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The Effect of Natural and Artificial Light via the Eye on the Hormonal and Metabolic Balance of Animal and Man[1]

F. Hollwich and B. Dieckhues

Universitäts-Augenklinik, Münster i. W.

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Abstract. Color change of the plaice and frog, and development of the testes in duck are induced by light stimuli via the eye. Eliminating experiences on the frog *(Hollwich)* and on the duck *(Benoit)* showed that these stimuli – beside vision – use a separate way, the so-called 'energetic portion' of the visual pathway *(Hollwich)*. In compared studies on blind and on temporarily blind patients involved by cataract in both eyes, we found significant low levels of ACTH and cortisol. The levels normalized after cataract extraction. – Furthermore, we studied the influence of strong artificial illumination (3,500 and 3,200 lx) on healthy persons with considerable and, on the other hand, with minimal difference of their spectral composition to daylight. We found stress-like levels of ACTH and cortisol in the first group. These findings explain the agitated mental and physical behavior of children staying the whole day in school under artificial illumination with strong spectral deviation from daylight. Therefore, to avoid mental and physical alterations, the spectrum of artificial illumination should be largely similar to that of natural light.

S. O. Mast in 1916 was the first to demonstrate the influence of light via the eye on a hormonal reaction. When the head of a plaice was put on a dark background, the plaice turned dark. When its head was put on a light background, the plaice changed to a light color (fig. 1).

The same reaction could be shown in an experiment with a frog. Furthermore, when we closed the lids of the frog with sutures, his color no longer changed. In both animals, therefore, the adaptation of the color of the body to the surroundings (dark or light) is induced by the light entering their eyes.

1 This paper was presented at the meeting of the 'International Commission on Illumination' in Lausanne, Switzerland, on September 25, 1978.

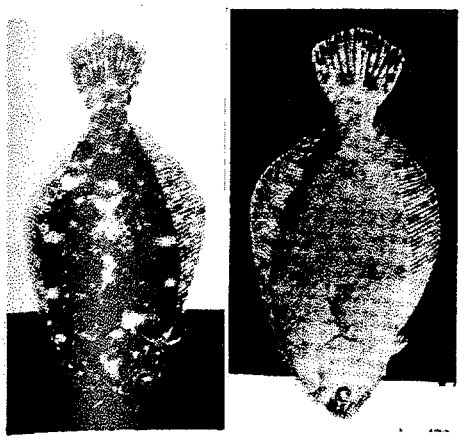


Fig. 1. Plaice. Right: head and eye on light background, light body on dark background. Left: head and eye on dark background, dark body on light background [*Mast*, 1916].

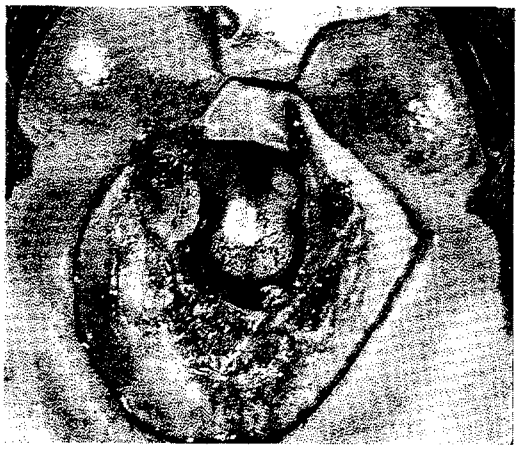


Fig. 3. The visual center (right and left lobus opticus) of the frog after trephination of its skull (operation picture).

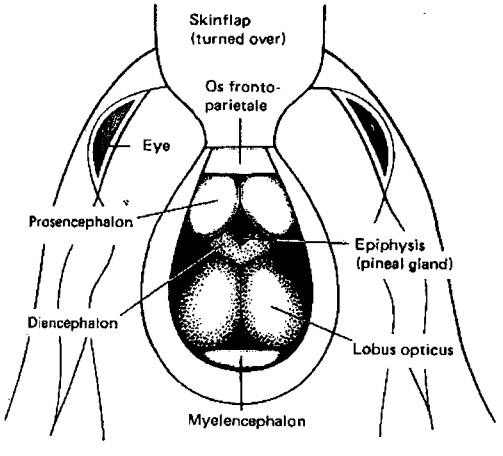


Fig. 2. Topography (drawing) of the frog's brain. Both visual centers (right and left lobus opticus) are visible.

To make sure whether the light stimulating the color change runs along the same neural pathway als does vision, we did further experiments with the frog [*Hollwich*, 1958]. After controlling the vision of the frog in a nystagmus drum by watching the characteristic neck movements, we destroyed both his visual centers (lobi optici) (fig. 2, 3). After putting the frog again in the revolving striated drum, it no longer showed the characteristic neck movements in the direction in which the drum was turning: the frog was totally blind.

Consequently, putting the frog first on a dark (fig. 4) and then on a light background (fig. 5), it changed color, just as before. This experiment shows that the light entering the eye must travel along two different pathways (fig. 6): one pathway running from the retina to the visual center serves vision, the other one obviously goes to the hypophysis, an endocrine gland which releases the specific melanophore hormone inducing the change of color.

Another experiment proved the role of the hypophysis in color change: if the gland is exstirpated, the color change no longer

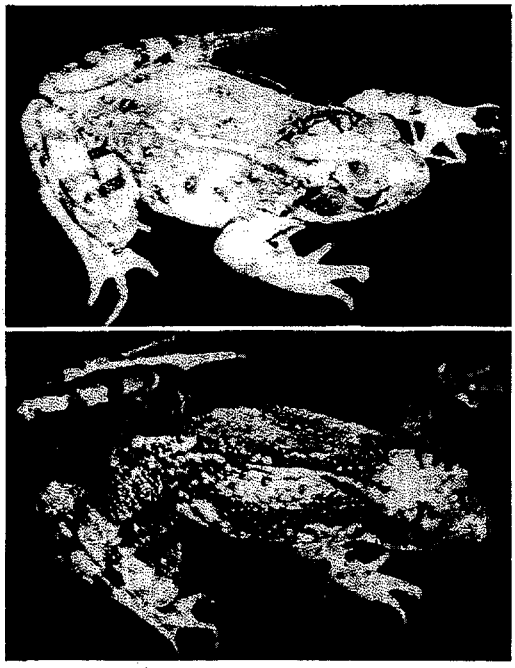


Fig. 4. Postoperative frog blinded due to diathermic destruction of his visual centers. Nevertheless, he changed his color adapting on light background (photographed on dark background for contrast purposes).

Fig. 5. Same postoperative blinded frog as in figure 4 adapting his color on a dark background.

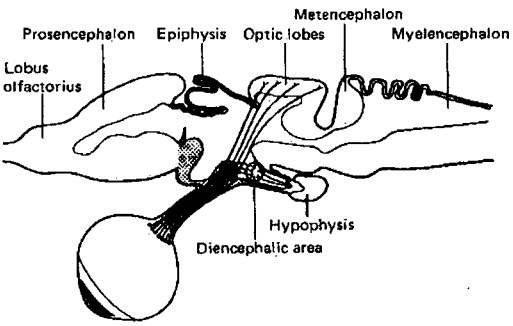


Fig. 6. 'Visual' (——) and 'energetic' (– – –) pathways of the optic system of the frog.

occurs. On the other hand, if an extract of the hypophysis is injected into a frog, the color *does* change.

Energetic Portion of the Optic Nerve

Therefore, we suggested two separate pathways for the light entering the eye. The first, serving vision, we designated as the 'optical portion' of the visual pathway, and the second one, stimulating endocrine function, we called the 'energetic portion' [*Hollwich,* 1948] of the optic nerve (fig. 6).

Studies on Light-Induced Development of Testes in Ducks

We demonstrated the importance of radiations of different wavelengths on the development of young ducks. Figure 7 shows the testes of 2 ducks of the same nest. The

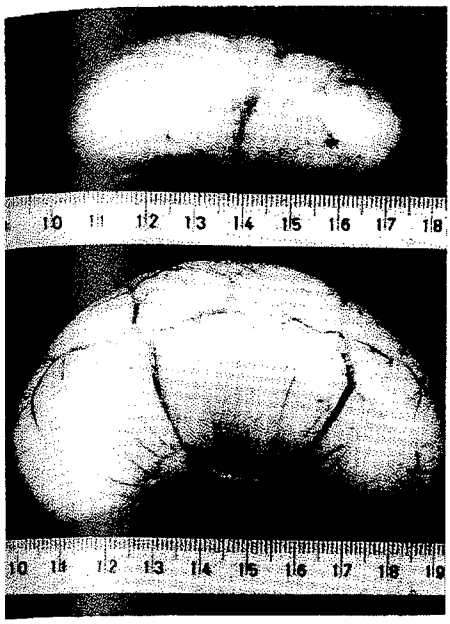


Fig. 7. Testes of 2 ducks of the same nest raised under different conditions. Above, the smaller testis of the duck raised under normal natural conditions. Below, the much bigger testis of his brother which additionally had been exposed for 46 days to 5 h of artificial monochromatic red light daily ($2.45 \cdot 10^{-4}$ W/cm²).

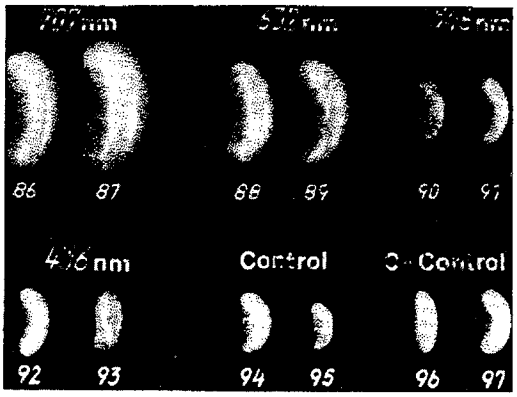


Fig. 8. Testes of ducks raised under additional exposure to monochromatic artificial light of different wavelengths. Above the wavelength, below the number of the testis. Each duck is represented only by one testis. Irradiation with orange light (632 nm) resulted in a 6-fold enlargement and irradiation with red light (707 nm) resulted in a 16-fold enlargement of the testes compared with a control group raised under dim light and with the testes of a 0-control group taken at the beginning. Shorter wavelengths such as green (546 nm) or blue (436 nm) light had no influence. The irradiation exposure ($2.45 \cdot 10^{-4}$ W/cm²) was 10 h daily during a period of 29 days.

smaller one (above) is the testis of a duck raised under normal conditions. Below is the much larger testis of a duck whose eye during 6 weeks was exposed for 5 h daily to red light. There was a twofold increase in weight compared with the control [*Hollwich and Tilgner, 1961a, b*]. In contrast, the testes of ducks irradiated with blue or yellow light showed no enlargement. In a second study [*Hollwich and Tilgner,* 1963], ducks were also exposed to different wavelengths (fig. 8). In this experiment, a control group was left in dim light. Monochromatic light of long wavelength – 707 nm (red) and 632 nm (orange) – was most effective. Shorter wavelengths such as yellow or blue were not effective. Our results confirm the studies of *Benoit* [1935, 1936, 1937, 1938, 1964, 1978a, b] and of *Benoit et al.* [1950a, b, 1952, 1953] in the same field.

Studies on Blind Subjects

We studied the biological rhythm of the ACTH, cortisol, HGH, testosterone and TSH levels in totally blind people, in persons with defective light perception (all blinded by trauma as adults during World War II) and in a normal control group (fig. 9). The cortisol curve of the totally blind (bilaterally

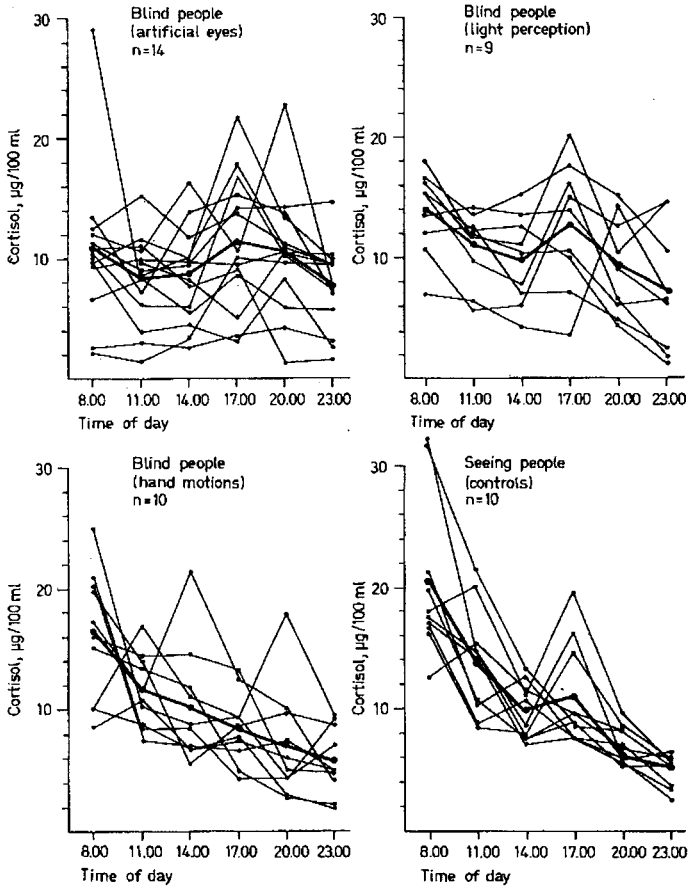


Fig. 9. Influence of the absence of light stimulating the eye on the rhythm and the level of cortisol in different groups of visually handicapped persons who were blind had only light perception or perceived only hand motions. The mean level of the first group with artificial eyes is significantly lower than that of the group with hand-motion vision or of the control group (seeing persons) of the same age distribution. Also the circadian rhythm is clearly changed.

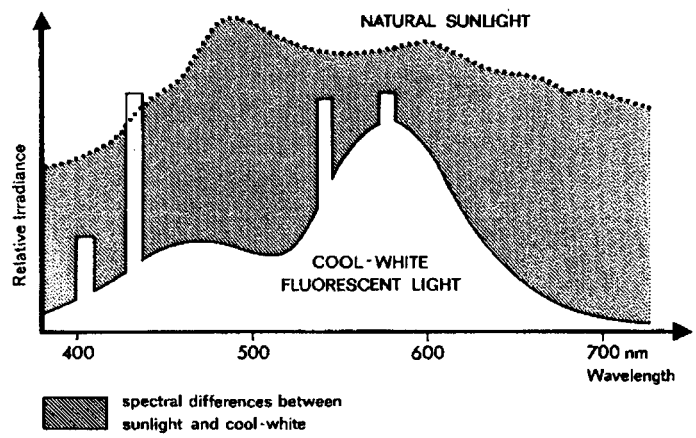


Fig. 10. Emission spectra of a cool-white fluorescent lamp and of sunlight. There is a striking deficiency of the artificial light, especially in the red and the blue-violet ranges.

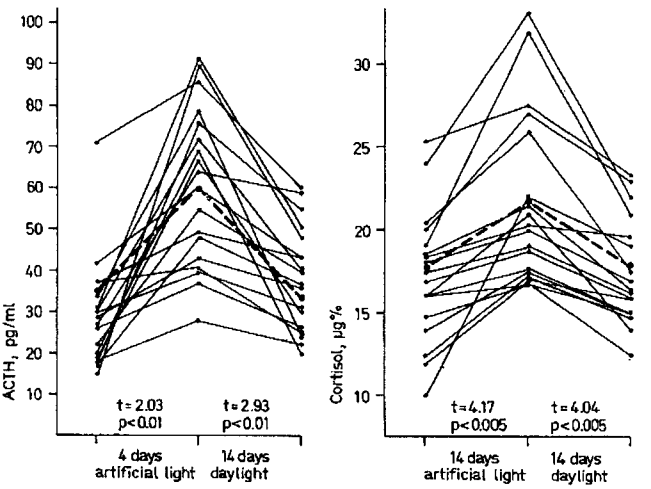


Fig. 11. Influence of 3,500 lx of cool-white fluorescent lamps on volunteer young individuals during a fortnight. Left half of each picture: stress-like increases of ACTH and cortisol. Right half of each picture: parameters of the same individuals after living a fortnight under normal daylight conditions. —— = Individual curves ($n = 18$); – – – = average curve. Significance Student's t test): significant increase of ACTH under artificial light: $t = 2.03$, $p < 0.01$. Significant increase of cortisol under artificial light: $t = 4.17$, $p < 0.005$.

artificial eyes, no light perception) differs in its mean value significantly from the curve of normal subjects (heavy line) but also remarkably from that of people seeing hand movements or having light perception. Even so, in all the above-mentioned tests we found that the levels of those blind people with bilaterally artificial eyes or those with no light perception were the lowest ones.

Furthermore, we studied the ACTH and cortisol levels in patients temporarily blind in both eyes by cataract. We examined the levels before and after removing the cataract. Before extraction we obtained approximately the same lower level as we found by the blind. After the cataract extraction we found normal levels of ACTH and cortisol. These results have been published extensively in previous papers [*Hollwich,* 1966; *Hollwich and Dieckhues,* 1971].

Influence of Artificial Light of Different Fluorescent Tubes on Human Subjects

In this study we compared the effects of fluorescent lamps (cool-white) with those of

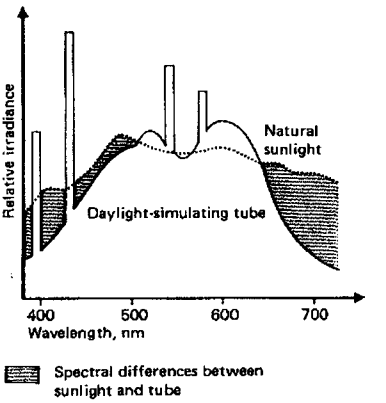


Fig. 12. Spectrum of a daylight-simulating tube compared with the visible spectrum of the sun.

normal daylight conditions (fig. 10). We tested ACTH and cortisol (fig. 11).

Our study shows, on the one hand, that strong artificial illumination (cool-white) of 3,500 lx increases the release of ACTH and cortisol (fig. 11). On the other hand, it shows that the short period of a fortnight of exposure to this condition suffices to create stress-like levels of ACTH and cortisol.

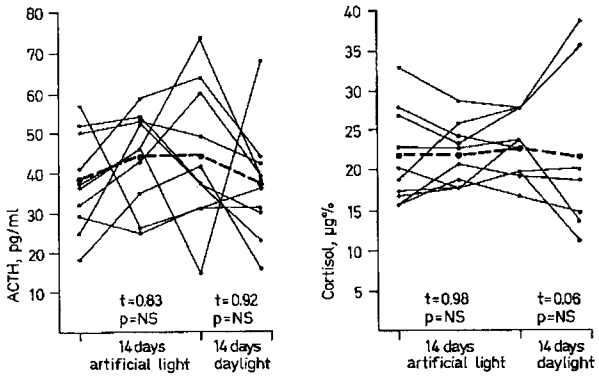


Fig. 13. Influence of 3,200 lx of daylight-simulating tubes (left half of each picture) on volunteer young individuals compared with daylight (right half of each picture). In contrast to the curves shown in figure 11 (cool-white tubes) the mean curve shows only a moderate rise. —— = Individual curves (n=10); – – – = average curve. No significant increase (Student's t test) of ACTH (t = 0.83, p = NS) and cortisol (t = 0.98, p = NS) after lightning.

We also studied the influence of another artificial light source, approximately of the same luminous intensity (3,200 lx) but of different spectral composition. We compared the effect of a cool-white fluorescent lamp with a tube simulating sunlight in the visible and ultraviolet ranges (fig. 12).

Discussion

Comparing both lamps, we found that the stress-like effect of the cool-white tube was absent in the sunlight-simulating tube (fig. 13). Therefore, since the luminous intensity was approximately the same, the different metabolic and endocrine effects on human subjects are due to the different spectral components of the lamps. In other words, the spectral components play the decisive role. We may, furthermore, conclude that the more the spectrum of the artificial light source differs from that of natural light, the more the biological endocrine system in man will be disturbed. During short periods of time the disturbance of the endocrine system of man, induced by unbalanced artificial light, involves his comfort [*Hoefling*, 1973], his efficiency as well as fatigue [*Hollwich and Dieckhues*, 1972; *Hollwich et al.*, 1975, 1977]. Our studies explain the effects of spectral differences in illumination on the fidgety behaviour and subsequent fatigue of pupils performing mental activity [*Maas et al.*, 1974]. Furthermore, during long periods of time artificial light with a certain degree of lack of brightness [*Harmon*, 1942, 1946, 1951] due to its reduced spectrum involves first of all the health of the child in school but also the man working in his office or in industry [*Hollwich*, 1979]. We should therefore bear in mind that artificial light, for the human individual at least, remains a mere substitute; it can never fully replace natural light, which, as a vital element like water and air, forms the basis of our health.

Finally, the pathway of light, entering the eye, to the endocrine glands, which are primarily – beyond vision – photosensitive, the hypophysis and the epiphysis [*Wurtman*, 1969] is demonstrated schematically in figure 14 [*Hollwich*, 1948] and figure 15 [*Kappers*, 1969].

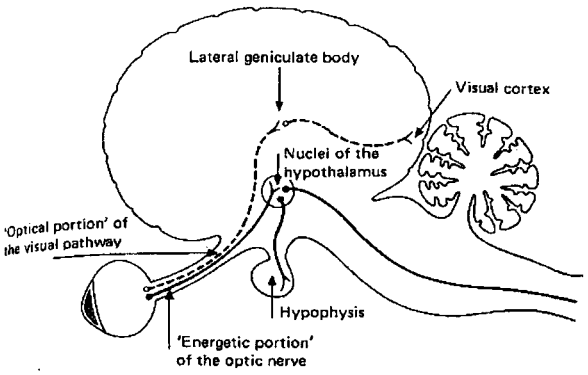


Fig. 14. Scheme of the way of light entering the eye and running to the hypophysis via the 'energetic portion' of the optic system [*Hollwich*, 1948].

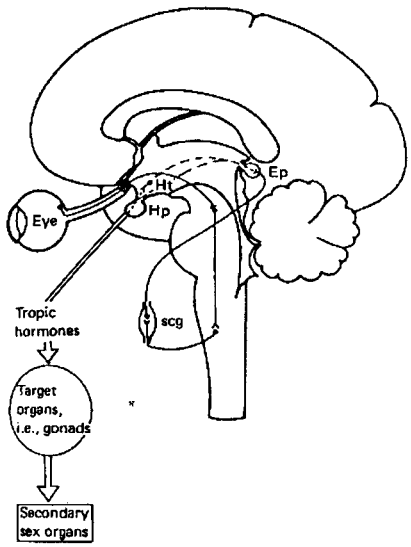


Fig. 15. Scheme of the way of light entering the eye and running to the epiphysis (pineal gland) via the sympathetic nervous system [*Kappers*, 1969]. —— = Nervous pathways; – – – = hormonal pathways. Ep = Epiphysis; Hp = hypophysis; Ht = hypothalamus; scg = sympathetic ganglion.

toires sur la grenouille [*Hollwich*] et la stimulation par la lumière sur le canard [*Benoit, Hollwich* et *Tilgner*] montrent que ces stimuli – à part la vue – utilisent une voie séparée, dite «partie énergétique» des voies visuelles [*Hollwich*]. Dans des études comparatives, des aveugles et des aveugles temporaires à cataracte des deux yeux, nous avons trouvé des taux d'ACTH et de cortisol significativement bas. Ces taux se normalisent après extraction de la cataracte. – En outre, nous avons étudié l'influence d'une forte illumination artificielle (3500 et 3200 lx) sur des personnes saines, avec une composition spectrale différent fortement de la composition de la lumière du jour, alors que pour d'autres, la différence était minime. Nous avons trouvé des taux d'ACTH et de cortisol indiquant une tension dans le premier groupe. Ces constatations expliquent l'agitation mentale et le comportement physique d'enfants qui restent toute la journée à l'école, lorsque l'illumination artificielle diffère fortement du spectre lumineux de la lumière du jour. Il en résulte que, pour éviter des altérations physiques et mentales, le spectre de la lumière artificielle devrait être fortement semblable à celui de la lumière naturelle.

Résumé

Les changements de couleur du carrelet et de la grenouille, le développement des testicules du canard, sont provoqués par la stimulation lumineuse à partir des yeux. Des expériences élimina-

Zusammenfassung

Der Farbwechsel von Scholle und Frosch sowie die Keimdrüsenreifung der Ente werden durch Lichteinfall in das Auge gesteuert. Wie Ausschaltversuche am Frosch [*Hollwich*] und Belichtungs-

versuche an der Ente [*Benoit, Hollwich* und *Tilgner*] zeigten, verlaufen diese stimulierenden Lichtreize unabhängig vom Sehvorgang über den «energetischen Anteil» der Sehbahn *(Hollwich)*. Weiterhin zeigen Blinde, denen diese Lichtimpulse fehlen, sowie Patienten mit beiderseits getrübten Linsen in unseren vergleichenden Untersuchungen signifikant erniedrigte ACTH- und Cortisolwerte. Bei den Kataraktpatienten tritt nach der Operation wieder Normalisierung ein. – Den Einfluss künstlichen Lichtes (3500 und 3200 lx) auf Versuchspersonen untersuchten wir mit Leuchtstoffröhren starker sowie minimaler Abweichung ihrer spektralen Zusammensetzung vom Tageslicht. Wir fanden eine stressartige Erhöhung des ACTH- und des Cortisolspiegels bei den zuerst genannten Leuchten. Diese Tatsache erklärt z. B. die Hyperkinese von Schülern, die sich ganztags unter Kunstlicht starker spektraler Abweichung aufhalten. Künstliche Lichtquellen sollten deshalb – zur Vermeidung psychischer und physischer Alterationen – in ihrer spektralen Zusammensetzung dem Sonnenlicht angeglichen sein.

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Prof. Dr. Dr. h. c. F. Hollwich,
Antonienstrasse 1,
D–8000 München 40 (FRG)