The Effect of Long Photoperiod on The Visuospatial Working Memory in Wistar Rats (*Rattus norvegicus*)

[Pengaruh Pencahayaan Panjang Terhadap Memori Kerja Visuospasial Tikus Wistar (*Rattus norvegicus*)]

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ABSTRACT

Nowadays, the boundary between day and night cannot be distinguished clearly because of artificial lighting at night. Artificial light exposure at night effects the circadian rhythm of the organism body. Light is the primary stimulus in determining the circadian rhythm of an organism. Circadian rhythms play an important role in determining the sleep patterns of an organism. Circadian rhythm disruptions can cause negative effects on health, including cognitive function deficits, such as a working memory. The aim of this study was to determine the effect of long photoperiod on the ability of visuospatial working memory of Wistar rats (*Rattus norvegicus*). Total of 16 rats comprising two groups were used. The first group was treated with a normal photoperiod, 12 hours light and 12 hours dark, while the second group was treated with a long photoperiod, 21 hours light and 3 hours dark. In this study two different object recognition methods were used to investigate the visuospatial working memory in rat, namely Novel Object Recognition (NOR) to test the visual working memory and Object Location Recognition (OLR) to test the spatial working memory. The results showed that long photoperiod exposure significantly decreased the ability of the spatial working memory, but did not show any effect the visual working memory of the studied rats.

Keywords: Circadian rhythm, photoperiod, behavior, working memory, *Rattus norvegicus*

ABSTRAK

Saat ini, batas antara siang dan malam tidak dapat ditentukan dengan jelas karena adanya penerangan buatan di malam hari. Paparan cahaya buatan pada malam hari pada organisme dapat memengaruhi ritme sirkadian pada tubuh. Cahaya berperan sebagai rangsang utama dalam penentuan ritme sirkadian suatu organisme. Ritme sirkadian berperan penting dalam menentukan pola tidur organisme. Gangguan ritme sirkadian dapat menyebabkan efek negatif terhadap kesehatan, termasuk berkurangnya fungsi kognitif salah satunya adalah memori kerja. Tujuan penelitian ini untuk mengetahui pengaruh pencahayaan panjang terhadap kemampuan memori kerja visuospasial tikus wistar (*Rattus norvegicus*). Penelitian ini menggunakan 16 ekor tikus yang dibagi menjadi dua grup. Grup pertama merupakan grup yang diberi perlakuan pencahayaan normal, 12 jam terang dan 12 jam gelap. Grup kedua merupakan grup yang diberi perlakuan pencahayaan panjang, 21 jam terang dan 3 jam gelap. Penelitian ini menggunakan metode rekognisi objek untuk menguji memori kerja visuospasial pada tikus wistar (*Rattus norvegicus*); yaitu uji *Novel Object Recognition* (NOR) untuk menguji memori kerja visual dan uji *Object Location Recognition* (OLR) untuk menguji memori kerja spasial, terhadap pengaruh pencahayaan panjang. Hasil penelitian didapatkan bahwa paparan fotoperiode panjang pada tikus secara signifikan menurunkan kemampuan memori kerja spasial dan tidak berpengaruh terhadap kemampuan memori kerja visual tikus yang diuji.

Kata Kunci: ritme sirkadian, pencahayaan, perilaku, memori kerja, *Rattus norvegicus*

INTRODUCTION

Light is the main stimulus in determining the circadian rhythm of an organism, such as sleep cycle, patterns of hormone secretion, blood pressure, and levels of alertness (Hedge 2013). Mammalian circadian rhythm is generated by suprachiasmatic nuclei (SCN), which has recurring period close to 24 hours (Rivkees 2007). Circadian rhythm disruption can be caused by photoperiod

(length of light in a day) exposure, shift work and jetlag (Davis *et al.* 2001; Stevens *et al.* 2007). Circadian rhythms influence metabolic cascades in numerous domains and links occur between several diseases and circadian rhythm disruption such as impaired cognitive functions, cardiovascular diseases, obesity, and diabetes (Zelinski *et al.* 2014). Altered photoperiod and disrupted circadian rhythms are associated negatively with memory and mood in both humans and animal models

(Landgraf *et al.* 2016; Alhola & Polo-Kantola 2007; Obayashi *et al.* 2013; Touitou *et al.* 2017; Meng *et al.* 2018).

Memory can be classified by its duration and storage capacity, namely sensory memory, short-term memory or working memory, and long-term memory. Sensory memory is the shortest memory formation process, it lasts less than one second and it is facilitated by sensory abilities such as visual or audio (McBride & Cutting 2018). Working memory refers to the capacity to hold information briefly in memory while performing other mental operations on the information (Mirsky *et al.* 1995). Baddeley & Hitch (1974) stated that there are three main functional components of working memory, namely the phonological loop, visuospatial, and central executive. The phonological loop keeps auditory information active in consciousness for the purpose of immediate problem-solving. The visuospatial sketchpad allows people to keep visual images and spatial information active in the mind for problem-solving. The central executive component allocates cognitive resources, focuses attention that is needed to solve problems, and controls cognitive interference (Baddeley 2012). This system interacts with long-term memory in retrieval process which is necessary to solve problem and to help processing new information in long-term memory retention (Holdnack *et al.* 2016).

The effect of long photoperiod in rat show a decrease of cognitive function on long-term memory (Barnes *et al.* 2017). Experimental research using Wistar rats (*Rattus norvegicus*) has been widely conducted and about photoperiods related to long-term memory have been conducted several times (Barnes *et al.* 2017; Dellapolla *et al.* 2017, Fitria *et al.* 2021; McDonald *et al.* 2007).

Therefore, this research aimed to investigate the effect of long photoperiod in short-term memory, especially visuospatial working memory ability of Wistar rats (*R. norvegicus*). Object recognition method is a commonly used behavioral assay for the investigation of various aspects of learning and memory in rodent, it is also relatively fast and efficient tool for testing different phases of learning and memory (Lueptow 2017). This research applied two different object recognition methods to test the effect of long photoperiod in the visuospatial working memory in Wistar rats

(*R. norvegicus*), namely Novel Object Recognition (NOR) test to test the visual recognition memory and Object Location Recognition (OLR) test to test the spatial memory.

MATERIALS AND METHODS

Rat care and data collection were conducted in Animal House of Biology Faculty, Gadjah Mada University on April-May 2019. Design of this research has been approved by Ethics Commission for Medical and Health Research, Faculty of Medicine, Public Health and Nursing, Gadjah Mada University (KE/FK/0372/EC/2019).

The subjects were 16 male Wistar rats (*R. norvegicus*) aged 12 weeks and weighing between 200 – 275g (Barnes *et al.* 2017). Rats were housed in two groups based on treatment with ad libitum access to food and water. Rats care room temperatures were maintained at 21-23°C and humidity $\pm$ 60%. Light cage levels, while lights were on, was between 225-250 lux. The test room was isolated from noise and strong odors at temperatures of 21-23°C with humidity $\pm$ 60%. Timer lamp was used to adjust the photoperiod inside the cage.

A total of 16 male rats were used in this research were divided into two groups, those were Normal Photoperiod (NP) group (12 hours light: 12 hours dark) (Yasnikov & Deboer 2012) and Long Photoperiod (LP) group (21 hours light: 3 hours dark). The test used Object Location Recognition (OLR) and Novel Object Recognition (NOR) method (Figure 1).

This experiment was carried out for 4 weeks

Figure 1. Experimental design timeline

Remarks:

(Figure 1). At Week 1 all rats had normal photoperiod (12 hours light: 12 hours dark). All rats were habituated to the test box for two days, on the second and third day of Week 1. On the fourth day, the training and testing phases were carried out. At Week 2 and Week 3 the NP group was housed in 12 hours light: 12 hours dark, while the LP group was housed in 21 hours light: 3 hours dark and during this week-long period, no behavioral test occurred. At week 4 all rats underwent a final object recognition test. The behavior testing is carried out in a test room different from the care room. The test room is isolated from noise and strong odors. Before starting the behavioral testing, all rat conducted acclimation to the testing room that was carried out for 30 minutes (Denninger *et al.* 2018). The acclimation process was carried out before the habituation phase. All the phases are carried out in the light phase, the habituation phase and the training phase starting at 09.00 AM.

There were three phases on object recognition test; habituation phase, training phase, and test phase (Figure 2). The habituation phase was carried out for two consecutive days, on the second and third day. In the habituation phase, the rats were removed from the cage and then put into the test box (40x40x40 cm) by facing the rats against the wall of the box. Each rat was allowed to explore the test box for 10 minutes (Denninger *et al.* 2018). The habituation phase aimed to familiarize the rats with the test box. Rats that have been habituated to the test box are characterized by reduced exploratory activities of rats towards the test box, such as surrounding the box or climbing the wall of the box (Antunes & Biala 2012). The rats that had undergone the habituation phase were then transferred to a temporary cage, separated from the rats that had not undergone the habituation phase. The rats were

then returned to the care room.

The training phase began on the fourth day. For this phase, two identical objects were placed in adjacent corners of the chamber. Once the objects were in the testing chamber, rats were placed in the chamber and allowed to freely explore for 10 minutes. Rats that have undergone the training phase are transferred to a temporary cage, separated from rats that have not undergone the training phase. This phase aimed to introduce rats to the objects, marked by rat exploration activities such as sniffing or holding both objects (Antunes & Biala 2012). The test phase was carried out on the same day as the training phase, with an interval of five minutes between the two phases (Figure 2). In this study, two main tests were conducted, namely OLR for testing spatial memory and NOR for testing visual memory. Five minutes after the training phase, one of the objects was moved and the rats were allowed to explore the box for 5 minutes (OLR test). Five minutes afterwards, the object that had not been moved was replaced with novel object, and then rats was allowed to explore for five minutes (NOR test) (Barker *et al.* 2007; Gaskins *et al.* 2010; Carlini 2011).

Tests were carried out individually, between training phase and test phases the rats were placed in individual cages. The testing box and objects were always wiped clean with alcohol 70% after an animal was exposed to it to remove olfactory cues. After rats had completed the test phase, they were returned to their home cage and left undisturbed. Each rat's behavior during all phases was recorded from above the box, to be analyzed afterwards (Barnes *et al.* 2017).

Recording of total animal exploration on the objects from all testing phases were than analyzed using recorded and ANY-maze (version 6.10) software. The results of the analysis of each animal were exported to Microsoft Excel format, and used to calculate the Recognition Index (RI). RI is the percentage of time used by rat to explore new object (T_N) divided by a total of time to explore familiar object (T_F) and new object; $RI = T_N / (T_N + T_F)$. Exploration process defined as rats interaction time with the object, when its nose was place for about 1 cm from the object and it directly pointed the object, so the view of eye and nose is in line with the object (Barnes *et al.* 2017).

Independent t-test was used on 95%

Figure 2. Experimental design

Remarks:

confidence. The test was used to compare the total of exploration time of the animals on the object and the RI values of the two groups of animals. It also used to investigate the effects of LP exposure on the OLR and NOR tests.

RESULTS

Based on the observation that has been carried on, these are the following results

(Figure 3).

The results show that long photoperiod exposure significantly decreased the spatial memory abilities of rats. It can be seen from the number of Recognition Index, it show that RI number of long photoperiod (LP) group was lower than RI number of normal photoperiod (NP), it clearly showed in Figure 3a. RI was calculated from the time the animal explores new objects divided by the total exploration time

Figure 3. Result of object location recognition (OLR) and Novel Object Recognition (NOR) test

Remarks: a. Recognition Index (RI) Object Location Recognition; b. Average of exploration time for new object; c. Average of exploration time for familiar objects. d. Recognition Index (RI) Novel Object Recognition; e. Average of exploration time for new objects; f. Average of exploration time for familiar objects.

* Confidence 95%: NP: Normal Photoperiod, LP: Long Photoperiod

for new objects and familiar objects. Meanwhile, the result of this research showed that long photoperiod exposure did not affect visual working memory abilities of rats. It can be seen from the absence of a significant difference between the RI values of the NP and LP groups (Figure 3d). There was also no significant difference in the exploration time for newly replaced objects and familiar objects between the NP group and the LP group (Figure 3e and 3f).

DISCUSSION

The results showed that the lowest RI number of OLR test was in LP group (Figure 3a), it was because the exploration time of rats was longer on familiar object (not move) than new object (move) (Figure 3b and 3c). This indicates that the LP group rats could not distinguish the displacement of an object, indicating a lack of spatial working memory ability of the rats. Conversely, the NP group rats show the high RI values. This is due to the fact that the exploration time on the newly moved object is longer than the familiar object. This show that the NP group rats have a good spatial working memory, and it can distinguish the displacement of an object.

The results of OLR test were in line with the study of McDonald *et al.* (2013) which show that changes in photoperiod exposure can reduce cognitive function abilities. Besides, memory ability on OLR test has correlation with spatial working memory functions and relates to the role of the hippocampus in spatial processing and navigation abilities in the brain (Warburton & Brown 2015). Hippocampus is the main component of the human brain and other vertebrate. It has important role in information consolidation from short-term/working memory to long-term memory, and on spatial memory that allows navigation. The hippocampus is located in the inner (medial) temporal lobe, forming part of the limbic system (Martin 2003). Barker & Warburton (2011) suggested that the hippocampal lesions decrease the spatial working memory ability. In this study, the decrease in spatial working memory could be caused by the exposure of long photoperiod which can produce circadian rhythms disruption. Moreover, disruption in circadian rhythms have been studied

causing damage to memory-dependent hippocampal function (Craig & McDonald 2008; Ruby *et al.* 2008). Wang's *et al.* (2020) study on effects of circadian rhythm disorder and long photoperiod on the hippocampus of SHR and WKY rats, showed that the disruptions had adverse effects on the hippocampus in WKY and SHR rats, which were manifested as memory loss, the numbers of neurons and astrocytes in the hippocampus were decreased, changes in hippocampal plasticity, and reduced blood flow in the brain.

Light exposure in the dark phase can change the circadian rhythm controlled by the SCN (Snider *et al.* 2018). On cellular level, the formation of circadian rhythms in SCN is formed from the process of transcription-translation feedback of CLOCK and BMAL1 proteins which activate the expression of the Period (Per) and Cryptochrome (Cry) genes (Bedrosian & Nelson 2017). Period (Per) gene expression will produce the protein Per1 which use to maintain circadian rhythm at the cellular level. Per1 expression in the cell is very sensitive to light. Exposure of light in dark phase can distract the process of Per1 expression in SCN nucleus (Lamont *et al.* 2007). Fonken *et al.* (2013) said that light exposure to rats in night time resulted suppression of the Per1 expression process. Per1 expression does not only happen in SCN, but it also happens in the brain especially hippocampus. Per1 expression in hippocampus is important to regulate the hippocampus circadian rhythm and it also has function in memory processing. Rawashdeh *et al.* (2014) showed that rats with Per1 expression interference have a reduction in spatial working memory. Based on that explanation, long photoperiod exposure can decrease spatial working memory ability which depends on hippocampus. This caused by the change in excess light input, it will disrupt the process of circadian rhythm and Per1 expression which results in decreased spatial working memory.

The results of this study indicate that there is no effect of long photoperiod on visual working memory based on the NOR test. Memory ability on the NOR test correlates with visual working memory and its process, the process occurs in the perirhinal cortex of the temporal lobe and it does not relate to the role of the hippocampus in processing spatial

abilities (Cai *et al.* 2013). This concept is supported by study on perirhinal cortical lesions which cause visual working memory impairment but no spatial working memory impairment (Barker *et al.* 2007).

On the other hand, Barnes *et al.* (2017) showed that there was a decrease in the ability of long-term visual memory resulted from long photoperiod exposure. It is because the process of forming long-term memory involves the function of the hippocampus in consolidating information from short-term/working memory to long-term memory (Martin 2003). The hippocampus has function of forming long-term memory, and depends on the SCN as the main regulator of circadian rhythms. SCN regulates MAPK (mitogen-activated protein kinase) protein oscillations, which requires the hippocampus in the process of transcription-translation of long-term memory formation. Lesions of SCN showed oscillation damage process of MAPK protein in the hippocampus-dependent circadian information from SCN (Eckel-Mahan 2012). It is supported by Eckel-Mahan's study in 2018, showed that constant light exposure obscured the circadian rhythm and hippocampal MAPK activity. Kelly *et al.* (2013) confirmed the role of MAPK in long-term memory formation, MAPK inhibition in rats decreased long-term memory skills in the NOR test but not in short-term/working memory abilities. The ability of visual working memory of rats in this study can be used properly even though it is exposed by long photoperiod, because its process does not depend on circadian rhythms and the process occurs in the perirhinal cortex of the temporal lobe. It is supported by Shimizu *et al.* (2016), SCN impairment significantly decrease long-term memory abilities on the NOR test but it does not affect short-term/working memory abilities.

CONCLUSION

Long photoperiod on the visuospatial working memory of male Wistar rats (*Rattus norvegicus*) significantly reduces the ability of spatial working memory based on the OLR test, however it does not affect the ability of visual working memory based on the NOR test. It is

also show that male Wistar rats (*Rattus norvegicus*) can distinguish the substitution of an object and those have good visual working memory.

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AUTHOR CONTRIBUTION

NA is the key contributor, designing research, collect and analyse data, and write manuscript. SH as a supervisor in this study.

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