BROAD SPECTRUM LIGHT AND NIGHT-TIME MENTAL PERFORMANCE: EFFECTS OF INTENSITY AND DURATION

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ABSTRACT

The present study examined the effects of light intensity and duration on mental performance at night. A number of investigations have found light levels as low as 500 lux can have a significant impact on cognition, but there have been few, if any, systematic experiments that have investigated the potential trade-off between the intensity of the light and its duration. Light levels of 100 (normal room lighting), 300, 600 and 1,000 lux were paired with one of two different light exposure times: 15 and 60 minutes. Sixteen volunteers completed tests of critical thinking, simple maths, letter cancellation, recall, and recognition between 2300 and 0100 hours once a week for four consecutive weeks. Body temperature and subjective sleepiness levels were also recorded. The results showed that, in general, light intensities, irrespective of duration, of 300 and 600 lux had a positive effect on critical thinking and recognition memory. In contrast to some previous findings, there was little or no effect on sleepiness levels, core body temperature, recall, letter cancellation or the simple maths task. Surprisingly, the 1,000 lux light level had no effect on any of the tasks. It was concluded that changes in the intensity of broad-spectrum light can affect night-time cognitive performance, but that the intensity of the light cannot be traded for duration. However, further investigation of the manner in which light intensity is varied, either by distance from the light or by varying the brightness of the light source, is required before firm conclusions can be drawn.

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INTRODUCTION

Background

All living organisms undergo rhythmic activities, either those generated from within their own body structures (endogenous), or those operating in their surrounding environment (exogenous). These rhythms have been defined as "a sequence of events that repeat themselves through time in the same order and at the same interval" (Minors & Waterhouse, 1981, p. 2). However, rhythms can and do change their characteristics, such as by the period, amplitude, or phase of the rhythm.

Of the numerous exogenous cycles, one of the most obvious is the 24-hr night/day cycle that "submits plants and animals to a highly predictable daily rhythm of light and temperature" (Moore-Ede, Sulzman, & Fuller, 1982, p. 1). Another is the daily cycle of tidal rhythms caused by the gravitational pull of the moon.

Most endogenous rhythms, or oscillations, although linked to rhythmic changes in the environment, have been found to persist independently of these changes when an organism is cut off from them. For example, when an organism is exposed to constant light or constant dark all endogenous rhythms continue to cycle, although the period usually exceeds that of the 24-hr period by approximately 1 hr. Such rhythmic activity is said to be *free-running* (Minors & Waterhouse, 1981).

One of the first reported studies of the persistence of the circadian rhythms in the absence of environmental cues was by Jean Jacques d'Ortous de Mairan, who, in 1729, reported how a heliotrope plant still opened its leaves during the day and closed them at night, despite the absence of sunlight (Moore-Ede et al., 1982).

In 1827, Augustin de Candolle first demonstrated that circadian rhythms "ran free" with their own endogenous period when he found that the daily leaf movement of a plant persisted in total darkness and that the leaves opened an hour or two earlier each day, thereby displaying a periodicity of 22 to 23 hrs (Moore-Ede et al., 1982).

The shift from studying circadian rhythms as biological curiosity to critical time-keeping devices can be traced back to August Forel in 1910. Forel, who breakfasted outside his home each morning, noticed that worker bees arrived to sample some marmalade on the table. After a few days, Forel noticed that the bees arrived just before breakfast was served each day. When he was forced to eat inside as a result of the bees' constant attention, Forel found that the bees continued to arrive for several days, as if expecting to find food. Furthermore, he noticed that the bees only arrived at that time of day and did not come back at any other time. Forel, and a graduate student, Beling, in 1929 undertook an experiment where bees were marked and offered sugar water at an artificial feeding place at the same time each day. On the day of the study when no food was offered, each marked bee arrived at the training time, or very close to it. Furthermore, Forel and Beling found that if the bees were offered food on a 19-hr or 48-hr cycle, they showed no capacity for recognising the pattern and entraining to it (Moore-Ede et al., 1982).

During the course of evolution, certain frequencies of oscillations in biological systems have developed as an organism's internal clock, known as the circadian timing system. Franz Halberg in 1959 coined the term *circadian*, standing for endogenously generated cycles lasting approximately 24 hrs (Moore-Ede et al., 1982). The cellular machinery which generates this ability for temporal organisation in organisms is known as the biological clock, and its output as a circadian rhythm (Dunlap, et al., 1995). Human beings, like other animals, have been found to have these autonomous body clocks which impact on a large array of functions, including body temperature, sleepiness, secretion of hormones and neurotransmitters, and performance (Eastman, 1991). The most familiar of these is the rhythm that controls sleepiness and wakefulness (Kalat, 1998).

For any structure to be considered a biological clock it must be a structure that measures the passage of time independently of any input from the environment, and it must be used to time biological events. To be able to keep time, clocks must have a degree of resolution that is sufficient for the timing task. They must also have uniformity: sufficiently accurate periodicity enabling the prediction of other periodic phenomena in the environment. Biological clocks generally have relatively high resolution; they can measure time intervals shorter than their own. They also have high uniformity showing little variation in period from cycle to cycle (Moore-Ede et al., 1982).

Underlying Theories

The Physiological Location of Circadian Timekeeping

Once researchers had defined circadian rhythms and established that all mammals have them, their efforts then focused on what part of the brain controlled this rhythmicity. As early as 1918, neuropathological studies in humans indicated that an area in the interior hypothalamus was important in the regulation of one major rhythm - sleep (von Economo, 1929, cited in Moore-Ede et al., 1982).

In the 1950s and 1960s, Carl Richter undertook an extensive series of experiments (Richter 1957, 1958, 1967) where he placed lesions in various locations throughout the nervous system of rodents, finding that the only place where lesions disrupted the circadian rhythmicity was in an area of the anterior hypothalamus, now known as the suprachiasmatic nuclei (SCN). Over several decades of research, Richter used the free-running activity rhythm of blinded rats as the marker of the circadian rhythm, subjecting his animals to a range of conditions including "the removal of adrenals, gonads, pituitary, thyroid, pineal, or pancreas; electroshock therapy; induced convulsions; prolonged anesthesia, and alcoholic stupor" (Moore-Ede et al., 1982, p. 152). He found that each of these procedures failed to disrupt the rat's free-running circadian rhythm.

These early studies, and many since on both human beings and animals, lend support to the hypothesis that the SCN, located in the hypothalamus (see Figure 1), is the main circadian pacemaker.

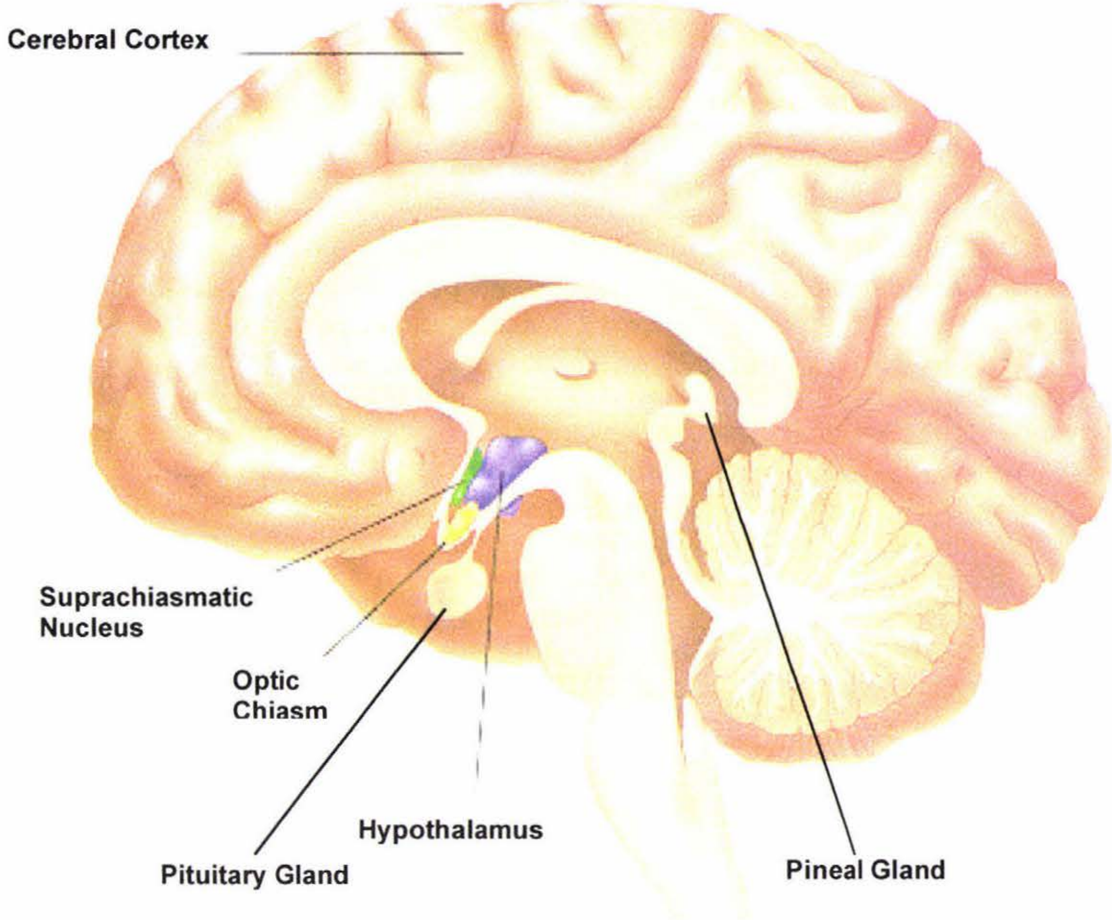

Figure 1: Midsagittal section of the human brain showing the pineal gland, pituitary gland, suprachiasmatic nucleus, and hypothalamus. Source: Kalat, 1998, p. 247.

It is known that circadian rhythms are entrained (adjusted or re-set) by environmental cues known as *zeitgebers* (time-givers). The most significant environmental cue to the SCN is light. Information travels via the optic nerve, where a small pathway, the retinohypothalamic tract, conveys information to the SCN about the light-dark cycle (Kronauer & Czeisler, 1993).

Klein and Moore (1979) found that sectioning of all visual pathways in animals beyond the retinohypothalamic tract does not affect stable entrainment, but that sectioning of the retinohypothalamic tract itself abolishes entrainment. This outcome further supports the notion that the primary circadian pacemaker involves the SCN. Although the existence of the retinohypothalamic tract has not been directly observed in humans as yet, it is almost certain it exists – as in other mammals.

Until recently, conclusive evidence to support the hypothesis that the SCN is the main circadian pacemaker had not been found. Moore (1995) concludes that four lines of evidence now strongly support that idea that the SCN is in fact the primary circadian pacemaker: the SCN is a major site of the retinohypothalamic tract input; ablation of the SCN eliminates circadian function; circadian functioning is maintained in the isolated SCN, both *in vivo* and *in vitro*; and transplantation of foetal SCN tissue into the third ventricle of arrhythmic, SCN-lesioned animals restores rhythmicity. However, research on monkeys found body temperature persisting, despite drinking behaviour becoming arrhythmic following total bilateral lesions in the SCN (Fuller et al., 1981). This research suggests that the circadian rhythm of core body temperature is controlled by a clock outside the SCN.

It now appears that there are two groups of rhythms in all mammals (including humans) which are driven by different pacemakers. Rhythms such as REM sleep, core body temperature, plasma cortisol, and urine potassium excretion are driven by one pacemaker, known as the body temperature rhythm. Slow-wave sleep, skin temperature, plasma growth hormone, and urine calcium excretion are driven by another pacemaker, known as the sleep-wake cycle rhythm (Moore-Ede et al., 1982). This conclusion is based on such studies as that carried out by Czeisler, Weitzman, Moore-Ede, Zimmerman, and Knauer (1980) in which humans were isolated from environmental cues for periods of at least two months. It was found that their circadian rhythms desynchronised into the two above-mentioned groups, and that this desynchronisation was not linked to the age or psychological state of the participants. Further, Czeisler and his co-workers found that both pacemakers changed their period during the study, indicating that there must be mutual coupling between the two. The coupling links are thought to be neural or hormonal and act to ensure mutual entrainment under normal conditions.

Characteristics of Circadian Rhythms

Moore (1995) believes that circadian rhythms have two prominent characteristics: they are normally entrained to the light-dark cycle, and when this zeitgeber is absent, the rhythm "free runs" with an approximate 24-hr period. As a result of these two properties, researchers have inferred that there are three essential components of a circadian timing system: visual pathways that mediate the entrainment process, circadian pacemakers, and efferent pathways that combine with pacemakers to effector systems which express circadian functioning (Moore, p. 89).

Most organisms have to adapt to environmental changes on a daily basis, such as changes in the light-dark cycle due to the rotation of the earth on its axis (Turek, 1997). The vast majority of organisms (if not all) on earth contain at least one biological clock that is normally synchronised with, or entrained to, the daily light-dark cycle. As a result of this entrainment, the biological clock is re-set each day to match the 24-hr period of the earth's rotation. However, when placed in total darkness, or total light, the rhythms regulated by the internal clock persist, but usually with a period longer than the earth's 24-hr orbit.

In order to remain synchronised with the 24-hr light-dark cycle, the circadian clock requires a method of receiving light information (Turek, 1997). However, this information can be obtained other than through the visual pathway. A study by Menaker and Underwood (1978, cited in Turek) found in studying extra-retinal photoreceptors in sparrows that the eyes were not needed for the light-dark cycle to entrain the circadian rhythm. As a result, the pineal gland was identified as having an influence; it was shown to have photoreceptive properties and was located in a position in many avian and reptilian species to easily detect external illumination. Furthermore, when the pineal gland was removed and isolated *in vitro*, it still produced an entrained (to the light-dark cycle) and a free running (in constant darkness) rhythm of pineal melatonin secretion. The pineal gland manufactures and releases the hormone, melatonin, and is "a small unpaired central structure, essentially an appendage of the brain" (Arendt, 1995, p. 6). The pineal gland is, in most species, a stalk connection to the habenular commissure, located just dorsal to the anterior cerebellum (refer to Figure 1).

The Pineal Gland and Melatonin

Melatonin, released by the pineal gland, reaches all parts of an organism with its primary role probably being that of a co-ordinator of biological rhythms. It has been found to influence, particularly, the sleep-wake cycle, but also acts as an internal calendar for the timing of seasonal events, as an internal clock for the timing of daily events, and appears to help synchronise circadian rhythms (Arendt, 1995). The pineal gland's primary function is to "transduce information concerning light-dark cycles, particularly for the organisation of body rhythms, via the secretion of its major hormone, melatonin" (Arendt, p. 8).

In organisms with a SCN, circadian rhythms of melatonin synthesis and release are regulated via neural signals from the SCN. When the SCN is destroyed, pineal melatonin rhythm is abolished (Turek, 1997). A dense concentration of melatonin receptors in the SCN suggests that there may be a feedback loop between the SCN and the pineal gland (Weaver, Rivkees, Carlson, & Reppert, 1995). Furthermore, melatonin secretion is entrained to the 24-hr light-dark cycle via the retina and the retinohypothalamic tract to the SCN, and is believed to be circadian, as it has been found to persist in constant darkness and in blinded animals (McIntyre, Norman, Burrows, & Armstrong, 1989).

As a result of light-dark zeitgeber information received by the SCN, the pineal gland secretes melatonin during the night. Nocturnal values of melatonin are 30-70 times diurnal concentrations (Minors & Waterhouse, 1981). In the late 1950s, it was found that the pineal gland synthesises and releases melatonin into general circulation in the human body in high amounts during the night and low amounts during the day (Turek, 1997). Thus, as might be expected, melatonin release during the winter months, when the photoperiod is short, is greater than that during the summer.

Body Temperature, Melatonin, and the Sleep-Wake Cycle

Ogle, in 1866, studied the body temperature of human beings, and was the first to demonstrate the link between body temperature and endogenous circadian rhythms in mammals. Ogle found that body temperature rose in the early mornings prior to waking, and fell during the evening whilst his participants were still awake, and that this rhythm could not be explained by reference to any environmental influences (Moore-Ede et al., 1982). The circadian rhythm of body temperature is believed to be driven by a pacemaker located outside the SCN, but its actual origin is not known.

Body temperature displays a distinct cyclic variation on any given day (Reilly, Atkinson, & Waterhouse, 1997). The temperature at the core is relatively constant at 37 degrees celsius, with a daily range of oscillation between 0.6 and 1.0 degrees. This core temperature is maintained despite changes in environmental conditions (Reilly et al.). The normal diurnal temperature curve is a fall to minimum at dawn (between 0400 and 0600 hrs), with a considerable rise during the morning, another minor rise around noon, and a maximum peak in the afternoon (Van Loon, 1980). Interestingly, as the body temperature rises during the early morning an individual will become more alert and start to feel better, despite having been deprived of sleep for the entire night (Eastman, 1991).

Melatonin has been implicated in thermoregulation, with researchers finding that pinealectomies, and, indeed, continuous light, abolishes the deep body temperature rhythm in sparrows and pigeons. In mammals, it has been noted that melatonin acutely lowers body temperature, pinealectomies can increase it, and melatonin injections can reverse the impacts of pinealectomies (Arendt, 1995). Clusters of cells located in the hypothalamus regulate body temperature, and there is a neural link between the cells of the SCN and the hypothalamic area that controls core body temperature (Reilly et al., 1997).

Arendt (1995) believes that melatonin possibly has two effects on temperature, "an immediate action to lower body temperature and a secondary entrainment of the rhythm" (p. 180). How the two interact is unclear, but it may be that melatonin's effect of lowering body temperature may be an integral part of the entrainment process.

Studies of humans in isolation have repeatedly shown desynchronisation of the sleep-wake cycle and the core body temperature cycle. Furthermore, the circadian rhythm of core body temperature has been shown to be linked with the sleep-wake cycle, and has been found to be very sensitive to light levels (Moore-Ede et al., 1982). It has long been accepted that light influences circadian rhythms. As a result, a considerable amount of research has been generated to gain some understanding of the complex relationship between light and circadian rhythms.

The Impact of Light on Circadian Rhythms

Light stimulates change in the circadian rhythm via the secretion of melatonin. This was first discovered by Dr. Alfred Lewy who, after returning to Australia from a trip nine time zones away, drew a sample of his own blood for a newly developed melatonin assay. Although expecting to find large amounts of melatonin (as the sample was drawn during the night) he found only very low levels of melatonin. He wondered whether the sunlight on the trip home suppressed melatonin secretion (Eastman, 1991). Subsequent experimentation showed that light suppressed nocturnal melatonin secretion, but only at high-intensity levels. Lewy hypothesised that humans may require bright light for the entrainment of circadian rhythms and that artificial bright light may be able to be used to effect this change (Eastman, 1990). Countless studies have now shown that light of a suitable intensity and spectral composition can suppress melatonin production at night (Arendt, 1995).

The impact of light on melatonin secretion is directly dependent on the intensity, duration and timing of the exposure. Light can induce a phase delay (by suppressing melatonin secretion, so activity continues longer than normal), a phase advance (by commencing melatonin secretion so that activity ceases earlier than normal) or no phase shift at all, depending on when the light exposure has occurred with respect to a mammal's subjective day or night (Moore-Ede et al., 1982). The largest phase advance occurs early in the subjective night (when a diurnal animal has just gone to bed) and the largest phase delay occurs in the late subjective night (when a diurnal animal has just woken up). Light exposure during the subjective day has been found to have little or no impact (Moore-Ede et al.).

Although the human body can partially adapt the circadian rhythm to permanent night-work, this adaptation is never a mirror image of the natural cycles, and these rhythms rarely shift completely to match the work-sleep cycle of the shiftworker (Eastman, 1990). Knauth and Rutenfranz (1980) found that even after three weeks of continuous night-work, there was only a part adaptation of the daily body temperature rhythm. One reason for this is that shiftworkers revert to sleeping during conventional hours during their days off, so as to engage in social, sporting, and family activities which are typically scheduled around a diurnal schedule. These zeitgebers, coupled with the natural light-dark cycle, oppose the shifting of circadian rhythms (Eastman, 1991).

As global markets widened and demand for goods and services increased, shiftwork became an increasingly vital option for a number of industries. Consequently, research into the effects of shiftwork, and particularly night-work, became more urgent. Specifically, as the consequences of working at night were examined in terms of production quality and output, accidents in the workplace, and health and disruption of the personal lives of shiftworkers, strategies to eliminate or reduce these detrimental outcomes were sought.

Research into the use of different shift systems produced mixed results, with no particular shift system producing an effective solution to the problems specific to nightwork . A number of researchers (e.g., Hornberger & Knauth, 1995; Knauth, 1993; Penn & Bootzin, 1990; Wedderburn, 1993) have failed to find a shift system that consistently has a positive effect on the performance, health, well-being, and social lives of shiftworkers.

However, there is some disagreement over these matters. For example, Penn and Bootzin (1990) in a review of behavioural and cognitive methods for enhancing alertness, enhancing performance, and decreasing long-term negative consequences of shiftwork, found some potential for the techniques described above. They concluded that most of the techniques showed some promise, but that no one particular combination of techniques showed sufficient capability to address the real problems of performance, health, and well-being. Penn and Bootzin recommended further research into the arousing effects of bright light, reporting that bright light had been found to have positive effects on energy levels and arousal.

As many of the effects of working shiftwork were physiological, and therefore not easily addressed by behavioural techniques, researchers proposed that bright light appeared to offer some real hope for addressing the sleepiness and fatigue issues frequently observed in those working the nightshift. Given what researchers already knew about circadian rhythms and their resilience to change, the finding that bright light appeared to impact on the circadian rhythms during the nightshift generated a lot of excitement. The possibility that a strategy to combat the powerful effects of the circadian rhythm on shiftworkers had been discovered, resulted in a number of studies being undertaken to replicate these early findings.

Badia, Myers, Boecker, and Culpepper (1991) have highlighted the effects of light using four conditions: alternating 90 mins of dim light (less than 50 lux) or a bright light (5k lux to 10k lux), continuous bright light, or continuous dim light. In the control condition, participants who were exposed to the same dim and bright light 90-min conditions were exposed during daytime hours. Badia et al. measured differences between the groups in temperature, EEG spectral power and dominant frequency, sleepiness levels, and performance. The latter included digit recall, logical reasoning, two-letter cancellation, two-column adding, serial addition/subtraction, and a continuous performance task. The researchers found that for the alternating light conditions, body temperature decreased under dim light, but either increased or stayed the same under bright light. Under continuous light, body temperature dropped sharply across the night under dim light, but dropped only slightly under bright light. Sleepiness was reported greater under dim light than bright light, with the difference increasing over the night. The EEG showed that alertness was greater under the bright light condition, and performance on behavioural tasks, especially the digit recall, two letter search, and serial add/subtract, was significantly better. Badia et al. found that increases and decreases in light intensity resulted in increases and decreases in temperature, implying that melatonin secretion had been altered. Furthermore, the changes in temperature were usually observed within 30 mins of exposure.

Campbell and Dawson (1990) undertook a study where 25 participants completed several performance tasks under a low light condition (10 to 20 lux) for 8 hrs, and then on the second night performed the same tasks under either medium light (100 lux) or bright light (1,000 lux). The tasks included logical reasoning task, spatial manipulation and processing abilities, and a four-choice reaction time task. Those participants in the 1,000 lux condition maintained statistically significantly higher levels of alertness, and showed improved cognitive performance (but no effect on reaction time) compared to those in the other two light conditions. It was concluded that performance on tasks with a strong cognitive component is substantially augmented by continuous exposure to bright light.

In another study examining the effects of bright light on alertness and performance over a 24-hr period, Daurat et al. (1993) exposed eight males (two groups of four) to bright light (2,000 to 2,500 lux) and dim light (< 150 lux) over 2 nights, 2 weeks apart. Data on self-rated alertness, performance tests (including one-letter cancellation, logical reasoning, visual discrimination), EEG vigilance, rectal temperature, and wrist motor activity were collected throughout a 12-hr night-time period. The bright light condition showed that the circadian trough of motor activity was delayed by 2 hrs but did not modify the usual 24-hr pattern of body temperature. There were statistically significant increases in objective and subjective alertness and improved performance in the bright light condition.

As well as researching the effect of bright light on circadian rhythms and performance during night-work, some investigators turned their attention to identifying the level of light intensity necessary to have an influence on behaviour. For example, Myers and Badia (1993) exposed 15 participants to a control condition (<50 lux) and three light conditions (500, 1,000, and 5,000 lux), comparing body temperature and self-reported alertness across the four conditions. It was hypothesised that temperature and alertness could be altered by bright light, but only after the usual melatonin onset time of 2100 hrs. Thus, temperature and alertness were measured before and after 2100 hrs onset time. There were no differences across light conditions prior to 2100 hrs for any of the light levels, but temperatures and alertness scores obtained under the 500, 1,000, and 5,000 lux conditions after 2100 hrs were all statistically significantly different from the control, but not from each other. Myers and Badia tentatively suggested their results indicate that there is a threshold below which bright light will fail to suppress melatonin secretion; they suggest this threshold is approximately 500 lux.

Exposure to bright light can phase advance or phase delay both the temperature trough and night-time release of melatonin, depending on the time of exposure (Badia et al., 1991). Lewy, Wehr, Goodwin, Newsome, and Markey (1980) found exposure to bright light (1,500 lux) during the melatonin release period of 2100 to 0700 hrs showed plasma melatonin levels began to decrease within 10 to 20 mins, and, within an hour, daytime melatonin levels were reached. When the participants were subsequently returned to dim light, the melatonin levels returned to night-time levels within 40 mins.

Melatonin administered during daytime has resulted in reports of sleepiness, fatigue, and performance decrements, suggesting that the night-time decrements observed in alertness and performance may be due to melatonin. Thus, melatonin increase seems to cause a fall in alertness and task performance. Bright light suppresses melatonin release and this is most likely the reason why alertness and task performance improve under bright light (Badia et al., 1991).

In Search of the Light Intensity Threshold

The threshold for melatonin suppression in humans was initially assumed to be around 2500 lux. Sunlight can produce light intensities greater than 100,000 lux, but indoor light intensity rarely exceeds 500 lux (Eastman, 1991). McIntyre et al. (1989) reported that exposure for at least 1 hr at lux levels of 1500 or more was enough to suppress melatonin secretion. Further experiments undertaken on patients suffering from bipolar affective disorder, who were thought to be sensitive to an increased photoperiod, had their melatonin secretion suppressed by exposure to 2 hrs of 500 lux levels (McIntyre et al.).

McIntyre et al. (1989) carried out an experiment on 13 participants, subjecting them to five light intensity conditions, 3,000, 1,000, 500, 350, and 200 lux over a 7-wk period. Blood samples were obtained at 2200 hrs and at 0500 hrs, with the light exposure occurring between midnight and 0100 hrs on the night of the experiment. Following exposure to the light, participants were allowed to continue to watch television or sleep, with a background light of between 10 and 20 lux. Melatonin suppression was observed for all light intensities, except the 200 lux level. Even at the 200 lux level, it was found that melatonin levels measured at 0200 hrs were higher than those at 0030, 0045 and 0100 hrs, but not different from the 2400 hrs levels. This implies that suppression of melatonin had taken place. When participants returned to the background light, the melatonin concentrations began to increase immediately, and within 2 hrs were at the levels measured prior to the light exposure.

McIntyre et al. (1989) suggest that short exposure to light intensities of 1,000 lux or more are sufficient to obtain melatonin suppression to near daytime levels. They also propose that "1 hour of exposure to light of less intensity is capable of suppressing nocturnal melatonin and light of just 200 lux has some effect (16% suppression)"(p. 153). These results are consistent with the findings reported by Lewy et al. (1980) who found a 50% reduction in melatonin secretion in two participants exposed to 1,500 lux intensity, and by Boyce and Kennaway (1987) who reported a 30% suppression of melatonin when participants were exposed to 500 lux of light. McIntyre et al. discussed the differences in experimental design of the three studies, pointing out that Lewy et al. ran their light exposure conditions later in the night (between 0200 and 0400 hrs). They noted that this may mean that a light that is of insufficient intensity to suppress melatonin secretion at later hours, can do so at midnight. They go on to suggest that at midnight the synthesis of melatonin may be particularly sensitive to interference; hence, the differing results. Furthermore, they suggest that 1 hr exposure to light intensities of 1,000 lux or more is sufficient to suppress melatonin to near daytime levels.

Myers and Badia (1993) were interested to find out whether increases in body temperature and alertness would be directly related to light intensity, and whether these effects would occur only after the melatonin onset time (of around 2100 hrs). They exposed 15 male college students to light intensities of 50, 500, 1,000 and 5,000 lux on four separate occasions over a 4-wk period. The order of the light intensity was randomised for each participant. Body temperature, and subjective and objective alertness were measured. They found no difference in temperature across the four light intensities when temperature was measured between 1900 and 2100 hrs. However, temperature measurements between 2100 and 2300 hrs showed the effect of light intensity decreasing under 500, 1,000 and 5,000 lux light intensities. Furthermore, body temperature levels changed under the different light intensities as the night progressed, with the 500, 1,000 and 5,000 lux light levels all producing higher temperature than the 50 lux condition. However, there was no difference in temperature between the other bright light intensities. No differences were found in the objective measures of sleepiness across light levels at either pre- or post-melatonin release time. However, for the subjective sleepiness measure, significant differences were found after 2100 hrs for the 500, 1,000 and 5,000 lux light levels compared to the 50 lux level. The authors proposed that the threshold for melatonin suppression, body temperature enhancement and increased alertness is about 500 lux. They also note that their findings on body temperature suggest that melatonin plays a vital part in thermoregulation, mediating the effects of photic stimulation on body temperature.

McIntyre et al. (1989) reported significant melatonin suppression at light intensities greater than 350 lux. This study was undertaken between 0000 and 0100 hrs, which is less into the melatonin secretion period than the study of Lewy et al. (1980), who undertook their study between 0200 and 0400 hrs, and found that a bright light pulse of 1,500 lux or brighter for an hour is required to suppress melatonin. The study by McIntyre et al. suggests that less light is required to suppress melatonin early into the suppression window than is required later in the night.

Lewy et al. (1980) found nocturnal melatonin suppression with a light intensity of 2,500 lux, but not at 500 lux. Bojkowski et al. (1987) reported significant reduction in melatonin suppression at 300 lux, but the suppression was even more pronounced at 2,500 lux. Furthermore, a study by Laakso, Hatonen, Stenberg, Alila, and Smith (1993) demonstrated that 1 hr of night time exposure to 500 lux significantly reduced melatonin onset time, without affecting the usual suppression cessation time.

Despite the findings by Bojkowski et al. (1987) and Laakso et al. (1993) Wever (1994, cited in Boivin, Duffy, Kronauer, & Czeisler 1994), continued to argue that exposure to light intensity greater than 2,500 lux is required to exert direct biological impacts on the circadian pacemaker, and that findings using light intensities of less than 1,500 lux can be attributed solely to behavioural factors. In order to test Wever's statement, Boivin et al. undertook a study on nine male volunteers, subjecting them for 5 hrs to 1,260 lux in a 16-day laboratory study. Participants were isolated from environmental time cues and the experimenters were trained to avoid relaying any information that suggested the time of day-night, or the nature of the experimental conditions. The results showed that exposure to moderate light levels (1,260 lux) produced advances of the circadian phase, compared to a control group who were exposed to darkness in place of the light condition. Furthermore, the timing of the sleep-wake cycle, physical activity, meals, and social contacts were all controlled for; therefore, behavioural factors could not have contributed to the findings, as Wever had suggested.

The study by Boivin et al. (1994) supports the idea that light levels alone of less than 1,500 lux, can suppress melatonin and decrease sleepiness. This finding, and others demonstrating the ability of light to increase alertness and reduce sleepiness (Dawson & Campbell, 1991; Daurat et al., 1993; Myers & Badia, 1993) allowed researchers to begin to unravel the complexities surrounding light as an effective intervention for problems associated with night-work. In particular, research was needed to understand what factors influence mental performance of night-workers and how light interventions might affect the mental processes involved.

Influences on Work Performance at Night

To understand how light influences night-workers' ability to perform their jobs, an appreciation of the physiological changes that occur during the night hours and how these impact on work performance is required. It appears that sleep loss may cause a general slowing of psychomotor performance and information processing, but does not appear to have a compelling effect on watch-keeping and vigilance, due in part to these tasks requiring only continuous attention; speed is only of secondary importance (Gillberg & Akerstedt, 1998). In a study into the effects of sleep loss on performance, Gillberg and Akerstedt deprived 18 male students of sleep for 64 hrs and recorded their subjective sleepiness levels and their performance on a vigilance task, which required them to track a moving light stepwise over 14 equally spaced horizontal positions. They found that performance deteriorated gradually across the experiment, and was inversely related to subjective sleepiness. The effects of sleep loss were noticed even after the first minute and clearly evident within 8 mins of when testing commenced. These results support the hypothesis that performance decrements may appear after only 5-10 mins on a task following sleep deprivation. The researchers proposed that these findings indicate that sleep loss may affect performance on attention and cognitive functions differently than psychomotor functions.

In addition, the use of light interventions to decrease sleepiness and increase alertness has been shown to be successful in the studies by Dawson and Campbell (1991), Daurat et al. (1993), and Myers and Badia (1993). Furthermore, whilst the effects of bright light exposure on shifting circadian rhythm phases and increasing alertness have been clearly demonstrated, the duration, intensity, and number of nightly exposures to bright light has not (Thessing, Anch, Muehlbach, Schweitzer, & Walsh, 1994). Thessing et al. found that a single exposure to bright light of approximately 9,300 lux between midnight and 0400 hrs significantly decreased objectively measured sleepiness (recorded with a wrist activity monitor at 1-min intervals) and improved performance on the subsequent night, whereas a 2-hr exposure of the same intensity showed no difference to the dim (315 lux) light condition.

In summary, across a number of studies, sleepiness has been found to profoundly increase in the early morning hours, and is paralleled by an abrupt drop in cognitive performance (Leproult, Van Reeth, Byrne, Sturis, & Van Cauter, 1997). Furthermore, although research up to now has identified that light levels of 1,000 lux or more are effective at reducing sleepiness across the night, little is known about the effects of exposure duration, or about the possible interaction between exposure time and light intensity.

The Present Study

The research to date shows that bright light can affect mental performance during the night, providing significant benefits by reducing the effects of sleepiness experienced after the onset of melatonin secretion. However, there have been few systematic studies of the effects of bright light intensity, and whether intensity can be traded for duration. As earlier described, previous studies suggest that the minimum level of light required is between 200 and 500 lux.

With regards to the duration of bright light exposure, most studies that have considered duration (e.g., Gallo & Eastman, 1993; Laakso et al., 1993; McIntyre et al., 1989) have done so in the pursuit of testing what time period is required to suppress melatonin and/or phase shift the circadian rhythms. Studies into work performance at night and bright light levels have focused on the intensity of the intervention, with duration not being an independent variable. To date, no recorded studies could be found that have looked into the duration of bright light exposure on performance. Similarly, no studies could be located where duration and intensity of bright light interventions have been systematically varied to find out if one can be traded for the other. It is important to investigate this potential interaction between duration and intensity, for in the workplace it may not always be possible to produce sufficiently intense light to suppress melatonin. Under such circumstances, it would be valuable to know whether an increased duration of exposure would do just as well. It is surprising that no studies have investigated this possibility.

Based on research to date, the intensity of light required to reduce melatonin secretion (and therefore sleepiness levels) is expected to be between 200 and 500 lux. Furthermore, although duration has not been specifically studied with regards to work performance, an increased duration of bright light exposure is expected to have an improved effect on work performance, especially for the lower intensity levels of light. The reasoning here is that when a bright light intervention ceases, it takes only 40 mins or so for melatonin secretion levels to return to normal (Lewy et al., 1980). Provided that the light exposure occurs early in the night (around midnight), when melatonin secretion levels appear more sensitive to light exposure (McIntyre et al., 1989), it may be that only a relatively short exposure time is required to affect performance.

The main purpose of the present study was twofold. Firstly, to find out if different durations of bright light exposure influences work performance, and whether intensity and duration trade off. A secondary aim was to provide data that might more accurately pinpoint the minimum light intensity required to suppress melatonin secretion, leading to performance increments. Four light intensities were used: baseline (<100 lux), 300 lux, 600 lux, and 1,000 lux. Two duration periods of 15 mins and 60 mins were also used. All combinations of intensity and duration were investigated in a mixed factorial design with Duration being a between-groups factor and Intensity a within-groups factor.

METHOD

Participants

Sixteen individuals (8 male and 8 female) volunteered to participate in the present study. Their ages ranged from 19 to 40 (mean = 28.38, SD = 6.55. Participants were partially reimbursed for the four trips they were required to make to the laboratory, each receiving $25.00. Owing to the nature of experiments into night-work, participants are often required to undertake sleep deprivation or to participate at unusual hours. This may be the reason why only small numbers of participants are usually found in night-work studies. Numbers typically range from 6 to 15 participants.

Because of the inconvenient times participants were asked to attend the laboratory, they were allowed some input into which night each week, from Monday to Thursday, would be most suitable for them to attend. They attended the same night each week for four consecutive weeks. There was a total of 4 groups in the study, with equal numbers of males and females (2 of each) in each group. Due to unforeseen circumstances, the Wednesday night group commenced 1 week later than the other 3 groups. Furthermore, 1 participant in the Wednesday group missed the baseline (<100 lux) condition because of a family bereavement. This participant undertook the missed condition on the Monday night prior to the final week of testing for this group. (The usual Monday night group had completed their 4-wk testing by this time.) Another member of the Wednesday group also attended this special session as a "stand-in" participant, so that the real participant was exposed to conditions that, as much as possible, mimicked the night that he had missed. Thus, the real participant completed the session ostensibly in a 2-person group. The stand-in participant's results were not used.

Design

Four levels of light intensity, baseline (<100 lux), 300, 600, and 1,000 lux, and two levels of duration (15 and 60 mins) were studied in a mixed factorial design. Each participant was exposed to all 4 light levels (one weekly) in one of four groups of 4 participants. Two groups (8 participants) were exposed for 15 mins prior to behavioural assessment, with the other two groups being exposed for 60 mins prior to assessment.

Four levels of light were used with each of the two durations. The number of ways of presenting these 4 levels = 4! = 24. Thus, it was not possible to represent all possible orders of the 4 light levels. Therefore, one order was randomly selected – 300, baseline, 1,000, and 600 lux. One of the 15-min duration groups employed this order, and the other group the reverse order. Exactly the same procedure, using the same randomised order of light levels, was employed with the two 60-min duration groups.

Monday and Tuesday nights were randomly selected for the 60-min duration condition, leaving Wednesday and Thursday nights as the 15-min condition. (A schedule of the groups and order of conditions is shown in Appendix A.)

As there were two different bright light exposure duration groups (15 mins and 60 mins) two groups (4 participants to a group) were required to commence their exposure to the bright light at 2300 hrs (60 min groups) whilst the other two groups (15 min groups) did not commence under the bright light until 2345 hrs. However, as temperature and sleepiness levels were required to be taken at 2300 hrs, all groups were required to be at the laboratory by 2300 hrs each night. Due to the two different commencement times of the light exposure, participants in the 15-min duration conditions, who were still required to be at the laboratory from 2300 hrs, had their temperature taken and recorded their sleepiness levels at this time. They then sat at tables with the baseline light intensity until 11.45, when they moved into chairs set out for the bright light exposure at which time the bright light source was turned on. The 60-min duration participants, after having had their temperature taken and rating their sleepiness, went directly in front of the bright lights. On the nights where the groups were exposed to the baseline condition, they remained at the tables for the full 60 mins, until midnight, before testing began. All testing was also completed at these tables using the baseline light level.

On the first night, the study commenced at 2215 hrs to allow a full practice of all exercises (described below), with the exception of the Word Recall and Word Recognition tasks. The purpose of running participants through the Critical Thinking, Mathematics Sums, and Letter Cancellation Tasks before commencement of the study was to give them some familiarity with these tasks. On each subsequent night, the study commenced at 2300 hrs. Temperature readings were recorded and a self-rating sleepiness scale administered at 2300 hrs on each night of the study, and recorded on the Sleepiness and Demographic Questionnaire, and Temperature and Test Scoring

Form (Appendix B). On the first night of the study only, the demographic information was collected and the participants were given an information sheet (Appendix C) to read if they had not already done so, and a consent form (Appendix D) was then completed. (All procedures used in the present study were approved by the Massey University Human Ethics Committee.)

At midnight, temperatures and sleepiness levels were recorded again before commencing the behavioural tasks. Participants sat at tables under the baseline light intensity level at all times. The tasks took all groups no less than 40 mins and no more than 45 mins to complete each night. At the completion of the tasks, the temperature and sleepiness levels were recorded for a third time.

Using exactly the same method as McIntyre et al. (1989), light intensity was varied by seating participants at various distances from the light source. The actual output of the light source itself remained constant. Seating positions and light intensity were checked each night at the start of the exposure period and when participants were required to sit at the tables.

To ensure consistency across all 4 nights, standardised instructions (Appendix E) were utilised each night.

Apparatus

Eight twin tubes of special fluorescent broad-spectrum (daylight) lights (Power Twist Duro-Light, 40W) were used to provide the bright light. Exposure to white, or full-spectrum light, of sufficient intensity at night rapidly suppresses melatonin production (Arendt, 1993).

The lights were placed vertically against the wall behind their diffusing screens, with the participants seated the appropriate distance from the lights, depending on which light intensity condition was being studied. Prior to the study, the distance from the lights for the 300, 600 and 1,000 lux conditions were measured and tape placed across the floor marking the seating positions. On each night, the light levels were checked again by holding a lux meter (Dick Smith digital lux meter, accuracy ±5%) close to a participant's eyes. The seats were moved slightly from the taped markings where required to ensure the appropriate light levels were maintained. Each chair had an adjustable, built-in headrest to help the participants maintain their head position.

The room light was used for the baseline condition. A dimmer switch allowed the room light to be kept at less than but close to100 lux. This was checked each night before commencing the behavioural tasks, and at 2300 hrs for nights where the baseline light condition was the condition for that night.

Body temperature was obtained using a Braun ThermoScan Instant Digital Thermometer (percentage error not given)(Figure 2), which provided temperature in degrees Celsius with a resolution of 0.1 degrees.

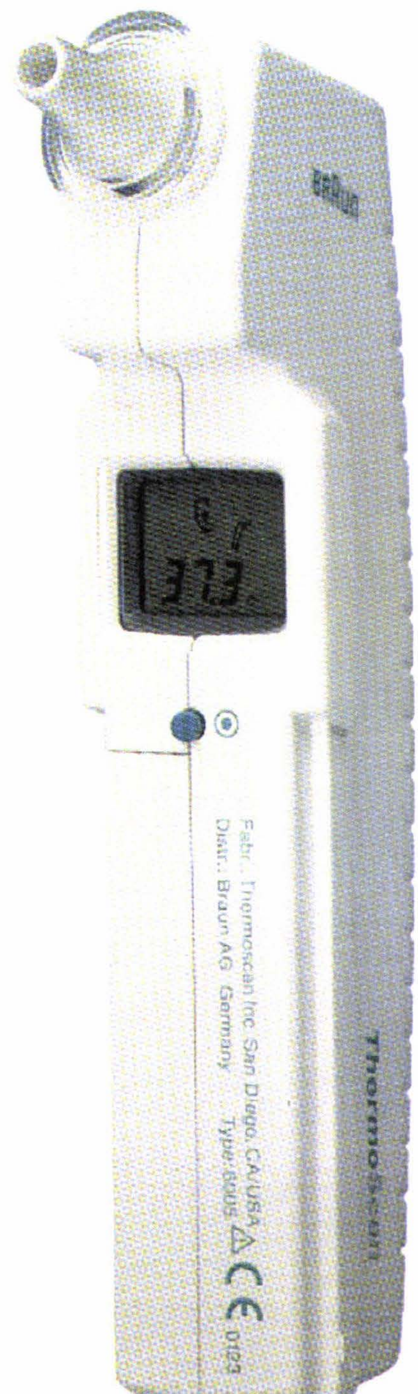

Figure 2: ThermoScan thermometer. The temperature probe is covered with a removable, clear plastic cap for reasons of hygiene.

The thermometer is inserted into the participant's ear (Figure 3) and records the body temperature from the eardrum by "detecting heat from the eardrum and surrounding tissue" (Braun Corporation, undated).

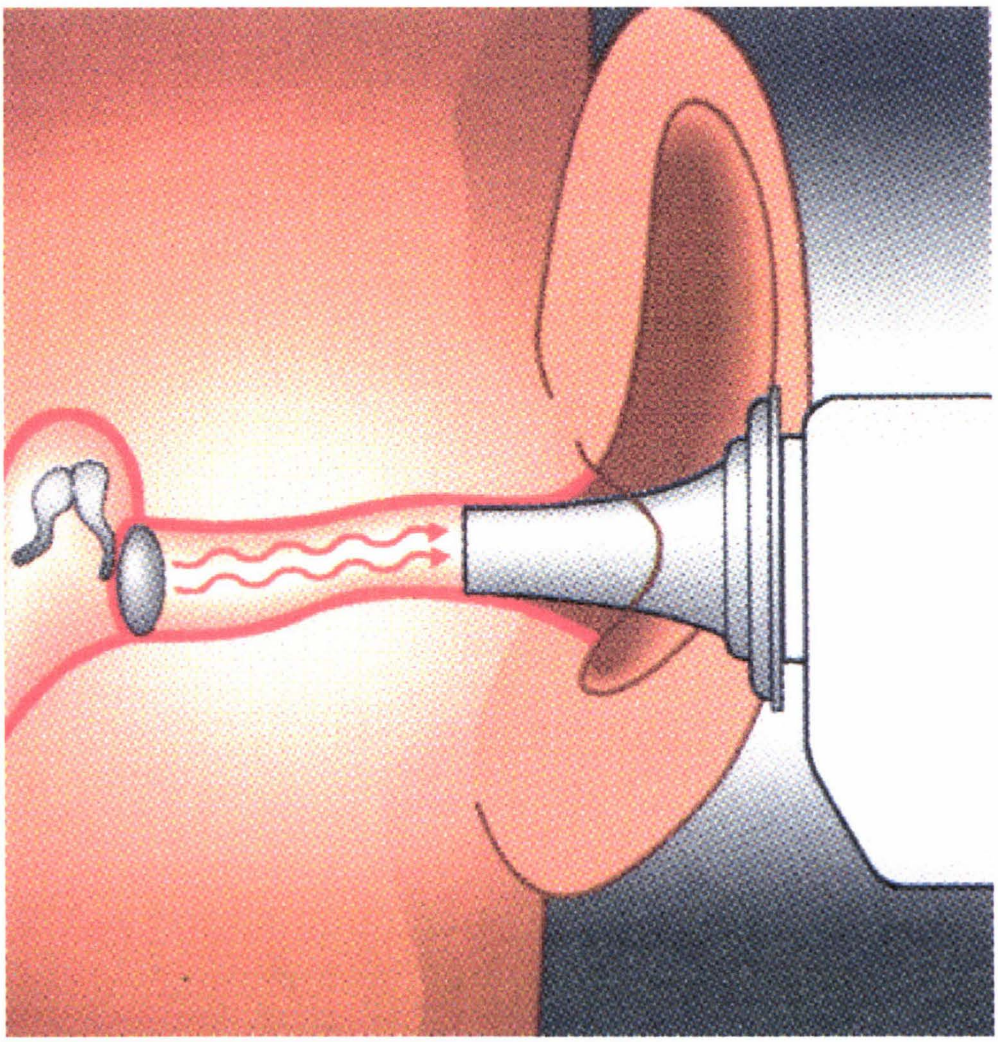

Figure 3: How the ThermoScan thermometer measures the core body temperature through the ear. The temperature of the eardrum is a good estimate of core body temperature (Braun Corporation, undated).

The ThermoScan thermometer records the core body temperature in one sec, taking a "picture" of the infrared heat given off by the ear drum, which is close to and shares its blood supply with the hypothalamus, the temperature control centre of the brain (Braun ThermoScan brochure, undated). Due to the ear's proximity to the hypothalamus, this method of temperature recording is considered more accurate than oral, or even rectal, techniques.

Measures

Subjective Sleepiness

The Stanford Sleepiness Scale (Hoddes, Zarcone, Smythe, Phillips, & Dement, 1973) was used to determine the subjective sleepiness of participants at 2300, 2400, and 0045 hrs. In a study into the Stanford Sleepiness Scale's ability to measure sleepiness, it was found, when averaged over a testing period, that the scale was "highly correlated" with performance on tasks found to be sensitive to moderate amounts of sleep loss. Thus, the scale is considered a good indicator of subjective sleepiness (Hoddes et al.). Despite being designed over 28 years ago, the Stanford Sleepiness Scale was still being used as a valid measure of subjective sleepiness in research as recently as the study by Leproult et al. (1997). Given that on any particular night of the experiment, participants would be exposed to some sleep loss on that particular night, this measure was considered the best available method for obtaining sleepiness levels.

Participants were requested to select the statement that best described how they felt at each particular time, each night. The Stanford Sleepiness Scale score values range from 1 (Feeling active and vital; alert; wide awake) to 7 (Almost in reverie; sleep onset soon; lost struggle to remain awake) (Hoddes et al., 1973).

Temperature

Body temperature was obtained using the ThermoScan Thermometer at 2300, 2400, and 0045 hrs; that is, readings were taken before exposure to the light condition, immediately after exposure to the light condition, and immediately after completion of the performance tasks, respectively. A clean cap was used on the temperature probe (the piece of the thermometer that is inserted into the participant's ear) for each measurement recording.

Performance Measures

A meta-analytic review of sleep deprivation on performance concluded that following sleep deprivation of less than 45 hrs, decreased performance on short cognitive tasks was more pronounced than on longer duration tasks. The opposite was true for participants who have been deprived of sleep for longer than 45 hrs (Casagrande, Violani, Curcio, & Bertini, 1997). Therefore, in the present study, where the group participants would be deprived of some sleep but substantially less than 45 hrs, the performance tasks utilised were kept to a completion time of between 5 and 10 mins. The tasks were based on previous research where statistically significant deficits for mental performance at night had been found. Five performance tests were used: word recall, critical thinking appraisal, mathematics exercises, two-letter cancellation task, and word recognition. Further information pertaining to each task is detailed below.

As the recall and recognition tasks used the same words on any particular night, the recall task was always assigned as the first task, and the recognition task always as the last task. This was to allow time to have passed after the first exposure to the words, before testing participants' recognition abilities. The other three tasks were randomly assigned an order, with critical thinking appraisal becoming the second task, the mathematics exercise the third, and finally the letter cancellation task. Four versions of these three tasks were developed, a different version being used each week. (Appendix F contains examples of all tasks.)

1. Word Recall Task

The 25 four-letter words which made up each of the word recall tasks were randomly chosen from Thorndike and Lorge's (1944) book of "The teacher's wordbook of 30,000 words". In order to ensure the words used were neither too common nor too obscure, parameters for selection of words into the selection pool were established. Only words used more than 20 times per 1,000,000, but less than 100 times per 1,000,000 words were included, and names of people or places were excluded.

Four separate word recall tasks were complied for use on each of the four nights. Participants were given a list of the 25 words and asked to read over the list for 1 min. The experimenter then read each word out, with a momentary pause of approximately 1 s, and instructed each participant to concentrate on each word as it was read out aloud. A further 30 s was given to read over the list again. Participants were then instructed to turn the paper over and to write down in any order as many of the words as they could remember in the 1-min timeframe given. The number of correct words was the dependent measure.

2. Critical Thinking Task

The Watson-Glaser Critical Thinking Appraisal (CTA) was utilised (Watson & Glaser, 1980). The CTA is made up of five separate sections: Inference, Recognition of Assumptions, Deduction, Interpretation, and Evaluation of Arguments. As the entire test takes a recommended 50 mins to complete, it was decided to use one of the five tests which make up the appraisal each night. As only four of the tests were required, the first test, Inference, was not used. The CTA has two forms, Form A and Form B. Form A was used during the practice exercises on the first night, and Form B was used during the testing.

Reliability of the CTA has been established using split half reliability, with correction for test length obtained using the Spearman-Brown formula. The coefficients range from .69 to .85 for Form A, and .76 to .82 for Form B. The reliability over time was obtained by administering the test to 2 groups of college students (N = 96) with a 3-month interval between testing. Means and standard deviations for the 2 test periods were extremely close, with test 1 showing a mean of 57.4 (SD 8.1) and test 2 showing a mean of 56.8 (SD 8.4)(Watson & Glaser, 1980).

The validity of the CTA has been established in a number of different settings by users who had a variety of needs and purposes in mind. The CTA was found to measure a sample of the specified objectives of a number of instructional programmes, which is an indication of its content validity. Construct validity was measured by the assumption that exposure to programmes to improve critical thinking should be reflected in CTA scores (Watson & Glaser, 1980). A number of studies, particularly those by Fogg and Calia (1967), found improvement on CTA scores following a 2-yr study into students' critical thinking abilities.

The CTA has also been found to correlate with other tests, including the Stanford Achievement Tests, overall grade averages, and general intelligence tests. Correlations between .61 and .70 are common with a number of other tests. Watson and Glaser (1980) found that the CTA reflected a dimension of intellectual functioning that was independent of that tapped by specific intelligent measures. Comrey (1974, cited in Watson & Glaser), in analysing a large sample of high school and college students who had completed the CTA, argued that the CTA measures an unidimensional aspect of ability which provides evidence of the test's internal consistency. The scores on the CTA subsets are related to the total score, with correlations of between .55 and .68 across all of the five tests on tests A and B, and between .50 and .69 where tests A and B were combined. In the present study, the number of correct responses and completion times were recorded.

3. Mathematical Sums

A total of 32 sets of adding, subtraction and simple multiplication exercises were developed. An even number of addition, subtraction, and multiplication exercises were used on each of the four nights. The difficulty of the sums were kept consistent across the tests, with the same number of double and triple digit sums, and long addition sums appearing in each night's tests.

Participants were asked to complete the sums as quickly and as accurately as possible. Calculators were not allowed, but scrap paper was provided for those who needed it. Completion time and number of correct responses were the two dependent measures.

4. Letter Cancellation Task

Tasks that are repetitive, simple, and of long duration tend to be particularly sensitive to performance deterioration. Furthermore, pencil and paper tests of vigilance (such as the letter cancellation task) appear to be effective at detecting performance deterioration due to sleep loss and circadian factors (Porcu, Bellatreccia, Ferrara, & Casagrande, 1998). The two-letter cancellation task is considered the task of choice when determining sleep deprivation effects, because it is less subject to variations with practice, and is completed quickly. The use of three or more letters in the cancellation task tends to show greater error variability (Casagrande et al., 1997).

A letter cancellation task using two-letter cancellation was selected as the vigilance task. The letter cancellation task required participants to search and mark sequentially, reading from left to right and top to bottom as fast and as accurately as possible, two target letters within a 36 x 50 matrix of capital letters (font: Times New Roman, 12 in.). A total of four separate pages of 1800 randomly selected letters were compiled, one for each of the four nights each group participated. The two target letters (there were two different target letters for each of the four tasks) appeared 150 times each, with a total correct score of 300. The completion times, number of hits, and number of false positives were recorded.

5. Recognition Task

From the 25 words presented in the Word Recall task, each word was paired with another randomly chosen 4-letter word from the selection pool. The order of the 25 words was randomised from the order they had appeared in the Word Recall task. Participants were instructed that they were to cross out the word in each pair that they had previously seen that night in the Word Recall task. The experimenter read each word pair out aloud, and then paused momentarily for approximately 2 s. Participants were instructed to cross out the word they believed they had seen previously, during the pause. The format of the task was a two-alternative, forced-choice task where the dependent measure, percentage of correct decisions, is relatively free from response bias (Green & Swets, 1966).

Demographic Information

Participants were asked their age and gender.

Procedure

The studied commenced at 2015 hrs for the first night, so that 45 mins of exercise familiarisation could be completed prior to the study commencing at 2300 hrs. Participants were required to sit for the specified period of time (15 or 60 mins) in chairs with headrests, facing the lights and positioned at the designated distance from them. The positions of the chairs were checked for the appropriate level of light and any small adjustments were made. Participants were instructed not to move the chairs during the exposure period, and to look into the lights at least every couple of minutes, keeping their heads against the headrests. The experimenter was always present, and participants were frequently asked to look at the lights. Participants were allowed to read, talk, or listen to the radio whilst the light exposure condition was running, as long as they did not obscure their faces or block the lights during this time.

At the completion of the light exposure, the lights were switched off and participants moved back to the work-tables to begin the exercises. Standardised instructions (Appendix E) were read out to each group at the appropriate time for each task. These instructions included what was expected of the participants at different stages during the experimental conditions, and what was required of them for each task. Questions were invited and answered immediately.

Statistical Analysis

All raw data were input into the Statistical Package for the Social Sciences (SPSS Inc., 1998), version 8. This was used to calculate all descriptive statistics, carry out the MANOVAs, and any follow up statistical tests.

RESULTS

Speed-Accuracy Trade-Off

For the critical thinking tasks, the maths tasks, and the letter cancellation tasks both time and accuracy were used as dependent measures. It is well known that these two variables may be negatively correlated, such that accuracy improves, but only at the expense of a slower completion time. Alternatively, completion time may improve but only because accuracy drops. Table 1 presents the correlations between the time taken to complete the above three tasks and the level of accuracy. The data are collapsed across all four sessions. As there were no differences between the two duration levels, the data are collapsed across duration as well.

Table 1

Correlations Between Speed and Accuracy for Maths, Letter Cancellation (LC), and Critical Thinking (CT) Tasks, Collapsed Across all Four Sessions and Both Durations

		Intensity		
Task	Baseline	300	600	1,000
Maths	-0.60*	-0.59*	-0.34	-0.17
LC	0.35	0.43	0.71**	0.57*
CT	0.15	-0.05	0.17	0.49

* Significant at .05
** Significant at .01

A significant negative correlation was found between speed and accuracy with regards to the maths task: the faster the participants completed the task, the less accurate their scores, and vice versa. Thus, caution is required when interpreting the maths task results with regards to Intensity and Duration, given that there is a speed-accuracy trade off.

Surprisingly, for the letter cancellation task, a positive correlation was obtained, indicating that the faster the participants completed the task, the more accurate they were. This is an unusual result, but again, caution is required when interpreting the letter cancellation results.

PERFORMANCE TASKS

The results for the performance tasks often showed effects at 300 and 600 lux, but not at baseline or for the 1,000 lux condition. Therefore, it appears that a curvilinear relationship between performance and intensity may exist. As a result, where the overall Multiple Analysis of Variance (MANOVA) results showed a main effect for Intensity, specific Analysis of Variance (ANOVA) contrasts were carried out between pairs of intensities to identify more specifically, at what intensity level the effect was occurring.

Recall Task

The recall task was scored out of a possible 25, and is reported here as a percentage score. The means and standard deviations (SDs) for all Intensity and

Duration conditions are shown in Table 2. (Refer to Appendix G for the full MANOVA tables.)

Table 2

Recall Task Mean Percentage Scores (M) and Standard Deviation (SD) for all Intensity and Duration Conditions

	Duration			
	60-mins		15-mins	
Intensity	M	SD	M	SD
Baseline	37.00	12.24	41.00	21.78
300	38.50	17.36	31.00	24.73
600	35.50	10.99	39.00	18.61
1,000	39.00	10.42	40.00	14.50

Table 2 suggests that Duration had little or no effect on word recall. The same result seems to hold for Intensity, although scores were lower at the 300 and 600 lux levels. The MANOVA results confirm these impressions, there being no main effects for either Intensity, $F(3,42) = 1.50$, $p < .20$, or Duration, $F<1$, and no interaction effect, $F(3,42) = 2.32$, $p < .10$.

Critical Thinking Task

a) Accuracy

Positive correlations between speed and accuracy were identified for the critical thinking tasks, as shown in Table 1. Although none of these correlations reached statistical significance, their presence suggests caution is required when interpreting the critical thinking task results.

The critical thinking task was scored out of a possible of 80 and is reported in Table 3 as percentage scores. (Refer to Appendix G for the full MANOVA tables.)

Table 3

Critical Thinking Task Mean (M) and Standard Deviation (SD) Percentage Scores for all Light Intensity and Duration Conditions

	Duration			
	60-mins		15-mins	
Intensity	M	SD	M	SD
Baseline	66.41	11.54	67.97	15.82
300	82.81	8.01	74.22	10.26
600	78.91	12.91	74.22	13.13
1,000	69.53	22.27	71.09	17.66

The 300 lux/60 min condition yielded the highest mean score, 82.81, followed closely by the mean percentage score for the 600/60 min condition, 78.91. The lowest percentage scores, 66.41 and 67.97, were for the two baseline conditions. It is interesting to note that the scores obtained in the 1,000 lux conditions were not much higher than those in the baseline condition. However, the MANOVA results revealed a main effect for Intensity, $F(3,42) = 4.13$, $p < .01$. There was no main effect for Duration and no interaction between these two variables, both $Fs<1$.

Specific contrasts between the Intensity levels showed that there was a difference in accuracy between the baseline and 300 lux levels, $F(1,15) = 9.12$, $p < .01$, and between the baseline and 600 lux levels, $F(1,15) = 8.44$, $p < .01$. However, there was no difference in accuracy levels between the baseline condition and the 1,000 lux level, $F<1$. In summary, for critical thinking accuracy, duration of exposure had no effect, but moderate levels of light (300 and 600 lux levels) seemed to improve performance, whereas the most intense light level (1,000 lux) did not.

b) Completion Time

The critical thinking completion time is shown in Table 4. (Refer to Appendix G for the full MANOVA tables.)

In considering completion times, the 600 lux/15 min condition showed the fastest completion time of 4.62 mins, followed closely by the baseline/15 min condition at 4.73 mins and the 600 lux/60 min condition at 4.76 mins. The slowest mean completion times were the baseline/60-mins condition, followed by the 1,000 lux/60 min condition. Interestingly, the 60-mins and 15-mins/1,000 lux conditions yielded the second and third slowest completion times respectively. Despite these strong trends, completion times yielded no main effects for Intensity or Duration, and there was no interaction between the two variables (all $Fs<1.37$).

Table 4

Critical Thinking Task Mean (M) and Standard Deviation (SD) Completion Times for all Light Intensity and Duration Conditions

	Duration			
	60-mins		15-mins	
Intensity	M	SD	M	SD
Baseline	5.73	1.92	4.73	1.45
300	4.89	1.53	5.20	1.57
600	4.76	1.01	4.62	1.67
1,000	5.67	1.70	5.43	2.36

Mathematics Sums

Negative correlations between speed and accuracy were found for the mathematics sums task, as shown in Table 1. For the 300 lux conditions, the correlation of –0.59 reached statistical significance. Therefore, caution is required when interpreting the results for the mathematics sums task, as the speed-accuracy trade-off may have confounded the results.

a) Accuracy

The mathematics sums exercise was scored out of a possible 32 and is reported here as a percentage. The means and SDs for all Intensity and Duration conditions are shown in Table 5. (Appendix G has the full MANOVA tables.)

The 300 lux/60 min condition showed the highest mean score at 92.19, followed by the 600 lux/60 min condition. The lowest mean scores were 81.25 for the baseline/15 min, and 82.42 for the 1,000 lux/15 min condition.

Table 5

Mathematics Sums Task Mean (M) and Standard Deviation (SD) Percentage Scores for all Light Intensity and Duration Conditions

	Duration			
	60-mins		15-mins	
Intensity	M	SD	M	SD
Baseline	87.50	10.30	81.25	15.40
300	92.19	8.18	83.59	15.38
600	91.41	5.22	84.38	18.75
1,000	90.63	6.25	82.42	22.47

No main or interaction effects for Intensity and Duration were found for the mathematics sum score, all *Fs*<1. However, it should be noted that all 6 mean scores (3 Intensity x 2 Duration) were higher than the comparable baseline.

b) Completion Time

Time to complete the mathematics sum exercise was recorded as actual completion time in minutes. Table 6 shows the means and SD. (Refer to Appendix G for the full MANOVA tables.)

The 600 lux conditions revealed the fastest completion times in both Duration conditions, with mean scores of 5.16 (15 min) and 5.42 (60 min). The two slowest completion times were in the 1,000 lux/60 min condition at 6.61, and the baseline/15 min condition at 6.59.

Table 6

Mathematics Completion Time Mean (M) and Standard Deviation (SD) Results for all Light Intensity and Duration Conditions

	Duration			
	60-mins		15-mins	
Intensity	M	SD	M	SD
Baseline	6.48	2.43	6.59	2.51
300	5.92	2.00	6.09	2.92
600	5.42	1.69	5.16	1.99
1,000	6.61	2.44	5.86	2.10

A main effect for Intensity, $F(3,42) = 4.29$, $p < .01$, was found for the mathematics sums. For Duration there was no main effect and there was no interaction effect, both $Fs<1$.

An ANOVA showed the intensity effect to be due predominantly to the difference between the baseline condition and the 600 lux condition, $F(1,15) = 18.54$, $p < .001$. The comparison between the baseline condition and 300 lux condition approached significance ($p = .13$), but there was no difference between the baseline condition and the 1,000 lux level condition, $F<1$. Overall, middle light levels produced an effect on completion time of the mathematics sums, but stronger light (1,000 lux) did not.

Letter Cancellation Task

In considering the speed-accuracy trade off for this task, positive correlations were found for all lux levels (see Table 1). It appears the faster the participants went, the more accurate they were at the task! Thus, while there was no speed-accuracy trade-off, caution is still required in interpreting these results because of the clear relationship between speed and accuracy, especially at the brighter light levels.

a) Accuracy

The letter cancellation task scores are out of a total possible score of 300, and are reported as the percentage correct. The means and SDs for all Intensity and Duration conditions are shown in Table 7. (Appendix G contains the full MANOVA tables.) The false alarms were not analysed as they amounted to less than 1% of the total letters cancelled for each participant.

The 1,000 lux/60 min condition revealed the highest mean scores of 91.71, followed by 91.42 for the baseline condition. The lowest mean scores were 90.33 and 90.50 for the 300 lux 15 and 60 min conditions, respectively. As suggested by these small differences, the MANOVS revealed no main effects and no interaction, all *Fs* <1.

Table 7

Letter Cancellation Task Mean (M) and Standard Deviation (SD) Percentage Scores for all Light Intensity and Duration Conditions

	Duration			
	60-mins		15-mins	
Intensity	M	SD	M	SD
Baseline	91.42	5.41	91.00	9.23
300	90.50	5.86	90.33	7.51
600	90.63	4.70	91.04	6.66
1,000	91.71	6.18	90.75	6.73

b) Completion Time

The actual time to complete the letter cancellation task was also recorded. Means and SDs are shown in Table 8. (Refer to Appendix G for the full MANOVA tables.)

The 300/15-min condition yielded the fastest completion time, followed by the baseline/15-min condition. In contrast, the slowest completion times were found in the 1,000/60-min and the 300/60-min conditions. Overall, all the completion times in the 15-min condition were faster than any of the completion times in the 60-min condition. Nonetheless, a MANOVA showed there to be no statistically significant main effects, and no interaction between Intensity and Duration, all $Fs<1$.

Table 8

Letter Cancellation Task Mean (M) and Standard Deviation (SD) Completion Times for all Light Intensity and Duration Conditions

	Duration			
	60-mins		15-mins	
Intensity	M	SD	M	SD
Baseline	8.55	1.35	7.94	1.02
300	8.66	1.39	7.87	1.26
600	8.60	1.23	8.29	2.25
1,000	8.75	1.27	8.38	2.01

Recognition Task

The recognition task was out of a total possible score of 25 and is reported as percent correct. The means and SD are shown in Table 9. (Refer to Appendix G for the full MANOVA tables.)

The highest scores for the recognition task was 87.00 and 86.50 in the 600 and 300-lux 15-min conditions, respectively. The lowest scores were found in the 300 lux/60 min condition (74.00) and in the baseline/60 min condition (75.50).

Table 9

Recognition Task Mean (M) and Standard Deviation (SD) Percentage Scores for all Light Intensity and Duration Conditions

	Duration			
	60-mins		15-mins	
Intensity	M	SD	M	SD
Baseline	75.50	14.73	77.00	10.42
300	74.00	17.10	86.50	8.26
600	83.50	10.13	87.00	7.93
1,000	77.50	6.74	78.00	14.81

There was a main effect for Intensity, $F(3,42) = 4.87$, $p < .01$, but not for Duration, $F<1$, and there was no interaction between Intensity and Duration, although it approached statistical significance, $F(3,42) = 2.35$, $p = .09$.

The follow up ANOVAs undertaken to identify the source of the main effect for Intensity produced statistically significant differences between the baseline and 300 lux/15 min condition, $F(1,7) = 7.92$, $p < .03$, the baseline and 600 lux/60 min condition, $F(1,7) = 9.33$, $p < .02$, and between the baseline and 600 lux/15 min condition, $F(1,7) = 25.00$, $p < .01$. No effect was found between the baseline and the 1,000 lux conditions, both *F*s<1.

Overall, it appears that Intensity has a strong impact on recognition performance, but mainly at moderate light levels.

Sleepiness

It will be recalled that sleepiness was assessed using the Stanford Sleepiness Scale (Hoddes et al., 1973), where 1= feeling active and vital, alert, wide awake; 2 = functioning at a high level but not at peak, able to concentrate; 3 = relaxed, awake, not at full alertness, responsive; 4 = a little foggy, not at peak, let down; 5 = fogginess, beginning to lose interest in remaining awake, slowed down; 6 = sleepiness, prefer to be lying down, fighting sleep, woozy; and 7 = almost in reverie, sleep onset soon, lost struggle to remain awake. The mean sleepiness levels, collapsed over the four nights, are shown in Table 10 along with their SDs.

It can be seen that while sleepiness levels increased across the session (as expected), there were no statistically significant effects due to Intensity or Duration, and no interaction between these factors. All means and SDs for each night, level, and factor can be seen in Appendix H.

Table 10

Sleepiness Mean (M) and Standard Deviation (SD) Scores for Each Intensity Level and Duration at the Three Times of Testing, Collapsed Across the Four Nights.

	60-mins			15-mins		
Lux Level	2300 hrs	2400 hrs	2445 hrs	2300 hrs	2400 hrs	2445 hrs
<100						
M	2.63	3.75	4.38	3.00	4.00	4.75
SD	1.06	0.89	1.30	1.07	0.76	0.89
300 lux						
M	2.75	3.63	4.00	3.13	3.88	4.88
SD	0.71	0.92	0.93	1.64	1.64	1.13
600 lux						
M	4.00	4.63	4.13	3.38	3.25	4.50
SD	1.31	0.92	1.46	1.06	1.04	0.93
1,000						
M	3.88	4.25	4.88	2.63	3.38	4.38
SD	0.99	1.28	1.89	0.92	1.06	0.52

Temperature

Temperature readings were taken at 2300, 2400, and 2445 hrs each night. Table 11 presents the temperature means and SDs, collapsed across the four nights.

Table 11

Temperature Mean (M) and Standard Deviation (SD) Scores for Each Intensity Level and Duration at the Three Times of Testing, Collapsed Across the Four Nights.

	60-mins			15-mins		
Lux Level	2300 hrs	2400 hrs	2445 hrs	2300 hrs	2400 hrs	2445 hrs
Baseline						
M	36.48	36.37	36.45	36.35	36.44	36.26
SD	0.55	0.54	0.50	0.39	0.23	0.28
300 lux						
M	36.57	36.38	36.43	36.41	36.32	36.43
SD	0.31	0.36	0.39	0.33	0.34	0.27
600 lux						
M	36.58	36.47	36.44	36.59	36.61	36.56
SD	0.58	0.45	0.61	0.22	0.29	0.25
1,000						
M	36.34	36.44	36.50	36.60	36.36	36.36
SD	0.48	0.47	0.45	0.30	0.18	0.33

Intensity and Duration appear to have had no effect on the temperature levels of participants. Comparing the temperature readings at the various light levels and durations across the three nightly recordings, a slight decrease was noted for all light conditions, except for the 1,000 lux, 60 min condition. This condition showed a very slight increase between 2300 and 2400 hrs. However, none of the temperature differences across any of the conditions neared significance (all Fs<1). The means and SD of the temperature levels at each of the three recording times for all combinations of Intensity and Duration can be found in Appendix H.

Demographic Information

The information on gender was collected to ensure that an even mix of males and females participated in each of the four groups. The participants' age information was collected to obtain the range, mean and SD data. No other analysis was done on this information.

DISCUSSION AND CONCLUSIONS

The main purpose of the present investigation was to find out if intensity and duration of exposure to bright light positively affected night-time cognitive performance. In particular, the study set out to discover if these two variables, intensity and duration, interacted such that one could be traded-off against the other. However, for all performance tasks (recall, critical thinking, mathematics sums, letter cancellation, and recognition tasks), sleepiness, and temperature readings the results showed there were no interaction effects between light duration and intensity. Furthermore, duration itself seemed to have no effect on performance. Any effects observed for the 60-min exposure were just as likely with 15 mins of exposure.

On the basis of previous findings (e.g., Lewy et al., 1980; McIntyre et al., 1989) it was anticipated in the present study that duration of light exposure would influence task performance. However, the results of exposure for both 15 and 60 mins of duration did not support this hypothesis. There were no main effects found for duration across any of the five performance tasks, nor on the sleepiness or temperature readings. Previous research has not studied duration of exposure specifically as an independent variable. However, studies into the effects of bright light, where the exposure time was between 30 and 60 mins, found statistically significant physiological impacts on temperature (Badia et al., 1991), and melatonin secretion (Lewy et al.; McIntyre et al.).

The present study also considered the intensity of light exposure on mental performance. A number of studies (Campbell & Dawson, 1990; Daurat et al., 1993; Dawson & Campbell, 1991; Myers & Badia, 1993; Penn & Bootzin, 1990; Thessing et al., 1994) have found statistically significant results when comparisons are made across varying intensities of light for melatonin secretion, circadian rhythms, sleepiness, alertness, and mental performance. Furthermore, these studies found that bright light impacted on logical reasoning, four-choice reaction time, two-letter cancellation, adding and subtracting mathematics sums, and tasks with a strong cognitive component. As a result of these findings, it was expected that the present study would similarly reflect an impact on at least the letter cancellation, critical thinking, and mathematics sums tasks, particularly at the 1,000 lux level conditions. This was expected for two reasons. Firstly, higher intensity light levels produces stronger effects, because the brighter the light the more pronounced is the melatonin suppression (McIntyre et al., 1989). Secondly, as statistically significant results had been found under 2,000 and 1,000 lux intensities for performance tasks (including letter cancellation, logical reasoning, and mathematics tasks) and alertness in previous research (Campbell & Dawson; Daurat et al.; Myers & Badia), it was assumed similar results in at least these tasks would be demonstrated in the present study.

However, the results showed that light had no impact on the accuracy of recall, simple arithmetic, or letter cancellation. There were no differences in performance between any of the four light conditions used. This was surprising, given that the mathematics sums tasks had previously been found to improve performance with light levels of 1,000 lux (Campbell & Dawson, 1990; Myers & Badia, 1993). Although not producing statistically significant differences, it was interesting to note that accuracy for the mathematics exercise, in the present study, tended to be better for the 60-min exposure across all light levels, including the baseline condition. Sitting under the light for an hour, rather than only for 15 mins, tended to result in greater accuracy in mathematics sums even though the effects were small. Given the small effect size and the small number of participants, the power of the statistical test here was likely very low. The study needs to be run again with a larger participant pool to confirm that the trend noted is real.

The result for the letter cancellation task is also surprising. Of all the tasks used in the current study, the letter cancellation task is the most frequently used task for identifying meaningful impacts of light on cognitive performance (Porcu et al., 1998). However, previous studies with the letter cancellation task have shown that the biggest effects between control and light-added conditions tend to be seen only after the participant gets tired during the task. In the present study, participants completed the task in under 10 mins, and it is acknowledged that this is probably too short a timeframe to tire the participants out sufficient for any effects to be observed. Nevertheless, the null results suggest that the letter cancellation task is not sensitive to minimal disruption to sleep patterns involving exposure to bright light in the early part of the night.

Statistically significant results were found in the critical thinking task at certain light levels. Differences were found between the baseline and 300 lux condition, and between the baseline and the 600 lux condition, but no difference was found between the baseline and the 1,000 lux condition. It is unlikely that the speed-accuracy trade-off noted for this task (Table 1) confounded the outcome because the trade-off effects were negligible at 300 and 600 lux (-0.05 and 0.17, respectively). And at 1,000 lux, the correlation between speed and accuracy was positive (0.49). That is, any increase in speed was related to better, not worse, performance.

Similar results were obtained for the recognition task. The main effect of the bright light was at 300 and 600 lux at both 15- and 60-min exposure durations. To date, no studies have been found which have specifically studied recognition performance under light conditions. Most performance tasks designed to test memory function in bright light studies have employed a recall exercise task, which utilises different cognitive processes than recognition (Kalat, 1998). However, a study by Bougrine, Mollard, Ignazi, and Coblentz (1995) found performance increments for a recognition task in their study into the stability of bright light circadian readjustment. They attributed improved performance effects, including reaction time, memory task, and mathematical and grammatical reasoning task to the immediate activating effects of bright light exposure on the reticular formation. Thus, it seems from the present study that tasks that tax the participant's cognitions (recognition memory and problem solving) are more likely to be sensitive to the effects of the bright light at the levels used in the present study than are tasks that require less reasoning and remembering – tasks such as letter cancellation and simple maths. Furthermore, it is likely that the recall task showed few effects of the bright light because it was always the first task done in the sequence, when participants were possibly more alert.

The present study indicates that certain intensities of light affects mental performance at some levels, but not at others. Most of the tests used in the present study (letter cancellation, mathematics sums, and recall) have been used previously in light studies and statistically significant improvements found where bright light conditions were compared to a control dim light condition. In the present study, the critical thinking task was introduced to ensure a task with cognitive load was included, as Thessing et al. (1994) found that tasks with a strong cognitive component appeared to be particularly sensitive to light exposure. Recognition and recall tasks were used so that different types of cognitive processes could be studied. It would appear from the present findings that the impact of light on mental performance might be somewhat dependent on the type of task employed. In particular, the logical reasoning (critical thinking task) and recognition abilities appear to have been improved by the application of bright light at moderate levels, whereas recall, mathematical calculations, and vigilance (letter cancellation task) may be less sensitive to bright light, at least in the early evening. The fact that previous findings (Badia et al., 1991; Daurat et al., 1993; Porcu et al., 1998) found these tasks were affected by bright light whereas the present study they were not, indicates that the effects of bright light on cognitive performance is inconsistent across tasks, bright light levels, and exposure times. This suggestion is further supported by the findings of McIntyre et al. (1989) who, in considering the inconsistencies between three studies, suggested that the differing results were due to the disparity in bright light levels and exposure times. Further research is required to establish which specific cognitive tasks are affected at which particular light levels and at what precise times during the melatonin secretion period.

In considering the completion times of the critical thinking, mathematics sums, and letter cancellation tasks, only the mathematics sums task produced significant affects, with the difference occurring between the baseline and the 600 lux condition. It appears from the intensity results in the current study, that 300 and 600 lux light intensities have an impact on some performance tasks both in terms of accuracy and speed, but that brighter light of 1,000 lux does not.

The most surprising result in the present study was that the 1,000 lux light level had no positive effect at all across any of the performance measures when the 300 and 600 lux light levels did. The study by McIntyre et al. (1989) found melatonin suppression at lux levels of 3,000, 1,000, 500, and 350, where light exposure had occurred between midnight and 0100 hours. One difference between the present study and that of McIntyre et al. was that the exposure to light in the latter study occurred 1 hr later. McIntyre et al.'s study was conducted in Melbourne during late April/early June, and the present study was conducted during late May/June. Therefore, both were conducted during the late Autumn/early Winter periods in the Southern Hemisphere, so day-light saving would not have been in effect during either study. Thus, there would have been a real 1 hr difference between the two studies with regards to the time that light exposure occurred. As a result, in the present study it is likely that the melatonin levels would not have been as high as those in McIntyre et al.'s study at the time of light exposure. The combination of this fact, with a shorter exposure time and a smaller sample size (less statistical power), may have compounded to yield a set of null results. In view of the present results, the time at which testing is carried out during the night seems important. However, this line of reasoning still does not explain why low levels of light should have an effect on some tasks, while a high intensity has no effect.

Furthermore, Badia et al. (1991), using considerably higher levels of light, 5,000 to 10,000 lux, against a baseline of <50 lux, found that sleepiness levels and temperature decreased under the bright light conditions, and that performance improved on digital recall, logical reasoning, and letter cancellation tasks. Badia et al.

also found that these improvements occurred under the bright light conditions whether the duration of exposure was continuous across the night or for a period of 90 mins only before undertaking the performance tasks. Given the links previously established between melatonin suppression, sleepiness levels, body temperature, and mental performance (e.g., Daurat et al., 1993; Myers & Badia, 1993) then it was expected that performance increments would be identified at the 1,000 lux/60 min condition at the very least; but this did not occur in the present study.

One possible reason for the apparent lack of effects on performance at the 1,000 lux condition is that the participants had to sit very close to the light source (less than 1 m), and close to each other, to ensure the correct lux intensity at the eye. During this condition, participants sometimes commented on the brightness of the light. This, coupled with the physical discomfort of the situation created by the lack of sufficient personal space, could have resulted in some stress, which may have confounded the outcome. The 600 lux level, which did appear to improve some aspects of performance, was approximately 90 cm back from the 1,000 lux position with respect to the lights. This difference allowed the participants more room and no one commented on the brightness of the light.

Another possible reason for the unexpected effects at the 1,000 lux level is based on the way light intensity was varied by changing the distance from the light source. At the 1,000 lux level, participants were less than 1 metre from this light source. Being 1 m x 1 m square in size, the light source dominated the visual field of the participants. This may have interfered in some way with the effects of the light at this level. It seems unlikely that the true relationship between performance level and light intensity is curvilinear as the present study suggests. Further research is urgently required that compares altering intensity by varying distance of the participants from the light source, and altering intensity by varying the brightness of the source while keeping the distance from participants to the source constant.

One problem that was anticipated with both the mathematics sums and letter cancellation tasks was the speed-accuracy trade-off. It was assumed that the faster the participants worked, the less accurate they would be in completing these tasks. Few studies into night-work and performance have concerned themselves with the speed-accuracy issue, despite the fact that mathematics sum and letter cancellation tasks have been widely used as performance measures for night-work studies. A speed-accuracy association will always be present where the completion time of these two tasks is timeframed. In future studies where the speed-accuracy issue could be a problem, it would be advisable to concentrate on speed or accuracy, rather than trying to unravel the complexities of their interacting influence. If accuracy is being studied, participants should be given plenty of time to complete the task and instructed to work slowly in order to be as accurate as possible. Similarly, if speed is a factor, then participants should be directed to work as quickly as possible; the time taken and errors made would then be analysed.

A secondary aim of the present study was to provide data to assist in more accurately identifying the light intensity threshold required to improve performance. The results showed that the 300 and 600 lux light intensity levels had positive effects on some tasks (namely the recognition and critical thinking tasks, and the completion time of the mathematics sums task) but not on others. It would appear from the results that the intensity threshold for some tasks is as low as 300 lux. This result is consistent with the finding of McIntyre et al. (1989) who found some melatonin suppression with exposure of 200 lux light levels (although this finding was not statistically significant), and relatively high levels of melatonin suppression under 500 lux levels. Further research is required to specifically identify the threshold level for performance increments, although, as the present study has indicated, the threshold where light impacts on cognitive performance possibly varies as a function of task type.

The present study also considered sleepiness and core body temperature, and what impact, if any, light had on these two functions. Previous research has established the link between sleepiness levels and mental performance, and the influence of light on both. Gillberg and Akerstedt (1998) found significant increases in alertness and performance on cognitive tasks with a light level of 1,000 lux. Given this finding, the present study was expected to find a significant result for the 60-min duration at the very least, and especially at the 1,000 lux condition across all tasks. However, no meaningful changes were observed for subjective sleepiness at any of the light intensity/duration combinations.

An important difference between the present study and previous similar ones is that sleep deprivation often occurred before light exposure in the latter. In the current study, no sleep deprivation occurred, except for the fact the participants could not go to sleep at their usual times (for almost all participants, this was between 2000 and 2300 hrs). Furthermore, in the present study the subjective sleepiness levels of the participants did not show any statistically significant changes as a result of light exposure compared to the control condition. Perhaps the lack of any sizeable amount of sleep deprivation led to rather weak effects of the light exposure. The fact that the participants did not experience sleep deprivation as a condition of the study, and did not report any changes in their sleepiness levels across conditions, may have been responsible for the lack of any effects in the letter cancellation task. It would appear, therefore, that the impact of light is more effective where there has been sleep deprivation during the previous night(s). It may be that the relatively low levels of light used in the present study coupled with the fact that participants were not sleep-deprived, conspired to minimise the effects of the light. Further research is required to obtain clear answers.

The link between melatonin suppression and body temperature has been shown to hold in a number of studies, with Arendt (1995) reporting that where bright light had suppressed melatonin secretion, body temperature was found to have decreased. Furthermore, Boyce and Kennedy (1987) and McIntyre et al. (1989) found significant melatonin suppression and temperature increases at light levels as low as 200 lux. Lewy et al. (1980) found that between 10 and 20 mins of exposure to bright light at both 500 and 1,500 lux levels suppressed melatonin, as long as the exposure was after the 2100 hr average melatonin onset time. Therefore, in the present study, where light exposure was between 2300 and 2400 hrs, if the light levels had suppressed melatonin, the participant's body temperature readings should have either been maintained across the 3 levels, or increased. In fact, all temperatures showed a small decrease across the various conditions as the night progressed, except for the 1,000 lux/60-min duration condition, which showed a slight increase. However, none of these findings were statistically significant. As a result, it may be that melatonin suppression did not occur in the present study or, at least, not to any great extent. This, despite the fact that McIntyre et al. reported that the melatonin level at midnight appeared to be very sensitive to suppression.

Limitations of the Present Study

One major limitation of the present study was the small sample size, with a total of 16 participants taking part in the study, 8 in each duration condition (the between-groups factor). However, to date, most studies into nightwork have had between 6 and 15 participants only, presumably because of the inconvenience these type of studies cause to participants. Thus, the statistical power of the test statistics is likely to be low, making the interpretation of statistically non-significant findings problematic. A null finding may mean that there was no effect (the usual interpretation), but it is also possible that the study lacked the power to detect a small but important effect, resulting in a Type 2 error. When tasks have small sample sizes like this, it becomes critically important to withhold a final conclusion until a meta-analysis, or some kind of overall analysis of a research area, has been conducted.

Another issue to be considered is the fact that most researchers have designed their own performance tasks for bright light studies, making it difficult to accurately compare across studies, and, in particular, to establish the specific cognitive load of the different tasks. It would be valuable to establish a set of mental performance tasks that could be consistently used across a number of different night-time studies, thereby assisting in the identification of different conditions on varying cognitive abilities. The only task consistently applied across studies currently is the letter cancellation task, and as the present study has showed, this task appears to be effective under only specific types of conditions.

Further Research

The present discussion has already identified a number of further studies that would contribute to the body of knowledge about the impacts of light and mental performance at night, but a few additional comments are warranted. Firstly, it was earlier speculated that sitting participants very close to the light source and invading personal space boundaries may have caused some acute stress, possibly making the participants more (or less) able to complete the tests under this particular light level. This hypothesis could be tested in a study specifically designed to see how light intensity and stress levels interact. It may be that central nervous system chemical changes and hormonal changes induced by stress can override the impact of increased melatonin levels.

Secondly, the present study suggests that different cognitive abilities are impacted by particular light conditions, possibly due to the fact that only relatively low levels of artificial light were used. Much more research is required to find out what cognitive abilities are most affected by exposure to bright light. In addition, sufficient research has now been done so that a meta-analysis of these cognitive factors may well yield some very interesting results.

Further research should also be undertaken on the impact of light levels on differing levels of sleep deprivation. In the present study the participants were not deprived of sleep, other than that they could not retire to bed at their usual time on the night of the experiment. As the present study showed a mixture of results, it is possible that any impact of light on mental ability for some tasks may only be able to be ascertained when a certain level of sleep deprivation has occurred.

Furthermore, it is difficult to compare studies investigating the impact of bright light on mental performance when each study utilises unique performance tests. If a standard set of specifically designed cognitive tests were developed, this would allow for more meaningful comparisons across night-time studies. Thus, greater understanding of the complexities of how light impacts on mental performance under different levels and durations could be gained, and researchers would more easily be able to identify the light threshold for specific types of cognitive function.

Conclusions

Although the present study showed mixed results for different cognitive processes, it appears that relatively low light levels of only 300 and 600 lux can have effects on some mental performance tasks at night. It is far from clear why the 1,000 lux light level had little or no effect, but this study has clearly shown that light intensity and duration of exposure do not interact, and, thus, cannot be traded. However, this outcome may only hold for the way light intensity was varied in the present investigation. Further work is urgently required that compares altering light intensity by moving participants relative to the light source, and holding the position of the participants constant while varying light intensity at the source. In addition, it may be best to attempt to control for the speed-accuracy trade-off by focusing on only either speed or accuracy (but not both) as the dependent variable. Furthermore, the length of time it takes to complete a task may be an important factor in increasing fatigue. Further research is required to examine the effects of light on tasks that very in duration, as well as in type of cognitive load.

The present investigation only partially replicated previous findings in showing that low level broad-spectrum light can affect task performance at night. At the low levels of light used, it may be important to run the tasks for longer periods of time than were used in the current study, or, alternatively, to deprive participants of sleep on several nights prior to completing the experimental tasks.

Finally, one of the most disturbing factors about the research examining the effects of bright light on night-time work performance is that a very large set of uncontrolled factors may affect task performance. For instance, level of sleep deprivation, light intensity, speed-accuracy trade-off effects, type of cognitive tasks, cognitive load, to name but a few. It is strongly recommended that research in this area moves towards more systematic investigation, using standardised tasks whose reliability and validity are well established. Until this happens, the interpretation of a specific set of findings will be open to a wide range of possible explanations.

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APPENDIX A

Order Of Exposure to Experimental Conditions across the 4-Week Period.

Day	Week 1	Week 2	Week 3	Week 4
Monday	300[1] 60	Baseline 60	1000 60	600 60
Tuesday	600 60	1000 60	Baseline 60	300 60
Wednesday	300 15	Baseline 15	1000 15	600 15
Thursday	600 15	1000 15	Baseline 15	300 15

[1]Within each cell, the upper number is the lux level and the lower number the duration of the exposure.

APPENDIX B

Sleepiness & Demographic Questionnaire
&
Temperature & Test Scoring Form

Name: ______________________________ Date: __________________________________

Rating of Subjective Sleepiness

Please rate your sleepiness levels by writing the relevant number that **best describes how you feel** at each of the following times:

A. Before commencing the study ______________________________________

B. After the first hour ______________________________________

C. At the conclusion of the experiment ________________________________

Sleepiness Levels

1. Feeling active & vital, alert, wide awake.

2. Functioning at a high level but not at peak, able to concentrate.

3. Relaxed, awake, not at full alertness, responsive.

4. A little foggy, not at peak, let down.

5. Fogginess, beginning to lose interest in remaining awake, slowed down.

6. Sleepiness, prefer to be lying down, fighting sleep, woozy.

7. Almost in reverie, sleep onset soon, lost struggle to remain awake.

Note: The sleepiness scale was taken from Porcu et al. (1973)

APPENDIX B Cont.

Demographic Information

1. Age: ____________________

2. Gender: ____________________

3. Time you usually - Go to bed: ____________ Wake up: ________________

4. Please circle one of the following regarding an average night's sleep:

   a. Sleep throughout the night with little or no disturbance

   b. Awake sometimes, but do not have trouble getting back to sleep

   c. Tend to toss and turn quite a bit during the night

   d. Tend to have periods of insomnia over 30 minutes at a time

   e. Do not sleep well; will be awake for long periods during the night.

5. Average number of hours sleep per night: ____________________

6. Average number of hours of exercise per week: ____________________

APPENDIX B Cont.

Temperature:

A. Before commencing the study: ______________________________

B. After the first hour: ______________________________

C. At the conclusion of the experiment ______________________________

SCORES:

1. Critical Thinking:

No. Correct: ______________________________

2. Maths:

No Correct: ____________________ Time Taken: ____________________

3. Word Recall:

Number Correct: ______________________________

4. Word Recognition:

Number Correct: ______________________________

5. Letter Cancellation:

Number Correct: ____________________ Time Taken: ____________________

No. Missed: ____________________ No. False Positives: ____________________

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APPENDIX C

Does Working at Night Affect Performance?

Information for Participants

Thank you for taking the time to read this information sheet regarding our study into mental work at night. We would like to invite you to take part in this study looking at whether performance levels are altered as a result of working during the night hours.

The researchers for this study are Ms Tania Baker, a postgraduate psychology student, and her supervisor, Dr John Podd (School of Psychology). Tania can be contacted at work on phone xxx-xxxx extension xxxxx, or at home on xxx-xxxx. Dr Podd can be contacted at work on xxx-xxxx extension xxxx, or at his home, phone xxx-xxxx.

Anywhere between 10% and 25% of a country's workforce are employed in night-work, with a majority of these working night shifts. A number of studies have found that the human body has "circadian rhythms" which influence the body's sleep and wake cycles. Between the hours of 11.00 p.m. and 7.00 a.m., a hormone called melatonin is released into the body which helps bring on sleep. There has been a number of studies both in New Zealand and overseas which have looked at working at night, and the effects night-work has on the worker, both personally and professionally. As a result, a number of suggestions have been made to assist in minimising the effects of melatonin on sleepiness so that night work can be done more efficiently and safely.

If you would like to be involved, you will be required to attend one of the Psychology laboratories for one night a week over a four-week period. On each of these nights, you will be asked to sit for one hour, and then to undertake four separate computer exercises which will be used to determine your level of mental performance during this time. Amongst other things, the level of light in the room may be altered as you work. Your body temperature will be taken (by placing a special thermometer inside your ear) twice each night; at the end of the one-hour sitting, and at the end of the computer exercises. You will also be asked to rate your sleepiness levels, prior to commencing the study, after the first hour, and at the end of each night. The exercises will each take about 10 minutes each to complete, and you will have a 5 minute break between each. There will be one other person doing the tasks at the same time, and at least one of the researchers present at all times. You will be able converse, listen to music, or read

APPENDIX C Cont.

during the first hour, so feel free to bring tapes or books if you wish. The research will start at 10.00 p.m. for the first night, to allow one hour of familiarisation with the exercises, before starting the study proper. It is important that we establish a base level for performance prior to the melatonin onset time of about 11.00 p.m., so that we can see what effect melatonin has. On the three following nights, the study will start at 11.00 p.m., and will be completed for all four nights by 1.00 a.m.

As previous research has shown that caffeine, alcohol, and other drugs can affect both melatonin release and performance, you will be asked to abstain from drug taking (except for prescription drugs) on the day you attend the laboratory.

You will receive a payment of $25.00 at the end of the study to help off-set travel costs to and from the laboratory.

To ensure your safety whilst arriving and leaving the laboratory, Campus Security will escort you from and to your vehicle each night. The psychology building housing the laboratory will be locked at all times during the research period.

As is the usual practice, informed consent will be obtained from you on the first night, prior to your involvement in the study. You are completely free to ask questions at any time and to withdraw from the study whenever you like.

You are entitled to a copy of your personal information, and a summary of the study results if you so desire. If you would like a summary, your personal results, or both, you can let us know by providing details of your address on your first night at the laboratory.

To protect your confidentiality, the consent form will be coded, and your respective code used for all data collection and analysis of information from the study, so that only Dr Podd and Ms Baker will be able to identify your individual results at any time. The consent forms will be kept in a secure place by Dr Podd.

Your Rights:

If you agree to take part in our study, you have the right to:

- Refuse to answer any particular questions.
- Refuse to participate in any of the performance tests
- Refuse to undertake any instructions given by the researchers
- Withdraw your participation in the study at any time.

APPENDIX C Cont.

- Have answered any questions you may have prior, during, or after the study, either directly or by contacting the researchers.

- Provide information on the understanding that it is completely confidential to the researchers. All information relating to your identity will be kept secure, and it will not be possible to identify you from any of the reports prepared from the study.

- Be given access to your own personal data, and a copy if you would like it.

- Be given access to a summary of the findings of the study when it is concluded.

Our understanding of mental performance during night hours suggest that working at night requires more effort than during the day. We hope that you will be willing to take part in our study to help us gather information about mental performance during night-time. Our results, and those of others like them, can then be used to improve the well-being and performance of those who are employed as night-workers.

Please indicate your willingness to be involved in the study by completing the attached form, and Tania will be in touch with you in the near future.

APPENDIX C Cont.

I am willing to be involved in the study in whether working at night affects performance.

Name: ____

Contact Phone Number: ________________________________

Best Time to Call: ____________________________________

Indicate any particular night that would be more suitable for you to attend the experiment:

____

Tania Baker. Ph: xxx xxxx, extension xxxxx (work), xxx xxxx (home).
Dr John Podd. Ph: xxx xxxx, extension xxxx (work), xxx xxxx (home)

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APPENDIX D

Does Working at Night Affect Performance?

Consent Form

I have read the Information Sheet for this study. My questions have been answered and I understand that I may ask additional questions at any time.

I also understand that I am free to withdraw from the study at any time, or to decline to answer any particular questions, perform any tests, or follow any instructions given in the study. I agree to provide information to researchers on the understanding that this information is completely confidential. I understand that no other person or organisation, other than Dr Podd or Ms Baker, will be able to identify my responses from any other participant in the study.

I wish to participate in this study under the conditions set out in the Information Sheet.

NB: On the consent form you are required to include your name and address so that the researchers can assure the Ethics Committee that informed consent has been obtained from all those who participate in the study. Also if you indicate below that you require a copy of your own or the overall results, these will be sent to the address shown, once the study has been completed.

Signed: ____

Name: ____

Address: ____

Phone: ____

Date: ____

Do you require a copy of your own results? Yes/No
Do you require a summary of the overall results? Yes/No

APPENDIX E

Standardised Instructions

1. The first thing I need to do is to take each of your temperatures by inserting this apparatus in one of your ears. This is not uncomfortable or dangerous at all, and I use a new cover each time, so it is hygienic. Your ears need to be clean in order to obtain an accurate reading, so there are some cotton buds here if you think you may need to use them.

When I insert this into your ear, it should feel as if your ear is blocked, like you have an ear plug in. So, you need to guide me as to how far I should push the nossle in without hurting you. I only have to hold it in your ear for one second to obtain your temperature. Any questions?

Take each participant's temperature

2. Now, I need each of you to complete this sleepiness questionnaire. Can you put your name and today's date on the top of the first page. Next, I need each of you to please read the list of seven statements about how sleepy you feel, and select one that best describes how you are feeling at the moment. You should put your answer beside the letter A. Can you please also complete the demographic information on the second page. Thank you.

Get each participant to complete the sleepiness questionnaire.

3. Now I need you all to take a seat. Please do not move the chairs from the position they are in. You need to sit with your heads back in the headrest and to look towards the lights at least once every couple of minutes. You may read, talk or just listen to the music during the next hour. I will let you know when this part of the experiment is over. If any of you begin to fall asleep, I will wake you up.

NB: For those who are only sitting in front of the lights for only the last 15 minutes, or when the condition is room lighting:

You are not required to sit in front of the lights yet, so please remain at the tables and I will tell you when to move to the chairs in front of the lights. Please do not move any closer to the room light, but remain behind the tables you are seated at, at all times.

4. Okay, we have finished that part of the experiment, now I need to take your temperatures again, and can you also record your sleepiness level from the same seven statements and mark your answer in box B. Thank you.

APPENDIX E Cont.

Take each participant's temperature and ensure they mark their sleepiness level at B.

5. We are now ready to commence the behaviour tasks. Please sit at the tables and I will read the instructions for each exercise. Three of the exercises require both speed and accuracy, that is, you will be asked to go as fast as you can, whilst trying to minimise your errors, so you will need to balance the two instructions. The other two exercises have a set time for completion. I will instruct you when to begin and when to stop for each exercise. There will some break between each exercise while I collect up the papers and issue out the next exercise. If you finish early, please just sit quietly until the others have all finished too.

1. Letter Recall Exercise

In this exercise, you are given a list of 25 words to familiarise yourself with for the next couple of minutes. Then I am going to ask you to recall as many of them as you can. Later, after completing other exercises, you are going to be given a list of paired words and asked to identify the word in each pair that is from this list. Are there any questions?

Please read over the list of words for the next minute.

Stop them after one minute

Now I am going to read each word out aloud, and ask you to concentrate on each word as I read it.

Read each word out aloud slowly

You now have another 30 seconds to study the list further before we begin.

Time 30 seconds

Okay, please turn the page over. When I tell you to begin, please write down as many words from the list as you can remember. You have 1 minute in which to complete this task.

Are there any questions?

You may begin now.

Time 1 minute

Okay, I will just collect up these sheets, and hand out the next exercise.

APPENDIX E Cont.

2. Instructions for Critical Thinking Task

I am going to give you two minutes to read the instructions for this exercise. Please take this time to read the instructions and example carefully, and then I will tell you when you can commence. When you begin the actual exercise you are required to mark the appropriate box in the answer sheet provided with the exercise. Please make sure you use the relevant block of answer boxes for the type of questions you are answering. For example, your test says _________ ,so you will indicate your answers in the __________boxes. You are asked to put a line through the appropriate box that corresponds to the answer you believe is correct. If you make a mistake, then simply put a cross (x) through the box and put a line through the new answer box. Please use this reading time to familiarise yourself with the answer sheet as well.

Are there any questions?

Please begin reading the instructions now.

Allow two minutes to read the instructions.

Okay, we are now ready to begin the task. You are required to complete this task as quickly as you can, whilst taking sufficient time to give each question the necessary consideration in order to select the answer you believe is most correct. This is not an easy exercise, so do not be concerned if you can not clearly identify an answer. Do not get hung up on one question, if you are not sure, then make a guess and go on to the next one. I will only allow a total of 10 minutes to complete this exercise, but please indicate by raising your hand when you have finished, so that I may record your completion time. I will instruct you when 8 minutes has passed, so that you can try and complete the questions within the 10-minute timeframe.

Has anyone any further questions?

You may begin the exercise now. You have ten minutes to complete this exercise.

Tell them at 8 minutes.

Stop them at 10 minutes

Okay time is up. You can now have a rest while I collect these up and hand out the next exercise.

Collect up the answer sheets and questionnaires.

APPENDIX E Cont.

3. Math Exercise

Please complete the following sums as quickly and as accurately as you can. You may use the blank paper given to you to assist in completing the sums. Calculators are not to be used. Are there any questions?

Please indicate when you have finished by raising your hand so that I can record your completion time.

Please begin now.

Okay time is up. You can now have a rest while I collect up the answer sheets and hand out the next exercise.

Collect up the questionnaires.

4. Letter Cancellation Task

In this exercise you are asked to put a cross (X) **through** the two letters that are stated at the top of the paragraph of letters. You are asked to move from left to right across the lines, and from top to bottom. Your performance will be judged on both speed and accuracy, therefore you should work as quickly as possible while minimising errors.

Are there any questions?

Please indicate when you have finished by raising your hand, so that I can record your completion time.

Please begin now.

Record times as each raises their hands

5. Word Recognition Task

The following 25 pairs of word are each made up of one word that you have seen in the word recall task, and a word you have not previously seen tonight. Your task is to put a cross **(X) through the word previously seen** in each of the pairs. This word occurs approximately equally often on the left and right sides.

I will read out each word pair and then pause momentarily. During this pause you should immediately cross out the word you have previously seen.

APPENDIX E Cont.

Are there any questions?

Okay let's begin.

Read out each word pair and stop for two seconds between each.

Collect up the questionnaires

Okay we have now finished the exercises and all that is required now is for me to take the final temperature readings and for you all to indicate you current sleepiness levels and write your answers at C on the questionnaire. For safety reasons, I think it would be better if we all left together or at least in pairs. This final part will only take a minute to complete.

Take temperatures and ensure all have recorded their sleepiness levels

Thank you for your assistance tonight – if you can be here next week by 10.50, so that we can start on time at 11.00 pm. Thanks.

APPENDIX F

Example of Performance Tasks

Word Recall Task

Participants were allowed to read over the words for one minute. Then the words were read out to them and they were instructed to concentrate on each word as it was read. Finally, they were asked turn the page over and to write down as many of the words as they could remember within one minute. The following lists are the words used for each of the groups on each of the weeks as shown:

	Week One	*Week Two*	*Week Three*	*Week Four*
1.	goal	term	seed	isle
2.	diet	sock	mule	fist
3.	area	sway	loom	fond
4.	clad	worn	beer	tube
5.	rack	drum	soup	zone
6.	leaf	sink	ugly	sink
7.	pour	crop	envy	papa
8.	dull	sank	drug	beam
9.	code	peep	folk	hood
10.	acre	dawn	twin	nail
11.	isle	wolf	fist	slip
12.	pant	risk	fowl	team
13.	pray	cart	fret	flew
14.	lace	feed	rail	peep
15.	calm	band	nigh	lion
16.	wink	twig	tool	urge
17.	drag	lash	wail	fork
18.	site	lean	heal	drag
19.	bite	main	flew	spin
20.	cage	mend	hung	vain
21.	bond	deny	alas	male
22.	cape	ours	rope	leap
23.	hire	goat	deed	lend
24.	weak	calm	rack	lean
25.	snap	brow	heap	chop

APPENDIX F Cont.

Critical Thinking Task

Participants were asked to complete one of the Watson-Glaser Critical Thinking Appraisal tests each week. A sample of the test for each week follows :

Week One – Recognition of Assumptions Test

Participants read a series of statements and decide for the assumptions that followed whether each assumption is made or taken for granted, based on the statement made.

Statement: There is not enough of everything to give all people what they think they want.

Assumptions: People should not expect to get something for nothing

Week Two – Deduction Test

Participants had to read a series of conclusions and decide if the accompanying statements, "follows" or "does not follow" from the conclusion given.

Conclusion: All great novels are works of art. All great novels capture our imagination. Therefore-

Statement: Whatever captures our imagination is a work of art

Week Three – Evaluation of Arguments

Participants had to read a series of questions and decide for each if the list of the arguments that followed were strong or weak arguments

Question: Is it possible to develop a controllable death ray that will, under certain conditions, kill living organisms on which it is focused as far as five miles or more distant?

Argument: No; some physicists have already tried to develop a controllable death ray and have not been able to do so

Week Four – Interpretation

Participants read a paragraph and judged whether or not each proposed conclusion logically followed from, beyond a reasonable doubt, the information given.

Paragraph: Of the 2,800,000 juniors and seniors in the nation's public high schools during a certain year, only 830,000 were enrolled in science and only 660,000 in mathematics courses

Conclusion: Some public high schools did not require science and mathematics for all juniors and seniors during that year.

APPENDIX F Cont.

Mathematics Sums Exercise

Participants were asked to complete a series of mathematics sums as quickly and as accurately as possible. A different set of sums was developed for each week. An example from one week is shown below:

1.	16 x 9	2.	98 - 55	3.	57 x 4	4.	59 - 26
5.	61 x 3	6.	92 38 + 77	7.	81 -57	8.	422 +115
9.	25 x 3	10.	28 +55	11.	17 x 8	12.	97 - 35
13.	632 +554	14.	95 - 61	15.	89 + 55	16.	86 x 4
17.	230 118 + 28	18.	82 + 23	19.	215 - 49	20.	78 x 8
21.	78 - 32	22.	871 - 552	23.	66 x 6	24.	915 - 82
25.	39 x 4	26.	445 + 65	27.	362 - 91	28.	48 x 7
29.	782 225 933 446 + 166	30.	589 667 114 715 + 322	31.	657 771 341 488 +192	32.	619 322 995 177 + 544

APPENDIX F Cont.

Letter Cancellation Task

In this exercise, Participants were asked to put a cross (X) through two given letters in a paragraph of letters provided. Performance was judged on both speed and accuracy. The order of letters was randomised, but controlled to ensure that an equal number of all letters of the alphabet appeared in each paragraph; the exception being the two letters to be cancelled where 150 appeared in each paragraph.

The following paragraph is the one used for the first week of testing. Each week had a different paragraph and two different letters to be cancelled. The letters to be cancelled in this paragraph are C and H.

EWZNREHQUMIMUCQMJPZDGVKJUQIYRAZEYUIRUJRCNVXNJQPEGUZK
HSECBCAYCUCLCHMJLCBVHWQSHEPILKREFCTGTFCSBQYPZDVYEKXH
GEPCXHETRBIQJUZESBZVVOWENFNXJPZCNKIAHXNIOKFBYCWLCZEHG
NLWXRLCLBMXGPBNZPXWOIVBGNRTNECNVZCUPHJCGNXWIDYBLFVK
QXRJHASCEWQRTCVBHYNJUIOPLKMNZHSXQWCECRFVBGTYHNMJUIKL
OPMNBVCXZAQWSEDRCTCYHGCCSXCDERFTGYHUJIKOLPMNBVCFCFS
AQPDMGHRDBCGOPCHORBNVRLTGHDOCPZHKSGDHUIIOLKPCUHDJRN
BXKBVHCDYCTCRESMHZDOPKHVTEUAGNOPLFCXWGBNPLJGFDQZXCS
AWECLGKIYORUCHNBBCFDREEWDCZXHSQPOLKMGYHBBVGCTFRCHS
WAQCZXCDGVCDSHYUIOPLKJGCDREFVCYHUJIMKOLPMJOUIHJGTFRDV
CFCRSEWQASZXDRCFVGTYHBUJYNCTJCHFHDMPOGECXBNQLOKNNED
MPEOASIHOCNVHCPSLKCPRJVNAPHPREORORLCHSYHQWERVHNHJUIO
PKHFSDAVXVBCBFCGFDBVNVKGKHOLHPUOIYUTYRGCHBSZNCCBCZD
AEWCXCCERVBGYTUJMNIKHOLPQWPLAKSJDHFYHURIEOZMXNCBVCF
HDTERYUJXGJFKQZWXHCRPMOIUNBGHFDRTSJKHVCYCSCVCFGCHSCX
GHSWOMNAWCSAVBKLJQCDSDEEFHNPMCDFHOCZKGIWNRTYEOIBSA
WCVSQTIZPWRXHITCCFZHKOMPQYBPZOAIQLXKSIEUVHCFDRTGHNBJU
EGPFMOWSRCCETVBCXHCHYQHSUJGIKHJBNVHCGFHDREQWSAXZOQP
ALSKHFDGFWIHUFLKCVBLSCCTGHLSBLHFADLIFCYALDFBALFHHLVBS
LIUVGWERPHSJCZLXCPAOOIRQWCZCVBHADHMSCPDIWIHCHLIWUHVL
ASIUGHASDCHAWOUFGYSLUFGOQHEFCHJVCBLASIUDCYTHELGVHCCK
JADLIFYAWLEICGAJVDLBHSFLHFDLIQWEYFQWEFGLQCVBCALHNSFNB
APFARPGKFLMBDSIHGWREOJQWPHJSDNHDAFBNHSKDCNVWEHPEWRI
GHNFHSFCVONIAWHHFHWIYHTNBSADFOIEQHGPQHIURAJDKSFYRHGN
BZLXALSHDFPOQWEYRASHDFZHXVHGYUWCSGQPOYTALGBAWFVGHR
CKFVLGHEUCBLSIIWIWCGNAGHIUPEHTIGYPOMNHVJCVNCNVFGQKWY
HROQWTCLDVDSVBALDSKJFHALIGYOQWTRIUQWPRCQWEFSDCLDGHP
ECYHACDLVBCGAHRQWUEJCFJWYRHVDLIURYHOETYPIVVLKJHFLASD
CHASGDFOIQWHRPOIUEQWRPIQWCHASLVBXHCVBXCKADLKAUWPOR
HYEFCASLVBASGDDACEARGASFGDSRTRHCFCSCDGNMYHRQKBWNJYP
OIQHRRXQEZFAADNJWNBKNDCFCERYURYUIUPOILKNBCDHTHWRTSDF
BXCVBSHDFHXCGNBASDFQWERQWHTRWHYTRUDCGBDZSFCSZVBXFG
HNVACGSFGHASCHTDYJHGFGFCFYTERWTRYTREFNFCXNGDSHYHDRC
APIUUGKHGDSADNBVBXAHRFGREHRYURTHFDVNIYTRNTQWQTABXW
USNVCAQEUTHDNFHCDHCBSRTFHGVBRSHFTVBCTFHGRTHFBAJDMWK

APPENDIX F Cont.

Word Recognition Task

The following 25 pairs of words are each made up of one word that Participants had previously seen (in the word recall task) and a word they had not seen. Their task was to cross (X) the word previously seen in each pair. Participants were told that previously seen words appeared on the left and right sides equally often. Each word pair was read out to the participants, and Participants were instructed to make their choice during the brief pause (approximately 2 seconds) that followed.

	Week One		*Week Two*		*Week Three*		*Week Four*	
1.	loud	hire	lazy	brow	ugly	jail	leap	mail
2.	belt	weak	dive	term	snap	rope	envy	chop
3.	pond	drag	envy	crop	heap	isle	beam	quit
4.	cape	soap	ours	robe	soap	rack	drag	tuck
5.	snap	soak	fist	band	feed	seed	lazy	lion
6.	limb	pant	main	pony	heal	sock	fist	melt
7.	cage	howl	lime	drum	nigh	film	wilt	tube
8.	pool	code	risk	barn	pink	alas	lend	hath
9.	pray	loom	tail	feed	wail	chop	task	isle
10.	boil	wink	twig	lamp	tool	rank	spin	beer
11.	lace	lent	cart	flat	mild	fret	bolt	slip
12.	isle	cell	tone	deny	drug	deer	flew	area
13.	lime	bite	wolf	sale	pipe	flew	tour	papa
14.	dull	jury	beef	peep	fate	mule	rack	zone
15.	bond	park	dawn	dull	lone	fowl	nail	twig
16.	calm	mast	mend	gift	rail	wrap	wrap	fond
17.	lawn	site	lash	dust	envy	pool	sink	puff
18.	rack	dine	maid	sway	rage	soup	vine	hood
19.	vest	leaf	sock	diet	fist	firm	male	prey
20.	clad	lean	hire	worn	peer	folk	team	moss
21.	pour	claw	lend	calm	lawn	twin	mild	fork
22.	monk	area	sank	term	hung	harm	urge	pack
23.	team	goal	lean	lock	deed	barn	weep	vain
24.	acre	link	sigh	sink	deck	loom	mill	lean
25.	wilt	diet	clap	goat	beer	beef	peep	tail

APPENDIX G

MANOVA Results

Recall Task Score

a) Within Subjects Effects

Source of Variation	df	SS	MS	F	p
Intensity	3	221.00	80.49	1.50	.23
Intensity x Duration	3	341.00	124.20	2.32	.10
Error	42	2062.00	53.65		

b) Between Subjects Effects

Source of Variation	df	SS	MS	F	p
Duration	1	1.00	1.00	.001	.98
Error	14	14198.00	1014.14		

APPENDIX G Cont.

Critical Thinking Task Score

a) Within Subjects Effects

Source of Variation	df	SS	MS	F	p
Intensity	3	1344.60	448.20	4.13	.01
Intensity x					
Duration	3	299.68	99.89	.92	.44
Error	42	4556.89	108.50		

b) Between Subjects Effects

Source of Variation	df	SS	MS	F	p
Duration	1	103.15	103.15	.20	.67
Error	14	7342.53	524.47		

APPENDIX G Cont.

Critical Thinking Task Completion Time

a) Within Subjects Effects

Source of Variation	df	SS	MS	F	p
Intensity	3	6.21	2.79	1.37	.27
Intensity x					
Duration	3	3.58	1.60	.79	.48
Error	42	63.70	2.04		

b) Between Subjects Effects

Source of Variation	df	SS	MS	F	p
Duration	1	1.15	1.15	.17	.69
Error	14	96.52	6.89		

APPENDIX G Cont.

Mathematics Sums Task Score

a) Within Subjects Effects

Source of Variation	df	SS	MS	F	p
Intensity	3	132.29	67.25	.85	.44
Intensity x					
Duration	3	13.89	7.06	.09	.91
Error	42	2190.25	79.52		

b) Between Subjects Effects

Source of Variation	df	SS	MS	F	p
Duration	1	904.69	904.69	1.44	.25
Error	14	8794.86	628.20		

APPENDIX G Cont.

Mathematics Sums Task Completion Time

a) Within Subjects Effects

Source of Variation	df	SS	MS	F	p
Intensity	3	13.55	4.52	4.29	.01
Intensity x Duration	3	2.14	.72	.68	.57
Error	42	44.20	1.05		

b) Between Subjects Effects

Source of Variation	df	SS	MS	F	p
Duration	1	.52	.52	.03	.87
Error	14	249.15	17.80		

APPENDIX G Cont.

Letter Cancellation Task Score

a) Within Subjects Effects

Source of Variation	df	SS	MS	F	p
Intensity	3	7.03	2.34	.16	.93
Intensity x					
Duration	3	3.91	1.30	.09	.97
Error	42	637.20	15.17		

b) Between Subjects Effects

Source of Variation	df	SS	MS	F	p
Duration	1	1.27	1.27	.01	.92
Error	14	1848.98	132.07		

APPENDIX G Cont.

Letter Cancellation Task Completion Time

a) Within Subjects Effects

Source of Variation	df	SS	MS	F	p
Intensity	3	1.12	.42	.45	.69
Intensity x					
Duration	3	.59	.22	.24	.85
Error	42	34.44	.92		

b) Between Subjects Effects

Source of Variation	df	SS	MS	F	p
Duration	1	4.33	4.33	.63	.44
Error	14	95.63	6.83		

APPENDIX G Cont.

Recognition Task Score

a) Within Subjects Effects

Source of Variation	df	SS	MS	F	p
Intensity	3	747.00	269.79	4.87	.01
Intensity x Duration	3	360.00	130.02	2.35	.09
Error	42	2149.00	55.44		

b) Between Subjects Effects

Source of Variation	df	SS	MS	F	p
Duration	1	324.00	324.00	.80	.39
Error	14	5667.00	404.79		

APPENDIX H

Means and Standard Deviations for Sleepiness, Temperature, and Performance Tasks, at each level of Intensity and Duration.

Measure/Duration	Condition	Mean	Standard Deviation
Sleepiness @ 11.00 p.m.			
60	Baseline	2.63	1.06
15	Baseline	3.00	1.07
60	300	2.75	0.71
15	300	3.13	1.64
60	600	4.00	1.31
15	600	3.38	1.06
60	1000	3.88	0.99
15	1000	2.63	0.92
Sleepiness @ 12.00 Midnight			
60	Baseline	3.75	0.89
15	Baseline	4.00	0.76
60	300	3.63	0.92
15	300	3.88	1.64
60	600	4.63	0.92
15	600	3.25	1.04
60	1000	4.25	1.28
15	1000	3.38	1.06
Sleepiness @ 12.45 a.m.			
60	Baseline	4.38	1.30
15	Baseline	4.75	0.89
60	300	4.00	0.93
15	300	4.88	1.13
60	600	4.13	1.46
15	600	4.50	0.93
60	1000	4.88	1.89
15	1000	4.38	0.52
Temperature @ 11.00 p.m.			
60	Baseline	36.48	0.55
15	Baseline	36.35	0.39
60	300	36.58	0.31
15	300	36.41	0.33
60	600	36.58	0.59
15	600	36.59	0.22
60	1000	36.34	0.48
15	1000	36.60	0.30
Temperature @ 12. Midnight			
60	Baseline	36.38	0.54
15	Baseline	36.44	0.23
60	300	36.38	0.36

APPENDIX H Cont.

15	300	36.33	0.34
60	600	36.48	0.45
15	600	36.61	0.30
60	1000	36.44	0.47
15	1000	36.36	0.19
Temperature @ 12.45 a.m.			
60	Baseline	36.45	0.50
15	Baseline	36.26	0.28
60	300	36.43	0.39
15	300	36.43	0.27
60	600	36.44	0.61
15	600	36.56	0.25
60	1000	36.50	0.45
15	1000	36.36	0.33
Recall Task			
60	Baseline	37.00	12.24
15	Baseline	41.00	21.78
60	300	38.50	17.36
15	300	31.00	24.73
60	600	35.50	10.99
15	600	39.00	18.61
60	1000	39.00	10.42
15	1000	40.00	14.50
Critical Thinking Task.			
60	Baseline	66.41	11.54
15	Baseline	67.97	15.82
60	300	82.81	8.01
15	300	74.22	10.26
60	600	78.91	12.91
15	600	74.22	13.13
60	1000	69.53	22.27
15	1000	71.09	17.66
Critical Thinking Time.			
60	Baseline	5.73	1.92
15	Baseline	4.73	1.46
60	300	4.89	1.53
15	300	5.20	1.57
60	600	4.76	1.01
15	600	4.62	1.67
60	1000	5.67	1.70
15	1000	5.43	2.36
Maths Task.			
60	Baseline	87.50	10.30
15	Baseline	81.25	15.40
60	300	92.19	8.18
15	300	83.59	15.38

APPENDIX H Cont.

60	600	91.41	5.22
15	600	84.38	18.75
60	1000	90.63	6.25
15	1000	82.42	22.47
Maths Time.			
60	Baseline	6.48	2.43
15	Baseline	6.589	2.51
60	300	5.92	2.000
15	300	6.09	2.92
60	600	5.42	1.69
15	600	5.16	1.99
60	1000	6.61	2.44
15	1000	5.86	2.10
Letter Cancellation Task			
60	Baseline	91.42	5.41
15	Baseline	91.00	9.23
60	300	90.50	5.86
15	300	90.33	7.51
60	600	90.63	4.70
15	600	91.04	6.66
60	1000	91.71	6.18
15	1000	90.75	6.73
Letter Cancellation Time			
60	Baseline	8.55	1.35
15	Baseline	7.94	1.02
60	300	8.66	1.39
15	300	7.87	1.26
60	600	8.60	1.23
15	600	8.29	2.25
60	1000	8.75	1.27
15	1000	8.38	2.00
Recognition Task			
60	Baseline	75.50	14.73
15	Baseline	77.00	10.42
60	300	74.00	17.10
15	300	86.50	8.26
60	600	83.50	10.13
15	600	87.00	7.93
60	1000	77.50	6.74
15	1000	78.00	14.81