Posture Change Affects Indices of Pupil Size - Korean Males in Their Twenties

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Abstract

To determine the effect of posture change on autonomic activity and to investigate valid parameters to reflex the autonomic activity from time-series pupil size data, a posture-related experiment was performed with 15 subjects, which involved measuring their electrocardiograms and pupil sizes.

The experimental procedure consisted of three-sequence postures--supine, sitting and upright--for 5 minutes each, with rest sessions between postures. The subjects were notified of the entire experimental procedure.

The parameters of the subjects' heart rate variability showed significant differences between the postures (heart rate: 63-70-80 beat, normalized low frequency power: 28-50-75, normalized high frequency power: 72-49-25 and ratio: 0.5-1.2-4.4 in supine-sitting-upright position respectively) as did the parameters of their mean pupil sizes (41300-53900-53700 pixels respectively) and the major frequencies (the third trend: 0.23-0.2-0.18 Hz respectively) of their pupil size variability according to changes in their autonomic activities induced by posture change.

The experiment thus proved that posture change affects autonomic activity and that such activity can be estimated by the parameters of pupil size as similar as heart rate variability.

Key words: posture change, head-up tilt test, pupil size, heart rate variability, autonomic activity.

I. INTRODUCTION

Posture change [1, 2] and the head-up tilt test [3, 4] have been used to diagnose or estimate the autonomic functions related to the cardiovascular system. That is, the cardio- vascular function affects autonomic activity and vice versa. These tests cause the activity level of the autonomic nervous system to change into a specific state with reliability. In the posture or tilt test, the supine position causes the activity of the parasympathetic nervous system to dominate that of the sympathetic nervous system because of the lower load of the cardiovascular system. That is we can observe the decrease of heart rate and blood pressure in supine position. Moreover, in the upright position, sympathetic activity exceeds parasympathetic activity, contrary to the response from a supine position.

Even though any evidence has been found that cardiovascular system relates to pupil directly, it is reasonable to say that the change of central autonomic activity induced by the need of cardiovascular system affects pupil (and its size).

The question is, does this change in the autonomic activity induced by the posture-related stimulus affect the pupil (size)?

Many researches are being conducted on posture change [5], various pains [6,7], mental workload [8], emotional stimuli [9] and the autonomic system [10] using pupil-related parameters, because it is believed that the pupil reflects autonomic activity. In addition, other research groups use changes in the pupil size to diagnose neuropathy or dysfunction in diabetes [11], hypersomnia [12], Leber's neuropathy [13], Alzheimer's disease, Parkinson's disease [14], visual field loss [15] and migraine headaches. [16]

Although there are many reports that the pupil size reflects autonomic activity, no systematic research has been conducted on the relationship between posture change and pupil parameters, or on pupil-size-related parameters, except for the pupil light reflex.

Thus, this study focuses on the relationship between posture change and pupil-related parameters through a simple experiment, and investigates parameters of pupil size variability, which describes discrete pupil size both in the time domain and in the frequency domain, named for heart rate variability.

The hypothesis proposed herein is as follows: Posture-

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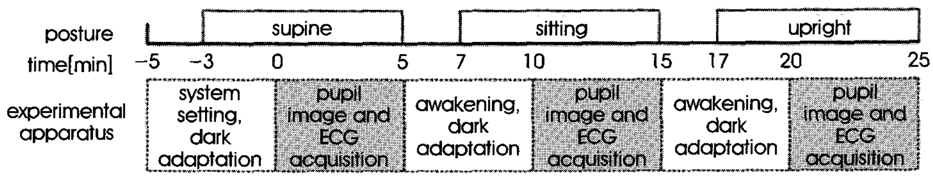


그림 1. 실험 절차
Fig. 1. Experimental procedure.

related autonomic activity affects pupil size variability, and its activity can be estimated by pupil-related parameters. Through the inspection of this hypothesis, parameters of pupil size variability will be proposed, which may replace heart rate variability (HRV) as a method of autonomic activity estimation.

II. MATERIALS AND METHODS

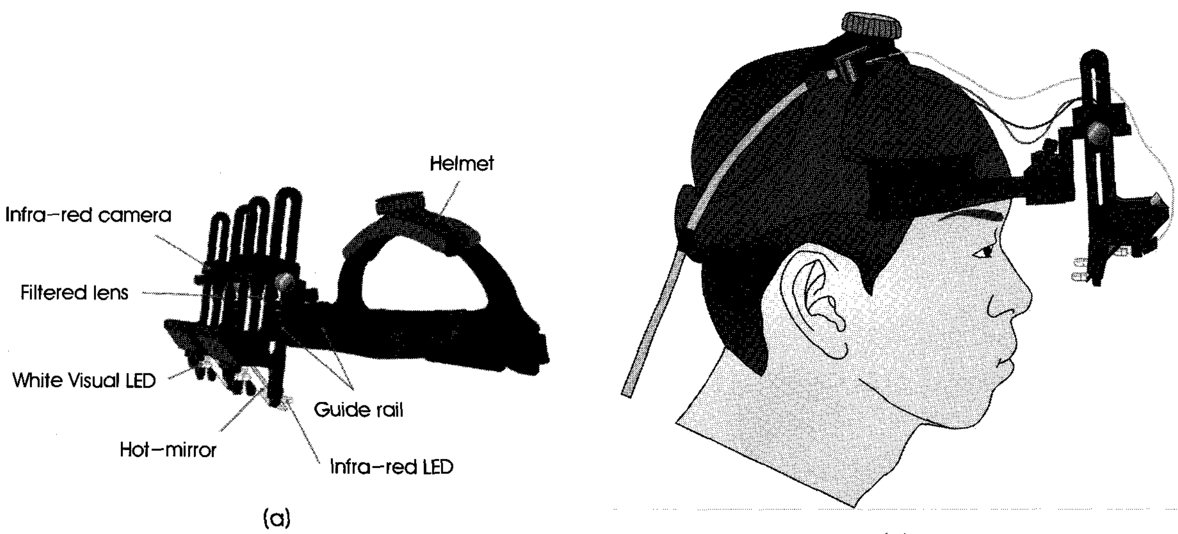
A. Subjects and Experimental Procedure

Fifteen healthy subjects (1 female and 14 male, aged 24.5 ± 2.4 years) participated in this experiment. None of them had a history of cardiovascular-related diseases and ophthalmic surgery. The subjects prohibited their drinking alcohol, caffeine and nicotine for three hours before the experiment, because these could affect the human autonomic nervous system. The systemic bias has to be minimized, which could affect autonomic activity.

Our experiment was performed in the dark room to control pupil. In this dark room, an illumination of 0.1 lux and a temperature of 24-25°C were maintained to create the proper conditions for the experiment and to prevent external noise. We maintain the subjects in specific postures, (lying on a bed, sitting on a chair and just standing) during experiment. Fig. 1 shows the experimental protocol.

All subjects agreed to participate in this experiment with consent form, and fully understood the experimental procedure. After each subject entered the dark room which has the proper illumination intensity. The subject posed in the prescribed position according to the instruction, and waited for 3 minutes to adapt to the internal illumination, the so-called dark adaptation, and to the posture condition. Afterwards, the subject's electrocardiogram (ECG) and pupil size were measured within 5 minutes for each type of posture. Two periods were placed between different postures. It was designed for awakening from possible sleepiness and former effect and for removal of effect on the former posture. The total experimental procedure thus lasted for 25 minutes.

The postures of the subjects during the experiment were



(a)

(b)

그림 2. 동공영상 획득시스템 (a) 및 착용 예 (b).
Fig. 2. The pupil image acquisition system (a), and its application (b).

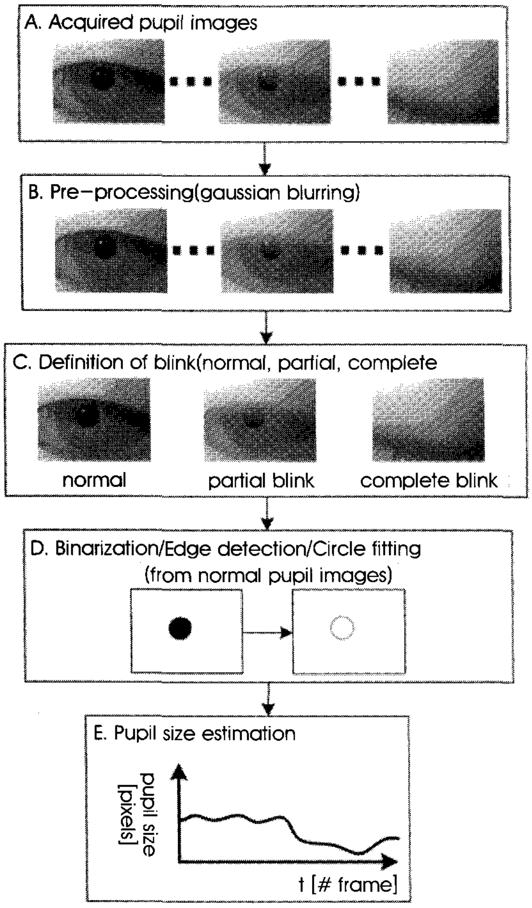


그림 3. 동공영상 저장시스템의 동공크기 예측과정. A. 시간순으로 데이터 로드. B: 노이즈 제거. C: 분석영상 선택. D: 이진화와 경계선검출을 통한 원적합. E: 동공크기 예측 (pixel or mm)

Fig. 3. The pupil size estimation process of the pupil image storage system. A: Load the pupil image file according to the time course. B: Gaussian blurring for noise reduction. C: Choice of the proper image for performing the image processing procedure, so that normal images would be selected and others skipped. D: Binarization for separation of the region of interest, edge detection and circle fitting of the normal pupil image. E: Estimation of the pupil size from the results in pixel or mm.

classified into three kinds: supine, sitting and upright. We defined the supine position as lying flat on one's back on the experimental bed with one's head on a pillow, the sitting position as resting one's bottom on the chair with one's upper body upright and with no back and head support, the upright position as standing one's back straight, so that no part of one's body is supported except one's feet respectively.

The ECG signal was acquired using ECG module, a Bioamp (AD Instruments, Powerlab/800, Australia) with a 1-kHz sampling frequency. Pupil images were acquired using the pupil image acquisition and storage system, which was specially designed in the authors' lab. [21] It consists of an infra-red camera and an illumination module, a hot-mirror module, a guide-rail module on the helmet, and a light stimulation module for light stimulation (Fig. 2). Specially, pupil image acquisition system we developed can be easily converted monocular into binocular system, vice versa. And it provides robust gray pupil image against visible ray's disturbances.

Our helmet system was designed for subjects wearing it to move their head and eyes freely and for our image processing to be robust against random head movements. It also gave the subjects a free field of front vision and weighed only about 130g, which means less invasive to unintended autonomic activation.

Pupil images were stored at 30 frames per second and were processed to estimate the pupil size (Fig. 3).

B. Data Analysis

A simple, general method was used to get the value of the HRV parameters, the procedure of which is as follows. First, the r-peak was detected from the acquired ECG signal and the time intervals (r-r time interval) between the r-peaks were calculated. These r-r time interval data were converted to even time-series data by interpolation and resampling, and information on the frequency-domain amplitude was derived using the Fast Fourier Transform (FFT, 1024 point). From the area

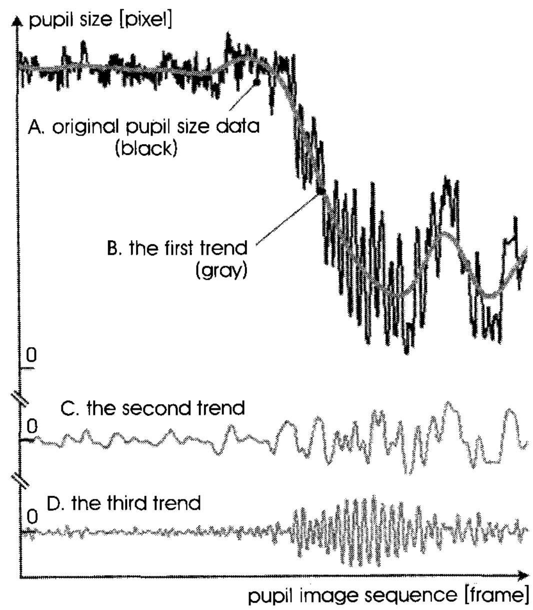


그림 5. 주요 트렌드 계산 방법 (예제). 원신호(A) = 첫번째 트렌드(B) + 두번째 트렌드(C) + 세번째 트렌드(D). (C)와 (D)의 평균값=0.

Fig. 5. An example of three major trends from the original pupil size data during 5-minute. Original data(A) = first trend(B) + second trend(C) + third trend(D). Mean value of second and third trend is 0.

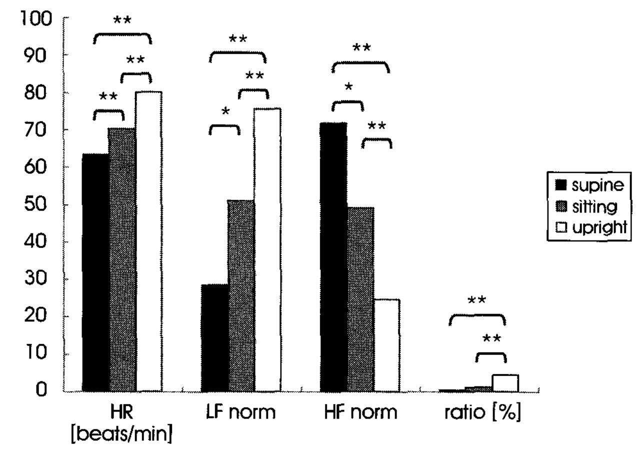


그림 6. 자세에 따른 HRV 분석 결과 (*p < 0.05, **p < 0.005).

Fig. 6. Results of the statistical analysis of the HRV for each posture (*p < 0.05, **p < 0.005).

(power) of the specific frequency band, which is generally fixed for HRV analysis, low-frequency (LF), high-frequency (HF), normalized-low-frequency (LFnorm), normalized-high-frequency (HFnorm), and ratio were calculated. [17] Additionally, the means of the standard deviations of the r-r interval (SDNN), the standard deviation of the mean r-r intervals (SDANN), the root mean square of successive differences between heart rates (RMSSD), and the mean heart rate (HR) were calculated. However, in this paper, the HR in the time-domain and the LFnorm, the HFnorm, and the ratio in the frequency-domain were selected as the main parameters in the interpretation of the experiment results.

The pupil size data can be also analyzed both in the time domain and the frequency domain, such as with HRV. The simplest method of analysis in the time domain is calculation and comparison of the (mean) pupil size itself. This method shows the absolute values and the trend of variations in the time course. From this parameter, simple information on the dilation and shrinkage of the pupil can be derived. In this paper, the mean pupil size during 5 minutes is used to compare the three kinds of posture (one mean-value per posture and three postures per subject). Analysis in the frequency domain of the pupil size is proposed lately [18] but not fully validated. We used their method in other experiments but we did not find any significance. Thus, we propose a parameter in the frequency domain, the so-called 'major frequency'. This is the attempt to represent the trend of pupil size variability (PSV) of a humans subjects' specific state as a single frequency. It can therefore give simple variability information on the PSV in a specific or entire data period (Fig. 4). Under the existing condition without any standard method for pupil analysis in frequency domain, finding such representative frequency is meant to reduce the noise information and to express the information more effectively, simply and intuitively.

Preceding studies related to pupil size in the frequency domain used only one type of pupil size variation [18]. In this experiment, however, three kinds of trends in size variations were used. The details of such are as follows. From the time-series pupil size data with analyzer's naked eye, the hardly changing trend was calculated and named the 'very low frequency trend (the first trend)'. The more frequently changing trend was named the 'low frequency trend (the second trend),' and the most frequently observed trend, the 'high frequency trend (the third trend)' (Fig. 5). The method used to calculate the three major trends from the original variation data is originated from the detrend method [19],

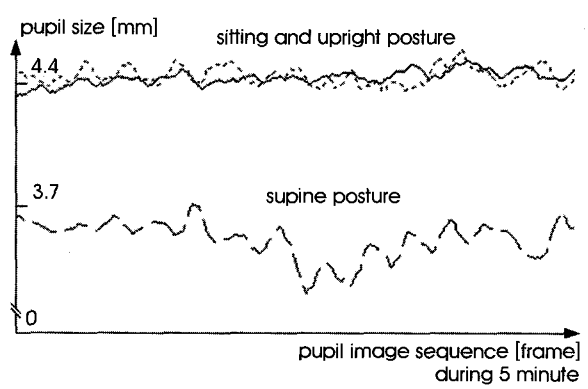


그림 7. 개인의 결과 예
(파선: 누운 자세, 점선: 앉은 자세, 실선: 선 자세, 1 pixel = 0.07mm).

Fig. 7. An example data of this experiment from one subject during five minute (Dashed: supine, dotted: sitting, solid: upright, 1 pixel = 0.07mm).

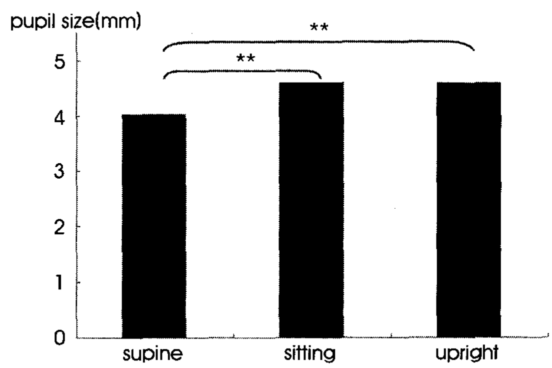


그림 8. 각 자세에서의 평균 동공크기
(*p < 0.05, **p < 0.005, 1 pixel = 0.07mm).

Fig. 8. The mean pupil size of each posture
(*p < 0.05, **p < 0.005, 1 pixel = 0.07mm).

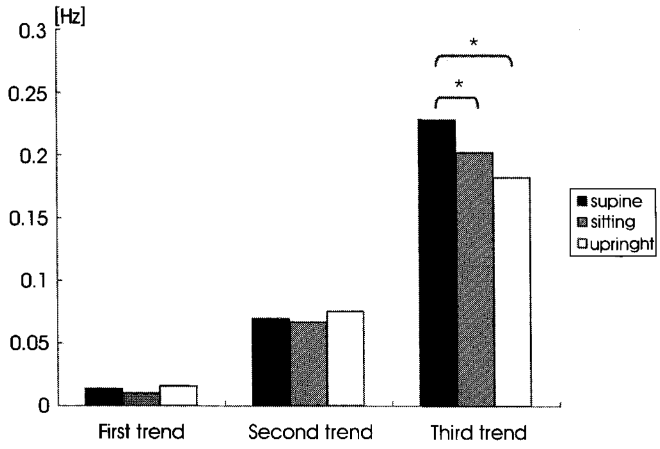


그림 9. 각 자세의 PSV의 주요주파수 (*p < 0.05, **p < 0.005).
Fig. 9. The major frequency of PSV for each posture (*p < 0.05, **p < 0.005).

which proposed the finding of the trend in the r-r interval data from the ECG signal to analyze the HRV. As a result, in this paper, the first trend represented the variations of 0 Hz to 0.05 Hz, the second trend represented the information on 0.05Hz to 0.15 Hz, and the third trend represented the variations over 0.15 Hz. Its criterion is determined empirically by our own in-house analysis of other experiments, so it was not from conventional frequency bands of HRV analysis. Practically speaking, the first trend gives information on average of pupil size in a specific phase so that it can hardly be observed during each experimental period (5 minutes) which average of pupil size is relatively fixed. The second trend and third trend, on the other hand, provide dynamic information.

A statistical analysis was performed using the paired t-test to ensure differences in the responses in the supine, sitting and upright postures. Forty-five data from 15 subjects and 3 types of postures for each subject were used for the statistical analysis of the selected HRV parameter (HR, LF_{norm}, HF_{norm} and ratio) and PSV parameter (mean pupil size, major frequencies in three trends).

III. RESULTS

A. Result of HRV Analysis

The time-domain parameter of the HRV analysis selected in this paper is the heart rate (HR), and the frequency-domain parameters selected were the LFnorm, the HFnorm, and the ratio. Fig. 6 shows the results of the statistical analysis of each posture.

There were significant differences in most parameters of interest in the supine and sitting postures. That is, as the supine posture changed into the sitting posture, the LFnorm and the HR increased and the HFnorm decreased. As the sitting posture changes into the upright posture, the LFnorm, the ratio, and the HR increased and the HFnorm decreased. Moreover, the results of the supine and upright postures showed a higher LFnorm, ratio, and HR and a lower HFnorm with the upright posture. As a result, most parameters of HRV showed significant differences between postures.

B. Result of PSV Analysis

The time-domain parameter of the PSV analysis in this paper is the mean pupil size, and the frequency-domain parameters are the major frequencies in each trend. In the time-domain analysis, as the supine posture changed into the sitting or upright posture, the mean pupil size varied. In particular, as the supine posture changed into the sitting or upright posture, the pupil significantly dilated (Fig. 7 and 8). As the sitting posture changed into the upright posture, however, there was no significant difference in the pupil size.

Among the three types of trends, only the third trend showed significant differences in some cases, such as between the supine and the sitting postures, and the supine and the upright postures (Fig. 9). The major frequency of the third trend in the supine posture showed a larger value than that of the sitting and supine postures. This means that in the supine posture, the pupils shrink more frequently and dynamically than in other postures.

IV. DISCUSSION

A. Posture Change

According to earlier studies, posture change such as from supine to sitting to upright affects autonomic activity, physically through the cardiovascular system [1,2] and emotionally through the expectation and anticipation of posture [20].

In general, posture change from supine to sitting or upright immediately decreases blood pressure and the blood supply in the brain. If blood pressure decreases, the baroreceptors are inactivated. Then the Homeostasis of the human body increases the heartbeat and blood pressure to compensate for the shortage. As a result, the activity of the sympathetic nervous system increases. Moreover, the muscle contractions for maintenance of the posture and for balance of the body in the sitting or upright posture increases the activity of the sympathetic nervous system.

The center of blood pressure modulation is in midbrain (nucleus of the tractus solitarius, NTS) and the relationship between NTS and heart seems evident. So cardiovascular responses induced by posture change can be easily expected. But the relationship between cardiovascular center and pupil is not clear.

The sitting and upright postures need a higher degree of activation of the sympathetic nervous system than does the supine position. There is little difference in the degree of its activation, however, since to maintain the upright posture, the cardiovascular and muscular systems have to be more activated than when maintaining a sitting posture.

In this paper, an experiment involving different postures in sequence (supine-sitting-upright) was performed. Different postures were expected to require different autonomic activities and such HRV and PSV are expected to show different values in various parameters. The results of the experiment showed that the compensation mechanisms of the body induced by changes in posture may arise in all subjects.

The experimental procedure was explained to subjects. Thus, all the subjects understood the entire procedure. Moreover, the ECG and pupil size were measured after the subjects' stabilization and adaptation. It can thus be thought that the responses during the experiment were caused by physical factors such as the cardiovascular or muscular system and not by any expectation or anticipation induced by the experiment.

The reason for the change in the pupil size induced by posture change can be considered from the neurological point of view (central and peripheral interference).

If the peripheral cardiovascular receptor activate or inactivate by posture change, the cardiovascular modulation center (NTS) responses to that input signal. Then well-directed output signal will be transferred to target organs. In the brainstem, cardiovascular modulation center (NTS) and pupil size modulation center (Edinger-Westphal nucleus, EWN) can affect each other. This process can be thought as a central interference.

When the posture changed, the cardiovascular and muscular states also changed to compensate for shortages and to maintain the homeostasis. For example, if the activity of the sympathetic nervous system has to increase according to the compensation mechanism, the cardiovascular-related sympathetic center in the brain transmits a firing signal to the sympathetic ganglion. Then the innervated organs such as the heart and the pupil-dilate muscles also respond to the firing signal. Because sympathetic network around sympathetic chain is widely innervate too many organs. Thus, during this mechanism, as the heart-related functions increase, the pupils dilate as a side-effect. This can be thought as a peripheral interference of autonomic activation.

B. HRV and PSV

The purposes of this paper are to confirm the differences in pupil-related parameters according to posture change and to propose new parameters, which can replace the HRV analysis. The results of the HRV induced by the experiment were seen as a gold standard and were used to interpret the meaning of the proposed parameter of the PSV.

Pupil size is a generally used parameter in quantitative analysis in pupil-related autonomic study [8-10]. According to the results of the experiment conducted for this paper, pupil size can be a good and simple index for classifying postures between supine and other postures. It does not show any difference, however, between the sitting and upright postures. Thus, pupil size alone cannot adequately estimate autonomic activity.

The concept of 'major frequency' was also proposed as an index of PSV by us. As a result, the third trend, which is closely related to dynamic variations in pupil size, shows some significant results. It shows the same pattern as that of pupil size, which cannot distinguish between the sitting and upright postures. In the lower significance level ($p < 0.5$), however, it shows a difference between the sitting and upright postures.

As a result, it seems that pupil size is positively-related with the sympathetic activity, and spontaneous dynamic variation (third trend of pupil size) is positively related with the parasympathetic activity.

This experiment proved that posture change affects autonomic activity and confirmed that there are some differences in the aspects of pupil size change. A new index related to PSV for estimating autonomic activity can thus be proposed, such as HRV proper. Moreover, this paper proved that if someone wants the autonomic activity of a subject to change into specific states to perform the experiment and interpret the results, the proper level of autonomic activity could be induced and controlled by maintaining a specific posture.

V. CONCLUSION

A simple experiment was performed to prove that posture change affects the activity level of the autonomic nervous system.

The experiment was performed with 15 healthy young subjects in a dark room in which the intensity of the internal illumination and the temperature were maintained. The subjects participated in the experiment with a full understanding of the entire procedure. The subjects maintained three specific postures--supine, sitting, and upright--during the experiment, and ECG and pupil image of each subject were acquired. Each posture had to be maintained for 5 minutes, and the subjects were asked to awaken physically and emotionally at the inter-posture period to prevent the manifestation of the effects of the previous posture. Moreover, before the onset of the 5-minute measurement time, the subjects have to wait for 3 minutes to make them stable and able to adapt to the posture. The total experiment period was about 25 minutes.

The acquired data from the experiment were analyzed, using the paired t-test method, against each of the parameters of HRV and PSV to ensure the significance of the results. As a result, some significant differences between the results of the HRV and the PSV were observed, and it was proven that PSV can be an appropriate methodology for estimating autonomic activity. With more elaborate and refined studies, PSV-related meaningful indices can be proposed that could solve the problem of the low temporal resolution of HRV, which uses r-r interval information that gives us maximum 2 data per second.

The experiment was performed continuously for 25 minutes, however, in the supine-sitting-upright posture sequence. Thus, fatigue from the long duration of the experiment may have caused bias in the results. Moreover, the process of extracting three trends from the original pupil size data was conducted in an empirical manner. And it seems that the frequency band of PSV is similar with that of HRV. That is maybe the circumstantial evidence that the heart and the pupil affected by autonomic activity. But its details such as accuracy, weight-factor or time-delay of its influence are unknown. And this research is conducted with young men and women, so this result cannot be generalized to olds.

Thus, for a more advanced research, the experimental protocol has to be improved and the methods of analysis have to be carefully chosen. Then, the relationship between heart (HRV) and pupil (PSV), and autonomic activity and pupil will be revealed.

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