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COMMISSION INTERNATIONALE DE L'ÉCLAIRAGE
INTERNATIONAL COMMISSION ON ILLUMINATION
INTERNATIONALE BELEUCHTUNGSKOMMISSION

TECHNICAL REPORT

THE INFLUENCE OF DAYLIGHT AND ARTIFICIAL LIGHT ON DIURNAL AND SEASONAL VARIATIONS IN HUMANS. A BIBLIOGRAPHY

CIE 139 - 2001

UDC: 612.014.481-06

Descriptor: Optical radiation effects on humans

THE INTERNATIONAL COMMISSION ON ILLUMINATION

The International Commission on Illumination (CIE) is an organisation devoted to international co-operation and exchange of information among its member countries on all matters relating to the art and science of lighting. Its membership consists of the National Committees in 39 countries and one geographical area and of 7 associate members.

The objectives of the CIE are :

1. To provide an international forum for the discussion of all matters relating to the science, technology and art in the fields of light and lighting and for the interchange of information in these fields between countries.
2. To develop basic standards and procedures of metrology in the fields of light and lighting.
3. To provide guidance in the application of principles and procedures in the development of international and national standards in the fields of light and lighting.
4. To prepare and publish standards, reports and other publications concerned with all matters relating to the science, technology and art in the fields of light and lighting.
5. To maintain liaison and technical interaction with other international organisations concerned with matters related to the science, technology, standardisation and art in the fields of light and lighting.

The work of the CIE is carried on by seven Divisions each with about 20 Technical Committees. This work covers subjects ranging from fundamental matters to all types of lighting applications. The standards and technical reports developed by these international Divisions of the CIE are accepted throughout the world.

A plenary session is held every four years at which the work of the Divisions and Technical Committees is reviewed, reported and plans are made for the future. The CIE is recognised as the authority on all aspects of light and lighting. As such it occupies an important position among international organisations.

LA COMMISSION INTERNATIONALE DE L'ÉCLAIRAGE

La Commission Internationale de l'Éclairage (CIE) est une organisation qui se donne pour but la coopération internationale et l'échange d'informations entre les Pays membres sur toutes les questions relatives à l'art et à la science de l'éclairage. Elle est composée de Comités Nationaux représentant 39 pays plus un territoire géographique, et de 7 membres associés.

Les objectifs de la CIE sont :

6. De constituer un centre d'étude international pour toute matière relevant de la science, de la technologie et de l'art de la lumière et de l'éclairage et pour l'échange entre pays d'informations dans ces domaines.
7. D'élaborer des normes et des méthodes de base pour la métrologie dans les domaines de la lumière et de l'éclairage.
8. De donner des directives pour l'application des principes et des méthodes d'élaboration de normes internationales et nationales dans les domaines de la lumière et de l'éclairage.
9. De préparer et publier des normes, rapports et autres textes, concernant toutes matières relatives à la science, la technologie et l'art dans les domaines de la lumière et de l'éclairage.
10. De maintenir une liaison et une collaboration technique avec les autres organisations internationales concernées par des sujets relatifs à la science, la technologie, la normalisation et l'art dans les domaines de la lumière et de l'éclairage.

Les travaux de la CIE sont effectués par 7 Divisions, ayant chacune environ 20 Comités Techniques. Les sujets d'études s'étendent des questions fondamentales, à tous les types d'applications de l'éclairage. Les normes et les rapports techniques élaborés par ces Divisions Internationales de la CIE sont reconnus dans le monde entier.

Tous les quatre ans, une Session plénière passe en revue le travail des Divisions et des Comités Techniques, en fait rapport et établit les projets de travaux pour l'avenir. La CIE est reconnue comme la plus haute autorité en ce qui concerne tous les aspects de la lumière et de l'éclairage. Elle occupe comme telle une position importante parmi les organisations internationales.

DIE INTERNATIONALE BELEUCHTUNGSKOMMISSION

Die Internationale Beleuchtungskommission (CIE) ist eine Organisation, die sich der internationalen Zusammenarbeit und dem Austausch von Informationen zwischen ihren Mitgliedsländern bezüglich der Kunst und Wissenschaft der Lichttechnik widmet. Die Mitgliedschaft besteht aus den Nationalen Komitees in 39 Ländern und einem geographischen Gebiet und aus 7 assoziierten Mitgliedern.

Die Ziele der CIE sind :

11. Ein internationaler Mittelpunkt für Diskussionen aller Fragen auf dem Gebiet der Wissenschaft, Technik und Kunst der Lichttechnik und für den Informationsaustausch auf diesen Gebieten zwischen den einzelnen Ländern zu sein.
12. Grundnormen und Verfahren der Meßtechnik auf dem Gebiet der Lichttechnik zu entwickeln.
13. Richtlinien für die Anwendung von Prinzipien und Vorgängen in der Entwicklung internationaler und nationaler Normen auf dem Gebiet der Lichttechnik zu erstellen.
14. Normen, Berichte und andere Publikationen zu erstellen und zu veröffentlichen, die alle Fragen auf dem Gebiet der Wissenschaft, Technik und Kunst der Lichttechnik betreffen.
15. Liaison und technische Zusammenarbeit mit anderen internationalen Organisationen zu unterhalten, die mit Fragen der Wissenschaft, Technik, Normung und Kunst auf dem Gebiet der Lichttechnik zu tun haben.

Die Arbeit der CIE wird in 7 Divisionen, jede mit etwa 20 Technischen Komitees, geleistet. Diese Arbeit betrifft Gebiete mit grundlegendem Inhalt bis zu allen Arten der Lichtenwendung. Die Normen und Technischen Berichte, die von diesen international zusammengesetzten Divisionen ausgearbeitet werden, sind von der ganzen Welt anerkannt.

Tagungen werden alle vier Jahre abgehalten, in der die Arbeiten der Divisionen überprüft und berichtet und neue Pläne für die Zukunft ausgearbeitet werden. Die CIE wird als höchste Autorität für alle Aspekte des Lichtes und der Beleuchtung angesehen. Auf diese Weise unterhält sie eine bedeutende Stellung unter den internationalen Organisationen.

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COMMISSION INTERNATIONALE DE L'ECLAIRAGE
CIE Central Bureau
Kegelgasse 27, A-1030 Vienna, AUSTRIA
Tel: +43(0)714 31 87 0, Fax: +43(0)713 08 38 18
e-mail: ciecb@ping.at
WWW: <http://www.cie.co.at/cie/home.html>

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This Technical Report has been prepared by CIE Technical Committee 6-16 of Division 6 "Photobiology and Photochemistry" and has been approved by the Board of Administration of the Commission Internationale de l'Eclairage for study and application. The document reports on current knowledge and experience within the specific field of light and lighting described, and is intended to be used by the CIE membership and other interested parties. It should be noted, however, that the status of this document is advisory and not mandatory. The latest CIE proceedings or CIE NEWS should be consulted regarding possible subsequent amendments.

Ce rapport technique a été préparé par le Comité Technique CIE 6-16 de la Division 6 "Photobiologie et photochimie" et a été approuvé par le Bureau d'Administration de la Commission Internationale de l'Eclairage, pour étude et application. Le document traite des connaissances courantes et de l'expérience dans le domaine spécifique indiqué de la lumière et de l'éclairage, et il est établi pour l'usage des membres de la CIE et autres groupements intéressés. Il faut cependant noter que ce document est indicatif et non obligatoire. Pour connaître d'éventuels amendements, consulter les plus récents comptes rendus de la CIE ou le CIE NEWS.

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The following members of CIE TC 6-16 "Psychobiological Effects of Lighting" took part in the preparation of this technical report. TC 6-16 comes under CIE Division 6 - Photobiology and Photochemistry.

Author and chairman:	Rikard Küller	Sweden
Project assistant:	Marianne Küller	Sweden
Working members and advisors:	John L. Andreassi	USA
	Johan Beck-Friis	Sweden
	J. Derrick Kendrick	Australia
	Byron Mikellides	England
	Gerrit J. van den Beld	the Netherlands
	Lennart Wetterberg	Norway
	Richard J. Wurtman	USA

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THE INFLUENCE OF DAYLIGHT AND ARTIFICIAL LIGHT ON DIURNAL AND SEASONAL VARIATIONS IN HUMANS. A BIBLIOGRAPHY.

SUMMARY

In recent years, the study of the psychobiological effects of light has come forth as an important subfield of lighting research. This final report of TC6-16 consists of a bibliography with 1100 entries and a basic list of 120 key words. The bibliography deals with the impact of light, both natural and artificial, upon the biological clock. The effects cited include physiological variations between day and night, during the menstrual cycle, and during the different seasons of the year. Also included are psychological variations in emotional tone and alertness, as well as pre-menstrual tension and seasonal affective disorder. The selection of references has been restricted almost exclusively to research on humans. The bibliography covers the following topics: The biological clock; Melatonin and cortisol; Shift work and jet lag; Seasonality in hormones; Seasonal affective disorder; Light therapy; Other kinds of seasonality; Premenstrual syndrome; Windowless environments; Lighting characteristics; Individual and group differences; Confounding factors. There will be reason for CIE to plan ahead in order to assimilate this new knowledge, which will undoubtedly lead to the reformulation of present lighting standards and criteria.

INFLUENCE DE LA LUMIERE DU JOUR ET DE LA LUMIERE ARTIFICIELLE SUR LES CYCLES NYCTHEMERAL ET CIRCADIEN HUMAIN - BIBLIOGRAPHIE

RESUME

Au cours des dernières années, l'analyse des effets psychobiologiques de la lumière a émergé en tant que discipline importante en recherche sur l'éclairage. Ce rapport final du TC6-16 comprend une bibliographie de 1100 références et une liste de base de 120 mots clefs. La bibliographie porte sur l'impact de la lumière, naturelle et artificielle, sur les rythmes biologiques. Les effets recensés comprennent les variations physiologiques entre jour et nuit, pendant le cycle menstruel et au cours des différentes saisons de l'année. Elle comprend également les variations psychologiques du niveau émotionnel et de l'éveil ainsi que la tension prémenstruelle et le syndrome de la dépression saisonnière. La sélection des références a été limitée pratiquement exclusivement aux recherches chez l'homme. La bibliographie couvre les points suivants : - Les rythmes biologiques ; - Mélatonine et cortisol ; - Travail décalé et décalage horaire ; - Variations saisonnière des hormones ; - Syndrome de dépression saisonnière ; - Thérapie par la lumière ; - Autre type de variation saisonnière ; - Syndrome prémenstruel ; - Environnement sans lumière naturelle ; - Caractéristiques de l'éclairage ; - Différence entre les individus et les groupes ; - Facteur confondant. Ce travail constitue une base pour la CIE en vue de travaux futurs afin d'assimiler ces nouvelles connaissances qui, sans aucun doute, entraîneront à la reformulation des standards et des critères d'éclairage actuels.

DER EINFLUSS VON TAGESLICHT UND KÜNSTLICHEM LICHT AUF TAGESZEIT- UND JAHRESZEITABHÄNGIGE ZYKLEN BEIM MENSCHEN. EINE BIBLIOGRAPHIE

ZUSAMMENFASSUNG

In den letzten Jahren hat sich die Untersuchung der psychobiologischen Auswirkung des Lichtes zu einem wichtigen Teilgebiet der Lichtforschung entwickelt. Der Schlussbericht von TC6-16 besteht aus einer Bibliographie mit 1100 Einträgen und einem Grundvokabular von 120 Schlüsselwörtern. Die Bibliographie beschäftigt sich mit dem Einfluss von natürlichem sowie künstlichem Licht auf die biologische Uhr des Menschen. Die erwähnten Auswirkungen beinhalten physiologische Unterschiede zwischen Tag und Nacht, während des Menstruationszyklus, und zwischen den verschiedenen Jahreszeiten. Weiters sind psychologische Unterschiede bezüglich emotionalem Zustand und Wachsamkeit, sowie prämenstruelle Spannungen und jahreszeitlich bedingte Störungen beinhaltet. Die Auswahl der Referenzen wurde fast ausschliesslich auf die Forschung am Menschen beschränkt. Die

Bibliographie deckt die folgenden Themen ab: die biologische Uhr; Melatonin und Cortisol; Schichtarbeit und Jetlag; der jahreszeitlich bedingte Hormonspiegel; sich jahreszeitlich auswirkende Störungen; Lichttherapie; andere Arten von jahreszeitlich bedingten Veränderungen; prämenstruelles Syndrom; fensterlose Umgebungen; Lichtcharakteristika; individuelle und Gruppenunterschiede; weitere Einflüsse. Für CIE wird es Gründe geben, diese neuen Kenntnisse, die zweifelsohne zu einer Umformulierung der heutigen Lichtstandards und -kriterien führen werden, in ihre Planung einzubeziehen.

PREFACE

In recent years, the study of the psychobiological effects of light has come forth as an important subfield of lighting research. Research on diurnal variation of daylight, alerting and relaxing effects of light, and seasonal affective disorder, is worldwide. Even if the non-visual effects of light have been known for a considerable time, it is only during the last twenty years that these properties have been brought to the attention of the lighting society (Küller, 1981).

Several CIE committees (TC3-16, Psychological aspects of lighting; TC6-11, Systemic effects of optical radiation on humans; TC6-16, Psychobiological effects of lighting; TC6-17, Spatial and temporal variability of radiation exposure and human behaviour) have been working with related issues. A joint workshop including the above committees was held at the CIE Session in Melbourne, 1991. The objectives of the workshop were to summarise the state of the art; to suggest directions for future research; and to provide guidelines for the preparation of the final CIE-reports of the involved committees (Küller, 1991a).

It was decided that the different committees should continue their work in the ways already outlined. Concerning the question of parallel work being done by the various CIE committees, this could not be completely ruled out. However, the different committees were to approach the problem area by different routes and, therefore, the outcomes were likely to be complementary rather than identical. Concerning the work of TC6-16, it was suggested, amongst others, that a bibliography should be compiled, treating *the influence of daylight and artificial light on diurnal and seasonal variations*. It was further suggested that a basic list of key words might be helpful in order to promote communication in this rather complex field. Considering the rapid expansion of the research area, it was recommended that the reviewed material be compiled on a computer diskette (Küller, 1991b).

In 1991, the Environmental Psychology Unit at the Lund Institute of Technology managed to secure a six year grant for lighting research, and it became feasible to include the bibliographical work within the framework of this project. A great number of publications, including books, scientific papers, original research reports, and reviews of related fields, have been collected and compiled on a computer by the project assistant. A list of basic key words has been developed especially focusing human responses to ocular light stimulation. The chairman of the committee has then checked and corrected the material and composed a brief overview of the subject area, including basic key words for the various sub-areas. Finally, the working members of the committee have provided complementary additions or suggestions for exclusions, and the advisors have been given the opportunity to comment on the text.

The material was presented at a second workshop held at the CIE Session in Warsaw 1999. At this meeting it was decided that the bibliography should be presented in a printed version. During the final CIE ballot it was recommended that an electronic version including keywords should also be published.

On behalf of the Committee

Rikard Küller

Professor, Chairman of TC6-16

INTRODUCTION

This bibliography deals with the impact of light, both natural and artificial, upon what may be referred to as the biological clock. Mostly, references with at least some details about the lighting situation have been included. These may refer to latitude, season, time of day, outdoor or indoor illuminances, type of lamp, etc. The effects cited include physiological variations between day and night, during the menstrual cycle, and during the different seasons of the year. Also included are psychological variations in emotional tone and alertness, as well as pre-menstrual tension and seasonal affective disorder. Due to uncertain differences between different species, the selection of references has been restricted almost exclusively to research on humans.

THE BIOLOGICAL CLOCK

During the evolution of life on earth, sunlight with its characteristic spectrum and variation between day and night has played a decisive role. As a result humans display the typical 24 hour diurnal rhythm, including sleep and wakefulness, body temperature, metabolism and production of hormones. Furthermore, the variations of the physiological processes seem to be mirrored on the psychological side by an influence on behaviour and alertness (Akerstedt and Froberg, 1976; Aschoff, 1990; Aschoff et al., 1971; Halberg et al., 1959; Kelly et al., 1999; Mirmiran and Lunshof, 1996). (Basic key words: *activity, alertness, behavior, behaviour, body temperature, circadian rhythms, diurnal, heart rate, napping, nocturnal, performance, sleep, ultradian rhythms.*)

The timing of diurnal and nocturnal rhythms, and the functional variations related to them, depend on internal processes usually referred to as the biological clock. Such a clock would not be very useful, if it did not keep time with sunrise and sunset, and in order to do this, there must be some kind of synchroniser. Daylight is the most important factor in regulating these processes (Arendt, 1988; Duffy et al., 1996; Hollwich, 1979; Küller, 1981; Wehr, 1998; Wetterberg, 1993, 1994). This is mediated by the retino-hypothalamic pathway which originates in the retina and terminates in the suprachiasmatic nuclei (Brainard et al., 1988). The existence of such an "energetic portion of the visual pathway" had been suggested by Hollwich already in 1948.

According to recent chronobiological models, light entrainment is most efficient during the onset of daylight in the morning and the offset during the evening (Clodore et al., 1990; Czeisler et al., 1989; Dawson et al., 1993; Skwerer et al., 1988). Thus, variations in the length of day become a crucial factor. Still, little is known about the natural pattern of diurnal and seasonal illumination to which people are normally exposed (Cole et al., 1995; Eastman, 1990; Hebert et al., 1998; Savides et al., 1986) (*constant routines, dose-response, entrainment, free-running, phase shifts, SCN, timing, zeitgebers*)

MELATONIN AND CORTISOL

The synthesis of melatonin in the pineal gland may have a central position in mediating the effects of ocular light stimulation both when diurnal and annual variations are concerned. In the sixties, Wurtman and his associates put forth the melatonin theory of pineal function, which holds that the pineal body acts as a neuroendocrine transducer converting a neural input to hormonal output (Arendt et al., 1999; Dollins et al., 1993; Laakso et al., 1993; McIntyre et al., 1992; Wetterberg, 1978; Wurtman, 1975). A pronounced daily rhythm in the rate at which humans excrete melatonin has been well documented. Whereas the level is generally very low during the day, the excretion increases in the early evening, peaks during the night, and fades off in the early hours of the morning (Küller and Wetterberg, 1993; Lewy et al., 1980; Luboshitzky et al., 1998; Rivest et al., 1989; Sharma et al., 1989; Waldhauser et al., 1988). Results from recent studies have implicated melatonin in the functional activities of several organs, including the brain, the pituitary, thyroid and adrenal glands, and smooth muscles (Arendt and Pévet, 1991; Minneman and Wurtman, 1975). In addition to its rhythm regulatory effect, melatonin has also been found to affect the immuno-defense system (Hardeland et al., 1995). (*immuno defense, melatonin, pineal gland*)

The production of cortisol, which takes place in the adrenal cortex, is regulated by neurosecretion from the hypothalamus via the pituitary gland. Cortisol acts as a mobiliser of the organism and the concentration in the blood therefore varies with the actual demands. Basically the secretion of cortisol follows a diurnal pattern with high values during daytime and low values during the night. The highest level generally occurs early in the morning, possibly with a minor peak also late in the afternoon (Hollwich, 1979; Linder et al., 1990; Orth and Island, 1969; Osterman, 1974; Rivest et al., 1989; Sharma et al., 1989; Sherman et al., 1985). Also other hormones are known to display various circadian patterns. (*ACTH, cortisol, also other hormones*)

SHIFT WORK AND JET LAG

The chronobiological system may become disturbed during shift work, which is often associated with severe sleepiness on the night shift and to some extent on the morning shift. This sleepiness is at least as severe as that seen in hypersomnia and is associated with a strongly increased risk of accidents. The reason for night shift sleepiness is work at the circadian nadir, extended periods of wakefulness, and truncated sleep (Kecklund and Akerstedt, 1993; Akerstedt, 1995). Recent studies have illustrated the benefits of high illuminance levels during night work (Badia et al., 1991; Bougrine et al., 1995; Brainard and Bernecker, 1991; Campbell, 1995; Czeisler et al., 1990; Eastman et al., 1994, 1995, 1999; Foret et al., 1998; French et al., 1990; Kamei et al., 1994; Martin and Eastman, 1998; Thessing et al., 1994). (*accidents, activity, alertness, body temperature, circadian rhythms, ECG, EEG, heart rate, insomnia, napping, night work, performance, shift work, sleep, sleep disorders, sleepiness, ultradian rhythms*)

After time-zone flights, the environmental time is shifted abruptly. The sleep-wake cycle and the circadian system cannot follow this sudden phase shift. Therefore, some days are necessary to achieve adjustment to the new time zone. The effects resulting from the displacement between internal and external time are well known as jet lag. The sparse number of field studies do not yet allow a clear judgement on the beneficial effect of bright light treatment on jet lag (Boulos, 1998; Boulos et al., 1995; Redfern et al., 1994; Samel and Wegmann, 1997). Still, a computer program has been developed, which allows circadian researchers to display ambient lighting conditions at any geographical point at any time. Given a travel itinerary and a user-defined phase response curve for light, it recommends light exposure times that may accelerate the reentrainment of circadian rhythms to new time zones and reduce the deleterious effects of jet lag (Haupt et al., 1996). (*alertness, insomnia, jet lag, napping, performance, sleep, sleep disorders, sleepiness*)

SEASONALITY IN HORMONES

Recent studies indicate that, for persons living far from the equator, the production of various stress hormones and sleep hormones also display an annual pattern (Halberg et al., 1983; Touitou and Haus, 1993). Human melatonin secreted from the pineal gland shows a diurnal phase change from winter to summer, with earlier secretion in summer compared to winter (Arendt, 1993; Broadway et al., 1987; Illnerova et al., 1985; Laakso et al., 1994; Vondrasova et al., 1999). Two Swedish studies have shown a decline in the secretion of cortisol in morning urine during the dark season. The decline was most pronounced during a period lasting from November to December, followed by a noticeable rise already in February (Küller and Lindsten, 1992; Küller and Wetterberg, 1996). Studies in other climatic zones have indicated different patterns of cortisol secretion (Ahuja and Sharma, 1971; Kennaway and Royles, 1986; Okamoto et al., 1966; Van Dongen et al., 1998; Watanabe, 1964; Weitzman et al., 1975). (*ACTH, circannual rhythms, cortisol, GH, immuno defence, melatonin, pineal gland, serotonin, also other specific substances*)

SEASONAL AFFECTIVE DISORDER

A disturbance of the basic diurnal pattern may result in fatigue, sleep disorders, depressed mood and somatic disorders. The annual variation in number of daylight hours, together with inappropriate phase shifts in the circadian rhythm, are assumed to be main reasons for both the midwinter lethargy common in the dark season and acute states of depression occurring

during fall and spring, so called seasonal affective disorder (SAD) or, if the symptoms are less severe, sub-SAD. These are annually recurrent affective disturbances, often accompanied by vegetative symptoms, in the northern hemisphere usually appearing in the period November to February (Beck-Friis, 1993; Checkley, 1993; Lewy et al., 1987; Rosenthal, 1998; Rosenthal et al., 1984; Thompson and Silverstone, 1989; Wetterberg, 1994). (*activity, appetite, circannual rhythms, depression, insomnia, mental health, mood, performance, SAD, seasonal affective disorder, seasons, sleep, sleep disorders*)

Seasonal disturbances have been documented in several studies amongst others in Alaska, Denmark, England, Finland, Island, Norway, Scotland, Sweden, Switzerland and the central USA. In the southern hemisphere, SAD has been identified in Antarctica, Australia and in South Africa, during their winter season (e.g.: Hedge and Woodson, 1996; Levine, 1995; Lingjårde et al., 1986; Morrissey et al., 1996; Palinkas et al., 1996; Partonen et al., 1993; Weitzman et al., 1975). (*arctic, climate, latitudes, regions, tropical, also country, state or city, e.g. Sweden, California, Paris*)

LIGHT THERAPY

Exposure to bright light early in the morning has been shown to benefit many SAD patients, although some studies have successfully used early evening light to treat this disorder. Exposure to light early or late in the subjective night has been used to produce corrective phase delays or advances, respectively, in both the sleep pattern and other circadian rhythms. Supplemental light exposure in fall and winter can reduce the hypersomnia of winter depression, although the therapeutic effect may be less dependent on timing. There is also some evidence that the use of outdoor light exposure may be an alternative to conventional artificial light therapy in SAD (Beauchemin and Hays, 1996; Campbell et al., 1995; Dijk et al., 1995; Eastman et al., 1998; Lack and Wright, 1993; Lam, 1998; Lewy, 1987; Lewy et al., 1998; Lingjaerde et al., 1998; Terman et al., 1995; Wirz-Justice et al., 1996). (*dose-response, entrainment, light boxes, light exposure, light therapy, light visors, ocular hazards, phase shifts, timing*)

A large number of studies have dealt with the response of various clinical subgroups to light therapy. For instance, depressed patients with a seasonal pattern improved significantly more than those with a non-seasonal pattern, suggesting a specific non-placebo effect of light treatment in the former group (Terman et al., 1996; Thalen et al., 1995). Some improvement has also been obtained in patients with anorexia, bulimia, Alzheimer's disease and other kinds of dementia (Lam and Goldner, 1998; Mishima et al., 1994; Satlin et al., 1992; Wallin and Rissanen, 1994). (*Alzheimer's disease, anorexia, bipolar disorder, bulimia, depression; also other clinical groups and subgroups*)

OTHER KINDS OF SEASONALITY

Other seasonal patterns have been observed, which could relate to light exposure, namely, body growth, general health, birth rates, incidence of suicide and homicide, and the ability to concentrate and co-operate. Increased sick leave is found in northern countries during the winter, which might be related to reduced day length, as well as to other variables such as temperature, behavioural changes associated with weather, and to social variables (Küller and Lindsten, 1992; Küller and Wetterberg, 1996; Maes et al., 1993; Preti, 1997; Roenneberg and Aschoff, 1990; Souetre et al., 1990; Tiihonen et al., 1997). (*accidents, behavior, behaviour, birth rates, body growth, circannual rhythms, health, mortality, reproduction, suicides, violence*)

PREMENSTRUAL SYNDROME

Both ovulation and the menstrual cycle are thought to be susceptible to chronobiological influences. Studies of the oestrous cycle indicate the existence of seasonal variations in ovarian activity even in human females (Martikainen et al., 1996). This might account for the fact that blindness is associated with an age of menarche, which is earlier than normal (Reinberg, 1967; Wetterberg et al., 1976; Zacharias and Wurtman, 1964). Women suffering from premenstrual disorder (PMS) are believed to reflect a disturbance in the underlying circadian pacemaker or in the input pathways to the biological clock. Some studies suggest that light therapy may be beneficial for menstrual and premenstrual disorders (Kripke, 1993;

Lam et al., 1999; Lin et al., 1990; Maskoll et al., 1997; Parry et al., 1997). (*females, menstrual cycles, PMS, premenstrual syndrome*)

WINDOWLESS ENVIRONMENTS

Windowless or otherwise dark environments indoor environments might aggravate symptoms of SAD and sub-SAD. Static interior lighting is common in the workplace, which might disrupt the entrainment of the chronobiological system, particularly during winter. Such disruption of circadian rhythms can cause prolonged tiredness, lethargy, gastrointestinal distress, and emotional problems (Begeman et al., 1995; Keep et al., 1980; Küller and Lindsten, 1992; Küller et al., 1999; Rusak et al., 1996; Wilson, 1972). (*daylight, solar radiation, windows, windowless*)

Subterranean environments can provide very stable conditions over the day and over the year, but these conditions are also highly artificial. The variations, in terms of natural daylight, a view through the window, and in ambient indoor climate, are much smaller (Aschoff, 1985; Aschoff et al., 1986; Küller and Wetterberg, 1996; Rasmussen, 1973; Strogatz, 1986; Turner and Fine, 1991). Does this mean that underground spaces should be avoided for long term use, because of possible disturbances in hormone patterns and incidence of illness? Or should such spaces be favoured, because, after all, those who work there may avoid becoming afflicted by SAD? (*constant routines, isolation, subterranean, underground*)

LIGHTING CHARACTERISTICS

Many of the biological and psychophysiological effects of light appear to be moderated by characteristics of the light source and the lighting environment. Both the intensity of illumination and its spatial and temporal distribution may be of relevance. In indoor environments there may be additive effects of natural daylight and artificial illumination. Inadequate indoor lighting may influence the affective state, stress level and working capacity. Also the spectral composition of light is thought to be important, however, there is little agreement as yet on the spectral response curves for psychobiological mechanisms (Boivin et al., 1996; Boyce and Kennaway, 1987; Brainard et al., 1997; Küller et al., 1999; McIntyre et al., 1989; Morita and Tokura, 1996, 1998; Shanahan et al., 1997; Terman et al., 1989). (*artificial light, blue light, bright light, color temperature, colour temperature, darkness, dawn simulation, dim light, dusk simulation, fluorescent lamps, green light, illuminance, incandescent lamps, infrared radiation, light-dark cycles, lighting, luminance, red light, spectral, ultraviolet radiation, white light, yellow light*)

INDIVIDUAL AND GROUP DIFFERENCES

Differences in the chronobiological system have been found both on the individual and group levels. The most general division line seems to be between persons living close to, and far away from the equator, but also other climatic conditions may perhaps contribute to geographic group differences (Levine, 1995; Molin et al., 1996; Nayha et al., 1994; Palinkas et al., 1996). Gender and age, and certain personal qualities and habits, such as circadian type, may also be of importance (Carrier et al., 1997; Eagles et al., 1997; Jang et al., 1997). However, the single most disabling factor is the lack of eyesight. Most blind persons display free-running endogenous rhythms, but treatment with oral melatonin will induce a regular sleep/wake pattern (Czeisler et al., 1995; Folkard et al., 1990; Lockley et al., 1997; Palm et al., 1991; Ruberg et al., 1996; Sack et al., 1991, 1992). (*adolescents, adults, age, aged, blindness, children, circadian types, color blindness, colour blindness, elderly, females, gender, infants, light sensitivity, males, visual thresholds*)

CONFOUNDING FACTORS

Recent research indicates that entrainment may be mediated not only through the eyes, but also through the skin. Campbell and Murphy (1998) measured body temperature and melatonin concentrations throughout the circadian cycle before and after light pulses had been presented behind the knee. A systematic relation was found between the timing of the light pulse and the magnitude and direction of phase shifts. Other studies have failed to confirm

these findings (Lockley et al., 1998). The synthesis of vitamin D in response to ultraviolet radiation of the skin is likely to have a general physiological effect on the organism, amongst others influencing the individual's health status. Infrared radiation will influence the metabolic state of the organism by means of the hypothalamic function of heat regulation. Complicated and yet unknown interactions may exist between these effects and the effects of ocular light stimulation (Roberts, 1995). (*infrared radiation, non-visual, placebo, ultraviolet radiation*)

There might also be other alternative factors at work in synchronising biological rhythms. Significant correlations have been found with temperature and other climatic conditions. Electric and magnetic fields may be other, admittedly hypothetical, factors, and, in humans, psychosocial factors may be of considerable importance (Boyce and Kennaway, 1987; Griffiths, 1986; Honma et al., 1995; Maes et al., 1994; Molin et al., 1996). (*climate, lunar rhythms, moonlight, temperature, weather*)

CONCLUDING REMARKS

The psychobiological effects of lighting constitutes an intriguing field of research within many branches of science. Reviewing the field in 1981, Küller concluded that at least five major functional systems and several minor ones must be realised in order to account for the diverse non-visual effects of light. Today, twenty years later, we may conclude that the field has become even more complicated. Still, research on the psychobiological effects of lighting has come forth as a mature and salient field, and also as a strongly expanding subfield of lighting research. There will be reason for CIE to plan ahead in order to assimilate this new knowledge, which will undoubtedly lead to the reformulation of present lighting standards and criteria.

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BASIC LIST OF KEYWORDS

Research about the psychobiological effects of lighting is now being performed by specialists from many disciplines. The rationale behind a list of key words would be that it would make it easier for researchers of psychobiology and of lighting to communicate, and also for the practitioner, i.e., lighting engineers, architects, interior decorators, physicians and psychiatrists, to follow the latest developments. The main idea with the basic list is to give a clear view of the light sources used, the methods employed, and the main psychobiological results of the study. In the present bibliography, the labels, *light*, *chronobiology*, *general*, were employed to designate the main areas, and keywords to specify the content. The basic list of keywords is given below. The selection was based on the definition of the subject area, a scrutiny of the titles and abstracts of the various entries, and a compilation of keywords provided by the authors themselves. The list may be supplemented with more specific terms whenever needed. (Bold figures indicate the number of entries for each keyword.)

accident(s) **13**
ACTH (adrenocorticotrophic hormone) **25**
activity **59**
age **56**, *infant(s)* **16**, *child(ren)* **38**,
adolescent(s) **67**, *adult(s)* **357**, *elderly*
46, *aged* **146**
alertness (vigilance) **112**
Alzheimer's disease **8**
anorexia **12**
appetite **75**
arctic **25**
artificial light **35**
behavior, behaviour **62**
bipolar disorder **74**
birth rate(s) **19**
blindness **41**
blue light **8**
body growth **27**
body temperature **169**
bright light **322**
bulimia **16**
circadian rhythm(s) **661**
circadian type(s) **33**
circannual rhythm(s) **145**
climate **30**
color blindness, colour blindness **2**
color temperature, colour temperature **5**
constant routine(s) **46**
cortisol **140**
darkness **65**
dawn simulation **12**
daylight **104**
depression **287**
dim light **132**
diurnal **46**
dose-response **20**
dusk simulation **1**
ECG (electrocardiogram, EKG) **15**
EEG (electroencephalogram) **116**
entrainment **150**
fluorescent lamp(s) **29**
free-running **50**
gender **61**, *female(s)* **117**, *male(s)* **71**
GH (growth hormone) **18**
green light **9**
health **41**
heart rate **27**
illuminance **223**
immuno defence **14**
incandescent lamp(s) **4**
infrared radiation **5**
insomnia **43**
isolation **42**
jet lag **47**
latitude(s) **20**
light box(es) **13**
light-dark cycle(s) (photoperiod) **136**
light exposure (photic stimulation) **58**
lighting **76**
light sensitivity **20**
light therapy (phototherapy) **368**
light visor(s) **12**
luminance **8**
lunar rhythm(s) **6**
melatonin **309**
menstrual cycle(s) **50**
mental health **9**
mood **208**
moonlight **3**
mortality **9**
napping **17**
night work **63**
nocturnal **53**
non-visual **18**
ocular hazard(s) **10**
performance **97**
phase shift(s) **239**
pineal gland **63**
placebo **62**
premenstrual syndrome, (also) *PMS* **45**
red light **26**
region(s) **148**, (also country, state or city,
e.g.) *Sweden, California, Paris*
reproduction **27**
review **75**
SCN (suprachiasmatic nucleus) **26**
seasonal affective disorder, (also) *SAD* **380**
season(s) **192**

serotonin **34**
shift work **95**
sleep **316**
sleep disorder(s) **55**
sleepiness **64**
solar radiation (sunlight) **50**
spectral **77**
subterranean **5**
suicide(s) **29**
temperature **42**
timing **200**
tropical **8**

ultradian rhythm(s) **140**
ultraviolet radiation **15**
underground **5**
violence **12**
visual threshold(s) **10**
weather **16**
white light **36**
window(s) **14**
windowless **10**
yellow light **2**
zeitgeber(s) (pacemaker) **87**

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