale method of analysis.
 Lower: Results of analysis by scale method.
 The three graphs (a, b, and c) are analytical results at 20 (a), 15 (b), and 10 (c) seconds, respectively.

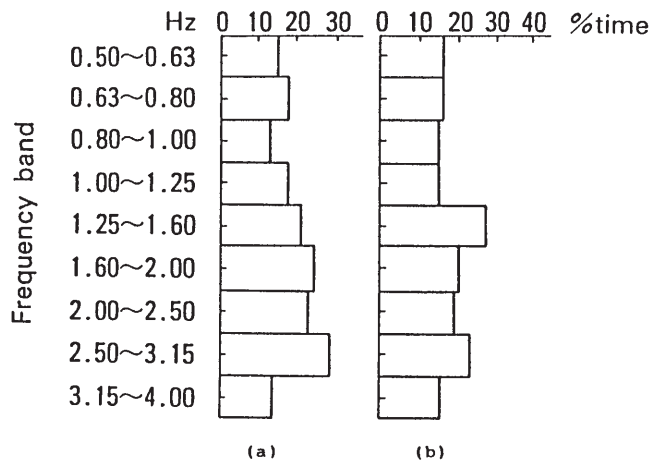


Fig. 4 Mean percent time distribution of young group and middle-aged group.
 (a): Group 1, nine young males.
 (b): Group 2, eight middle-aged males.

method falling into the former category, following the example of Campbell et al.⁶⁾, Suzumura⁴⁾, and Kurimoto et al.²⁾. However, conventional methods of measuring and evaluating the fluctuations in accommodation, not to mention their analysis, have had certain drawbacks. Campbell et al., for example, employed both the power spectrum and visual monitoring approaches; they used the visual monitoring for analysis of follow-up of the moving indicators, but for the determination of the peak frequency of high-frequency waves they used the results of power spectrum analysis. Their so-called high-frequency component was approximately 2 Hz (1.3–2.2 Hz). Kurimoto et al.²⁾, on the other hand, used a visual monitoring method and a frequency of 0.5–3.0 Hz for frequency analysis of accommodative fluctuation in order to determine asthenopia due to VDT work. They found that the frequencies lowered as the visual fatigue increased.

We used a scale method for analysis in the present study employing a mechanically simulated visual monitoring approach for the following reasons: Power spectrum analysis using Fast Fourier Transform (FFT) is basically applied to stationary wave forms; it requires that no matter which part is analyzed, a makeup ratio of the given wave component is stationary. This was called the ergodic theory⁷⁾. In the analysis of a biological phenomenon, it was often presupposed that ergodicity held. However, a biological phenomenon is complex, making it difficult to determine whether ergodicity indeed holds. For example, in the analysis of brain waves, the histogram method⁸⁾ was conventionally used as an analytical procedure because it fitted well the neurological stage classification of brain waves during sleep, and it was judged to be quite effective as such. This last approach basically correlates with the scale method under study here in terms of the object of analysis, namely, a wave form that is not stationary.

When accommodative fluctuation is analyzed using the simulation from the visual monitoring method as the basis, there can only be less than 10 long-period waves of about 0.5 Hz (2 sec period) in the course of 20 sec of data, from the theoretical standpoint; but, in fact, there are only around 3. Hence, in the scale method, the percent time value in this vicinity never increases very much. Still, in the lower spectrum method with FFT, data are presumed to be stationary, and the low-frequency wave power existing in the data becomes manifest on the whole. In this way, the time at which a low-frequency wave occurs or its duration is irrelevant. Thus, a spectrum with a trend different from that in the visual monitoring simulation results was obtained.

Suzumura has performed considerable research on asthenopia as an index of low-frequency “floating” accommodation. Initially, he used the visual monitoring approach⁴⁾. In 1980, the same author used a low bypass filter with a cutoff above 2.5 Hz to smooth out the wave form in “floating” accommodation, developing a device to emit a pulse at the moment the curve peak inclination changes from positive to negative⁹⁾. This method showed a good correspondence with the visual method, but the peak in some subjects was around 2.5 Hz, so distortion resulted in the high-frequency component at this level because of the low bypass filter. The scale method was a new computer analysis devised to avoid the drawbacks of these other conventional systems.

Analysis of the same wave by both the scale method and the power spectrum approach was presented in Fig. 2. The object in the scale method is the period in which the wave is manifest, while in the power spectrum method it is the power of the signal frequency component. Different though their objects may be, both methods employ frequency for spectral analysis, so the differences in spectrum with both were investigated.

Both methods managed to identify peaks in the vicinity of 0.8 Hz. As indicated under Results in connection with the 2.0–2.5 Hz range peaks identified by the scale approach, the use of the power spectrum method revealed several small peaks in the 2.0–2.7 Hz range. If these small peaks are added together, perhaps they tend to be similar to the results obtained by the scale method.

As for the handling of the results of frequency analysis, by the scale method, there is a one-third octave-based logarithmic scale, and as the wave reaches high frequency the real band range

amplitude increases; however, with the power spectrum, the frequency scale characteristically becomes the real value. Thus, for identification of a thin, sharp peak, the power spectrum capability can be tapped, while the scale method is appropriate to grasp the overall trend in spectra.

Campbell *et al.*⁶⁾ as well as Suzumura and Kobayashi⁹⁾ required 30 sec to analyze fluctuations in accommodation, compared with 20 sec in the present study. The target fixation load of the subject was lessened in the present study to prevent blinking^{6),10)}. The results in Fig. 3 reflect a stabilization at 15 to 20 sec, and 20 sec is considered suitable for analysis.

Campbell *et al.*⁶⁾ reported that, when the pupil was sufficiently dilated, a sharp peak band range existed around 2.0 Hz, whereas if the pupil were small this peak would disappear. The present investigators took this into consideration, darkening the testing room to enable adequate pupil enlargement to measure the fluctuations in accommodation. The reason for this peak's disappearance upon contraction was the avoidance of accommodative effort due to the great focus depth.

The results of comparison of the peak frequency in younger and older men (Fig. 4) revealed a lower peak frequency in the middle-age bracket. This finding of lower frequency with aging corresponded with the results of Campbell *et al.*⁶⁾.

The peak frequency band range in young men in the present study was 2.5–3.15 Hz, compared with 1.25–1.6 Hz in middle-aged men. Campbell *et al.*⁶⁾, and Suzumura and Kobayashi⁹⁾ set an upper threshold for frequency analysis at 2.5–3.0 Hz, both reporting peaks between 1 and 2 Hz. The fact that the present investigators used logarithmic frequency resolution may be one reason for the discrepancy with the results of Campbell and Suzumura. Suzumura and Kobayashi⁹⁾, on the other hand, employed a low-pass filter with a cutoff over 2.5 Hz. In this way, they found waves of over 2.5 Hz to be excluded from observation. This also serves to explain the discrepancies between the peak frequencies obtained by them and by the present investigators.

On the basis of the foregoing observations, the scale method of analysis of fluctuations in accommodation is considered effective as an objective evaluation approach simulating mechanically the visual monitoring approach to analysis. The Japanese Ministry of Labor¹¹⁾ announced its "Guidelines to Occupational Health in VDT Operation" on December 20, 1985. In its explanation of health examination methods, the Guidelines cited the analysis of fluctuations in accommodative frequency as a special means to investigate accommodative function. The scale method of computer analysis developed by the present authors falls well within the Guidelines set for analysis of fluctuations in accommodative frequency.

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