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PUPILLARY REFLEX DILATATION TO THE AUDITORY STIMULI

THE EFFECTS OF PARASYMPATHETIC ACTIVITY ON THE PATTERN OF THE PUPILLARY REFLEX DILATATION

By

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The change of the pupillary reflex dilatation pattern was investigated under the gradual change of the illumination. When the auditory stimuli were presented under the bright to dark session, where the pupil diameter was gradually increased, pupillary reflex dilatation showed a monophasic pattern. However, the reflex dilatation became polyphasic under the dark to bright session, where the pupil diameter gradually decreased.

Also, the reflex dilatation became polyphasic when the auditory stimuli were given at the point where the rebounding dilatation following the constriction began to occur. The earlier peak (P700) of the polyphasic pattern was due to the enhancement of D wave, which means the relaxation of the parasympathetic system. The significance of the parasympathetic inhibition upon the pupillary reflex dilatation pattern due to the sensory stimuli was suggested.

It has been well known that the pupil dilates phasically to the auditory stimuli (Ury, B., & Gellhorn, E., 1939; Ury, B., & Oldnung, E., 1940; Lowenstein, O., & Loewenfeld, I.E., 1950; Loewenfeld, I.E., 1958; Lowenstein, O., & Loewenfeld, I.E., 1961; Lowenstein, O., & Loewenfeld, I.E., 1962).

Clynes (1962), using the computer averaging techniques, studied the reflex dilatation of the pupil to the auditory stimulus for the first time, and found that the pupil begins to dilate about 150 msec after stimulation and reaches its largest diameter at 1500 msec. And it contracts slowly to the baseline diameter.

We also examined the pupillary change at the auditory stimulation and found that the pupillary reflex dilatation changes its pattern according to the change of the initial pupil diameter at the stimulation. The pupil shows the monophasic reflex dilatation under a dark or dim-light condition where the pupil is large. On the contrary, polyphasic reflex dilatation pattern is found under a bright condition where the initial diameter is small (Shiga, N., & Ohkubo, Y. 1979). And we supposed that the pattern of the pupillary reflex dilatation is affected by the equilibrium of the two antagonistic – sympathetic and parasympathetic – systems (Fig. 1.). When the

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parasympathetic system is indominate under a dark condition, the pupil shows a monophasic dilatation. But when the parasympathetic system is dominant under a bright condition, the sympathetic reflex dilatation is affected and changes its pattern to be polyphasic.

In this experiment, we controlled the balance of these two antagonistic systems experimentally by the continuous change of the degree of the illumination around the stimulus. And we examined the change of the pattern of the reflex dilatation.

![Figure 1. The changes of the pupillary reflex dilatation to the auditory stimuli. When the illumination is increased and the initial pupil diameter is small, a polyphasic dilatation pattern is found. But when the illumination is decreased and the initial pupil diameter is large, a monophasic dilatation pattern is found.](image)

**METHOD**

*Subjects:* The Ss were nine student volunteers, two of whom were female.

*Stimulus:* 1000 Hz, 0.2 sec duration, 60 dB pure tone was presented through a speaker set at 1 meter behind the S.

*Apparatus:* TKK multi unit system and RION AA39A and SONY TAF2 were used to produce and control the pure tones. The change of the pupil diameter was measured using the TKK automatic-infrared device, and was amplified and recorded with MR132B and RMG5204 (NIHON KOHDEN).

*Procedure:* The S's head was held in position with the aid of head-chin rest. The range of S's vision except the part of the TV monitor camera was restricted to an area covered with a sheet of white paper in order to reduce the effect of contrast as much as possible. The S's gaze and accommodation were fixed by requesting the S to focus his eyes on a mirror on the white paper, on which a pin-point red light was projected.
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The distance between the eyes and this fixation point was 120 cm. The S's left eye was monitored to pick up its pupillary changes.

The experiment was divided into three sessions.

1) The first session: Pupil dilation session.

The illumination of the experimental room was initially increased until the S's pupil was constricted to be smaller than 4 mm, and the light was gradually decreased to be dark by the lux controller. The pupil dilated at a speed of about 0.2 mm/sec and when the pupil diameter reached 5 mm, the auditory stimulus was given. The illumination was continued to be smaller after the presentation of the tone. For the control, the same process was taken without the presentation of the stimuli and the change of the pupil diameter after 5 mm by this change of the illumination was averaged.

2) The second session: Pupil constriction session 1.

In this session, the illumination of the experimental room was initially darkened until the S's pupil dilated to be larger than 6 mm, and the light was increased gradually to be bright. The pupil was constricted at a speed of about 0.4 mm/sec and when the pupil reached 5 mm, the tone was presented. The illumination was continued to be bright after the presentation of the stimuli. For the control, the pupillary change after 5 mm by the change of the illumination was averaged without stimuli.

3) The third session: Pupil constriction session 2.

In this session, almost the same paradigm of the second session was used. But as soon as the pupil diameter reached 5 mm, the change of the illumination was ceased. The pupil also stopped contracting and began to dilate after a short time. For the control, the pupillary change after 5 mm by this change of the illumination was averaged without stimuli.

In all these sessions, the presentation of the auditory stimuli at 5 mm of the pupil diameter was controlled automatically using the analogue comparator and volt generator (TKK).

At least 30–40 auditory stimuli were given in each session, but only 20 responses which were free from the eye or eyelid movements were selected and averaged by ATAC 201 (NIHON KOHDEN).

The whole experiment lasted for 1.5–2.0 hours.

RESULTS

A) The change of the pupil in session 1.

Fig. 2. indicates the change of the pupil diameter after 5 mm. In the control condition, the pupil shows the continuous dilation by the decrease of the illumination (Fig. 2. a). When the auditory stimulus is given at a diameter of 5 mm in the experimental condition, the pupil dilates similarly (Fig. 2. b). But the degree of the dilation is larger in the experimental condition. This indicates the effect of the auditory
stimulus on the pupil. Fig. 2. c shows this average disparity between the experimental and control conditions (experimental condition minus control condition). The monophasic pattern is found. This result resembles the observation which was seen in the former experiment, that is, a monophasic dilatation was found in the dark or dim-light sessions.

![Graph showing pupillary movements in session 1.](image)

Fig. 2. Pupillary movements in session 1. Solid line (b) represents the pupillary dilation after 5 mm in the experimental condition, where the auditory stimuli were presented. The dotted line (a) shows that of control condition, where the stimuli were not given. C shows the averaged pupillary reflex dilatation of five Ss. A monophasic pattern is observed.

B) The change of the pupil in session 2.

Fig. 3. indicates the change of the pupil after 5 mm in the light increasing session. In the control condition where the tonal stimuli are not presented and only the pupillary change following this change of illumination is averaged, the constriction of the pupil is seen (Fig. 3. a). When the tonal stimulus is given at a diameter of 5 mm, the reflex dilatation overlaps on this constriction (Fig. 3. b). As shown in Fig. 3. c, the average disparities between these two conditions take the two-phase pattern. The latency of these two peaks is 700 msec and 1600 msec, the amplitude of the former peak is 0.23 mm and that of the latter is 0.27 mm. That is, when the pupil is under successive constriction at the presentation of the auditory stimulus and this constriction is continued after the stimulus, the pattern of the reflex dilatation to the stimulus resembles the pattern which was seen in the small pupil condition of the previous experiment.

C) The change of the pupil in session 3.

Fig. 4. indicates the change of the pupil after 5 mm under the light increasing session, where the increase of the illumination is ceased at 5 mm. In the control condition, where the stimulus is not given and only the pupillary change after 5 mm is averaged, constriction and following rebound dilation is observed (Fig. 4. a). In the
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Fig. 3. Pupillary movements in session 2. The solid line (b) represents the pupillary constriction after 5 mm in the experimental condition, where the auditory stimuli were presented. The dotted line (a) shows that of control condition, where the stimuli were not given. C shows the averaged pupillary reflex dilatation of five Ss. A polyphasic pattern is observed.

In the control condition, reflex dilatation to the tone overlaps on this change (Fig. 4. b).

In the control condition, the constriction after 5 mm continues for 608.7 msec and 366.7 msec in the experimental condition \((t=5.336, p<0.001)\). And the degree of this constriction is 0.205 mm in the experimental condition and 0.257 mm in the control condition. The pupil constricts larger in the control session \((t=2.950, p<0.02)\).

On the contrary, redilation occurs significantly faster and larger in the experimental condition. In the experimental condition, the pupil begins to dilate by 366.7 msec after the stimulation and reaches its first peak at about 870 msec, then shortly constricts and reaches its second peak at about 1670 msec. In the control condition, the pupil begins to dilate by 608.3 msec after stimulation and reaches its first peak at about 1200 msec and its second peak at 2010 msec. The difference between these two conditions is significant for the first peak \((t=3.820, p<0.01)\), and for the second peak \((t=2.999, p<0.02)\).

In addition to this, an average pupillary diameter is 4.94 mm at the first peak and 4.99 mm at the second peak in the experimental condition, and it is 4.72 mm and 4.93 mm for each peak in the control condition. The difference between these two sessions is significant for the first peak \((t=2.386, p<0.05)\), and for the second peak \((t=2.487, p<0.05)\).

Fig. 4. c indicates the difference of the pupillary movements between these two conditions. Two-phasic dilatation pattern, whose peaks are found at about 750 msec (0.21 mm) and about 1500 msec (0.29 mm), is observed. This result resembles that of session 2.
Fig. 4. Pupillary movements in session 3. In this session, the increase of the illumination was stopped as soon as the pupil diameter reached 5 mm. The solid line (b) represents the pupillary rebound dilatation after 5 mm in the experimental condition, where the auditory stimuli were presented. The dotted line (a) shows that of control condition, where the stimuli were not given. In both session, Lowenstein’s D and E waves are seen. C shows the averaged pupillary reflex dilatation of nine Ss. A polyphasic pattern is observed.

DISCUSSION

In the previous experiment, we found that pupillary reflex dilatation to the sound stimulus shows a different pattern when the stimulus was given under the dark condition, where the pupil was large, and under the bright condition where the pupil was small. The pupil dilates monophasically in the dark session and reaches its peak about 1.6 sec after stimulation, but it dilates polyphasically in the bright session, whose peaks are seen at about 0.7 sec and 1.6 sec after stimulation. This change of the pattern in pupillary reflex dilatation was observed around 5 mm of the initial pupil diameter at the stimulation. (see Fig. 1.)

It is well known that the human pupil changes its diameter from 2 mm to 11 mm (Lowenstein, O., & Loewenfeld, I.E., 1962). The parasympathetic system is almost relaxed under the dark condition where the pupil diameter is large. From this, we speculated that the sympathetic reflex dilatation of the pupil occurs smoothly without
opposing effect under the dark or dim light condition. However, when the illumination is bright and the pupil is under bright adaptation and its diameter is small, activated parasympathetic activity suppresses the sympathetic dilatation and makes the dilatation pattern polyphasic.

If this speculation is right, it is hypothesized that if the parasympathetic activity is controlled experimentally, different reflex dilatation patterns will be found even if the auditory stimulus is given at the same diameter of the pupil.

This hypothesis is supported by the results as shown in Fig. 2, and Fig. 3. When the illumination was continuously decreased in session 1, the monophasic reflex dilatation was observed. In this case, it is interpreted that the increase of pupillary diameter following the decrease of illumination is due to the relaxation or inhibition of the parasympathetic system (Lowenstein, O., & Loewenfeld, I.E.). That is, when the parasympathetic system is relaxed, the reflex dilatation by the tonal stimulus becomes monophasic (Fig. 2. c). Contrary to this, the parasympathetic system is activated by the increase of the illumination, following the increase of the amount of light to retina.

In this way, in session 2, the pupil was constricted successively. And as soon as the pupil diameter reached 5 mm, the tonal stimulus was given, the reflex dilatation occurred, even though the constriction paradigm still continued.

The difference between the experimental and control conditions of the pupillary movements shows the polyphasic pattern (Fig. 3. c). That is, when the parasympathetic system was activated before the presentation of the auditory stimuli, the sympathetic system was influenced to change the reflex dilatation pattern to be polyphasic.

In session 3, the continuous increase of the illumination was stopped at 5 mm. As shown in Fig. 4. a, b, pupillary constriction continues for a short time and reverses its movement to dilation, whether the tonal stimulus was given or not. This is the rebound dilation which was observed by Lowenstein and Loewenfeld (1950).

They found that there are two peaks in rebound dilation after light reflex. One is the D wave and the other is the E wave. The former represents the relaxation of the parasympathetic system and the latter is due to the activation of the sympathetic system. In the control condition of session 3, D wave is seen about 600 msec after the pupil reached its maximum constriction and E wave is seen after about 1300 msec. Also in the experimental condition, D and E waves are seen about 500 msec and 1400 msec after the pupil reached its minimum diameter. This indicates that in both sessions, the parasympathetic relaxation occurred at first by the interruption of the increase of illumination. Therefore, according to the above hypothesis, the reflex dilatation component will become monophasic because of the relaxation of the parasympathetic system.

However, as shown in Fig. 4. c, the difference between the experimental condition and control condition of the pupillary reflex dilatation takes the polyphasic pattern, whose peaks are found at 750 msec and 1500 msec. This indicates that even under the parasympathetic relaxation, the pupillary reflex dilatation becomes polyphasic.

This polyphasic dilatation pattern is due to the result of the rebound dilation in
the experimental condition which occurred about 240 msec faster than the control condition. Certainly, Lowenstein and Loewenfeld clarified that the auditory stimuli activate the sympathetic system and decrease the amplitude of the light reflex, and they found also that the sympathetic activation inhibits the primary phase (D wave) of the light reflex, which represents the relaxation of the parasympathetic system. Undoubtedly the constriction is small in the experimental condition, but as described above, the amplitude of the D wave of the experimental condition is 0.13 mm and this is larger than that of the control condition, which is 0.10 mm, although not significant. Therefore the auditory stimuli seem to promote not only the sympathetic activity but also the inhibition of the parasympathetic activity. And this contributes to the earlier peak of the reflex dilatation (P700).

In this way, considering the effect of the parasympathetic relaxation on the pupillary reflex dilatation, one may explain why the pupil dilates monophasically under the dark condition and polyphasis under the bright condition, or why a monophasic dilatation pattern is observed under the continuous light-decreasing condition and a polyphasic pattern is observed in the continuous light-increasing condition.

First, both in session 1 and session 3 of this experiment, the parasympathetic activity was relaxed or was ready to be relaxed when the pupil diameter reached 5 mm. If the auditory stimuli promote the parasympathetic inhibition, the dilatation component due to this inhibition should appear under the condition where the parasympathetic system is reasonably activated. In session 1, the parasympathetic activity was already relaxed when the auditory stimulus was given, but in session 3, it was still under activation when the stimulus was presented. This is proved by the fact that the pupil still continued to constrict after ceasing the change of illumination. And in the experimental condition of the session 3, the parasympathetic inhibition component due to the tonal stimuli was added to the D wave and made the rebound dilation faster and larger than that of the control condition and made the difference between them polyphasic.

Second, in session 2 of this experiment, the parasympathetic system was activated by the increase of the illumination at the presentation of the stimulus, and the auditory stimulus promoted this parasympathetic relaxation (inhibition) and made the polyphasic dilatation pattern.

Third, in the previous experiment, monophasic dilatation pattern was observed in the dark condition and polyphasic pattern was seen in the bright condition. In the dark or dim light condition, the parasympathetic activity is relaxed and the inhibition component of the dilatation is not evident. In the brighter condition, however, parasympathetic activity is dominant, therefore inhibition component is observed clearly. This made the dilatation pattern polyphasic.

Lowenstein and Loewenfeld (1950) found that the amplitude of the reflex dilatation to the tonal stimuli became one-fifth or one-tenth of the intact side by the peripheral
sympathectomy. Contrary to this, only the small change occurred by the parasympa-
thectomy and they concluded that the most part of the reflex dilatation of the pupil is
sympathetic and only the remnant small part is due to the central inhibition of the
parasympathetic system. In addition to this, comparing the differential curves of the
reflex dilatation between the sympathectomized or parasympathectomized pupil and
the intact pupil, they remarked that the sympathetic activation and parasympathetic
inhibition by the sensory stimulus occur almost simultaneously.

But our results, using the computer averaging techniques, suggest us that the
parasympathetic inhibition by the sensory stimulus reaches its peak earlier than the
sympathetic activation reaches its peak. That is, the reception of the sensory
stimulus first produces the central parasympathetic inhibition and then activates the
sympathetic system. And this central parasympathetic inhibition makes P700 of the
pupillary reflex dilatation under the parasympathetic dominant situation.

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