閃動拍速對警示用白熾光之影響

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摘要

有必要提醒來往人車注意的場所，例如事故現場，很可能要有具有高警示力的燈組裝置。然而現場往往交通堵塞，經過的人車可能較長時間暴露在該光源刺激下。本研究提出了白熾燈的最佳閃爍速度，可以最大限度地提高警覺性，同時最大限度地減少長時間的不適。該拍速除了具有高警示力之外，長時間閃爍下可能壓迫感更小。以白熾光為例，實驗測試結果表明，在 40-140 次/分之間的閃爍速度，無論是手填 10 分量表、還是單電極腦波儀 Neurosky MindWave eSense 的數值，120 次/分的都表現出高提醒度，與相對較低的壓力。燈閃刺激在 120 次/分時的腦波放鬆度平均值是在 110-140 次/分區之間最高的，也是在 90 次/分以上具有最小標準差的一個。與之前關於聲音的節拍研究一致，由於人類具有的共振節拍特性，120 次/分也可能是閃光刺激的首選頻率。因此，研究建議長期連續使用白熾警示燈的閃爍速度為 120 BPM，以實現警覺性和舒適性的最佳平衡。本研究的結論是，刺激頻率 120 次/分是適合白熾光長時間持續閃爍的刺激拍速。

關鍵詞: 最佳閃爍速度、白熾警示燈、120 次/分、NeuroSky MindWave eSense、首選頻率、警覺與舒適平衡

Optimizing Flashing Frequencies for Incandescent Warning Lights: A Study on Tempo's Impact on Attention and Discomfort

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Abstract

In environments requiring heightened awareness, such as accident scenes, warning lights are essential for alerting pedestrians and vehicles. However, traffic congestion frequently occurs at accident sites, and prolonged exposure to high-intensity flashing lights can also cause discomfort for nearby individuals. This research investigates the optimal flashing tempo for incandescent lights that maximizes alertness while minimizing discomfort over extended periods. Experimental analysis identified a flashing speed range of 40-140 Beats Per Minute (BPM), with a tempo of 120 BPM found to balance effectively between high alertness levels and reduced perceived stress. This balance was evidenced by both subjective assessments on a 10-point scale and objective measurements using the eSense of a Neurosky MindWave single-electrode electroencephalogram to gauge brainwave relaxation responses during exposure to varying flash tempos. Notably, the 120 BPM tempo exhibited the most favorable relaxation metrics within the 110-140 BPM range, alongside the smallest standard deviation

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in stress levels for tempos above 90 BPM. These findings align with previous research on the impact of tempo in auditory stimuli, suggesting a natural resonance with the 120 BPM frequency that may enhance the efficacy of visual warnings. Consequently, the study recommends a flashing tempo of 120 BPM for long-term continuous use of incandescent warning lights, offering an optimal balance of vigilance and comfort. This tempo could potentially improve safety measures in high-risk areas without contributing to stress or discomfort.

Keywords: Optimal flashing tempo, Incandescent warning lights, 120 BPM, Neurosky MindWave eSense, Preferred frequency, Alertness and comfort balance

I. Introduction

Construction or accident sites often need to warn people and vehicles around, especially at night, it is likely that lights with a prompting effect are required. Suggestive lights help people and vehicles pay attention and improve traffic safety [1–3]. Wavelength, color temperature and light intensity all affect cognitive responses in the human brain, including attention and reaction time [4]. High-brightness incandescent lamps are not suitable for use in occasions that require relaxation, they are still very suitable as special reminders of people's attention. In general, the higher the color temperature of the light, the more effectively it can improve consciousness, reduce drowsiness, increase attention, and speed up reaction time, keep people awake and prevent people from falling asleep [5]. However, lighting exceeding a certain brightness may produce additional glare and affect the driver's adaptation level, which in turn reduces road traffic safety [2]. Box therefore recommends a highway HFC level of 0.5 (5.4 lux) [6]. On the other hand, flashing lights may be more of a warning than a constant source of light [7]. While the color of incandescent lighting has no relaxing qualities by itself, it should enhance one's natural focus when combined with flickering. External beats can affect attention [8]. Both visual and auditory rhythms influence sensorimotor coordination [9]. Light warnings travel faster and farther than sounds and can effectively provide warning functions at traffic accident scenes. Although existing research into how humans might prefer certain beats has been mostly limited to acoustic stimuli, the present study hypothesized that a similar phenomenon would be true for visual beat stimuli, whereby cues are not always proportional to flash speed. In addition, we reasoned that the flickering of light may also have a human preference frequency. Therefore, the purpose of this study was to find out the flickering frequency of a flickering incandescent light source as a reminder, which may be the most warning, and may be the most suitable for long-term use. This study suspects that the fixed flashing strong light can also cause people to feel, such as rhythmic music beats, so the flash switching time unit used in this paper is calculated in “BPM” (beats per minute), which is usually used as the beat unit of music.

II. Literature review

Regarding the speed of rhythmic stimulation, general perception is that the faster it is, the more attention it can attract. However, just as light stimulation does not mean that higher brightness can avoid vehicle collisions [6], the relationship between beat speed and effect may not always be positive, and people may prefer certain beat frequencies. Some studies on signal stimulation have shown that certain beats may have special effects on people, which can be mutually confirmed with the results of this experimental study. Among them, 120 BPM (2Hz) stimulation may have unique meaning to humans.

1. Brain waves, nervous system and external rhythmic stimulation

Stimulation of external rhythms affects the human nervous system [10]. The brain is part of the central nervous system. Brain waves can change the oscillation phenomenon through external periodic stimulation. External rhythm stimulation and EEG signals can be correlated in a phase-locked manner [11–12]. There have been many studies on the effects of auditory and visual stimulation on brain waves. The continuous beat in the sound [13] and the continuous rhythmic flicker in the light source [14] will affect the way the nervous system works. External stimuli can affect brain waves through entrainment [15]. Neural responses to visual flickers can be observed in electroencephalograms as steady-state visual evoked potentials (SSVEP) measured in early visual cortex at the same frequency as the entrained stimulus [16–17]. Intermittent photo stimulation (IPS), for example, is a commonly used procedure in pediatric and adult electroencephalography (EEG) laboratories [18]. The introduction of cortical network plasticity enables periodic stimulation to produce significant post-stimulus effects [19]. Rhythmic perceptual stimulation does not disrupt the nervous system beyond its normal operating range [20], and can elicit resonant responses in the brain at the frequency presented through vision or hearing [21–22].

2. 120 BPM stimulation frequency

Although faster beats tend to be more uplifting, the faster the speed does not necessarily mean the relative linear improvement of human response. In a study of objective flicker frequency (4-166 Hz) and subjective flicker perception using flashing light stimuli of two seconds length, it was noted that slow flicker frequency significantly prolonged the duration of the perception [16]. Eagleman and Pariyadath proposed that the more energy it takes to represent a stimulus, the longer its perceived duration, while eliciting a stronger neural response [23].

120 BPM (2Hz frequency) is noteworthy. In a study of the effects of music tempo on memory performance when using different learning strategies, participants achieved the highest memory performance at 120 bpm compared to the control, 60 bpm, and 165 bpm conditions [24]. This may because the human body has its own rhythm, such as heartbeat and breathing. It is possible that humans have special predispositions to certain frequencies. People have a special liking for certain speeds. In an analysis of more than 74,000 popular songs written between 1960 and 1990, it was found that 120 BPM (as 2Hz frequency) was the dominant tempo [25]. A study on the correlation between music rhythm and emotion pointed out: taking 10 BPM as the interval between 90-130 BPM, it was found that the sense of pleasure gradually increased from 90 BPM to a high point at 120 BPM (130 BPM did not change due to the speed increase in pleasure) [26]. In another study on how tempo affects whether music sounds sad or happy, it was suggested that to achieve a sense of "happiness", a tempo of 120 bpm was recommended [27].

The current literature on rhythmic stimulus synchronization is mostly about sound. A recent study suggested that the optimal rhythm for beat synchronization is determined by neural dynamic time constants preserved across species, rather than by species-specific physical movement time constants [28]. In this experiment, sound patterns with energy peaks between 120 and 140 BPM produced the largest neural responses in the auditory cortex. In terms of hearing, a study pointed out that the tempo for inducing the most precisely synchronized walking with auditory stimuli is about 120 BPM [29].

Previous studies on the value of 120 BPM are worth noting. A study pointed out in 2002 that BPM 120 (500 ms) is more realistic as characteristic period for preferred tempo [30]. Rhythm-based music induces a tendency for body movement, with optimal rhythm found at drum beats around 100-120 BPM [31]. Endogenous cerebral cortical entrainment of auditory frequencies 1-5 Hz, with maximum entrainment at 2 Hz (expressed in beats equals 120 BPM), consistent with natural human movement rhythms intrinsically preferred [32]. According to the resonance theory of rhythm perception, as a resonant system with natural frequencies, human beings' speed perception has characteristics like driving harmonic oscillators, and people's rhythm perception and production are closely related to natural movement [33]. Furthermore, a highly tuned human motion resonance frequency of 2 Hz was also demonstrated in studies [25]. A study noted that the preferred walking cadence is approximately 120 steps/min., and that the vertical acceleration of the head exhibits a major peak at this stride rate (2 Hz) [34].

A recent study of the effects of auditory stimuli on high-resolution vitality responses unexpectedly found that not only beats in music, but a very prominent peak at 120 BPM was also observed when a metronome was used purely [35].

On the other hand, studies on 2 Hz electroacupuncture (EA) stimulation are also worth noting. EA is a form of acupuncture that incorporates electrical stimulation applied to acupuncture needles [36]. When EA is performed at 2 Hz (2 cycles per second), it is believed to trigger the release of specific neuropeptides, including enkephalins, beta-endorphins (βE), and endorphins. Beta-endorphin (β-END) is an opioid neuropeptide that acts on mu and delta opioid receptors [37], and plays an important role in the development of hypotheses regarding non-synaptic or paracrine communication of brain messages. These neuropeptides are part of the body's endogenous opioid system and play a role in pain modulation and emotional regulation. Beta-endorphins act on mu and delta opioid receptors in the brain. Mild activation of the beta-END system leads to a state of bliss, while stronger activation leads to feelings of well-being, analgesia, and euphoria [38]. We therefore hypothesized that certain visual stimulation, particularly when it induces relaxation and altered states of consciousness, may affect the release of neuropeptides such as endorphins and enkephalins. These neuropeptides can influence mood and pain perception, such as the beta-endorphin effects that may be enhanced by 2 Hz. But based on current research, while this stimulation has the potential to affect neuropeptide release and emotional experience, its effects are not as well documented or understood as established methods such as electroacupuncture. In summary, there appears to be a link between flickering light stimulation (especially at specific frequencies, such as 2 Hz) and the release of neuropeptides, but the nature and extent of these effects require further study and may be subject to individual differences.

III. Method

Because places where warnings need to be made, such as accident sites, may often be in a traffic jam, passing people and vehicles will be exposed to incandescent light sources for quite a period. Therefore, the purpose of this study is to find out the flickering frequency that has high warning and is suitable for people to use for a long time. In this study, a set of high-brightness incandescent light sources was designed, and the subjects were tested in a dark and quiet large room. The flash frequency was between 40 BPM and 140 BPM, and the interval is 10 BPM. Then the handwriting and the Neurosky eSense data results of the single-electrode electroencephalograph were statistically analyzed. The purpose of this study is to find out the most suitable frequency and provide a reference for the light source settings that require warning effects.

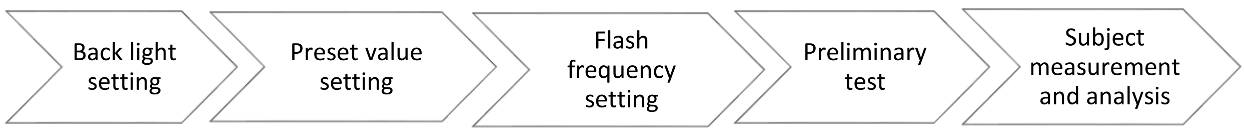

Fig. 1 *The design flow architecture of the experiment*

The design flow architecture of the experiment is shown in Figure 1. Because direct viewing from incandescent light sources is uncomfortable, the study was performed with backlight and eyes closed. The venue, lighting control system and lighting group were the stage engineering professional space and equipment of the Department of Pop Music Industry of Southern Taiwan University of Science and Technology. The lighting and on-site parameter settings are shown in Table 1 [39].

Table 1 *Lighting and field setting parameters*

Lighting Preset Parameters						
Preset value	**Luminaire brightness**	**Light source color temperature**	**Projetion width**	**Beaming angle**	**Projection space**	**Flickering frequency**
Parameter value	0%, 100%	White light source 6500K	8 lights 6 meters	8 lights 6 degrees	10 meters* 10 meters	40-140 bpm
Subject	Backlight	Eyes closed experience	Center seat	Angle 45 degrees	2.3 meters bevel	times/ minute
Lighting System Architecture: MA2 Lighting Controller, RGBW(Wash) 220V/180W Dyeing Light						

1. Experimental Design

The MA2 lighting control system, which is one of the most used stage control system in recent years, was used to adjust the lighting parameters and set the flashing speed [40]. The experiment was conducted in a quiet classroom that was large enough to simulate a wide space, closed and avoiding light sources other than MA2. Figure 2 is a photo of the on-site light group, MA2 control mixer and the environment. While Fig. 2 is about the experimental site, Fig. 3 is the software interface and parameter settings of the MA2 experimental lighting control. The room temperature was maintained at 26°C with quiet air conditioning, and the ambient noise level was kept below 20 decibels.

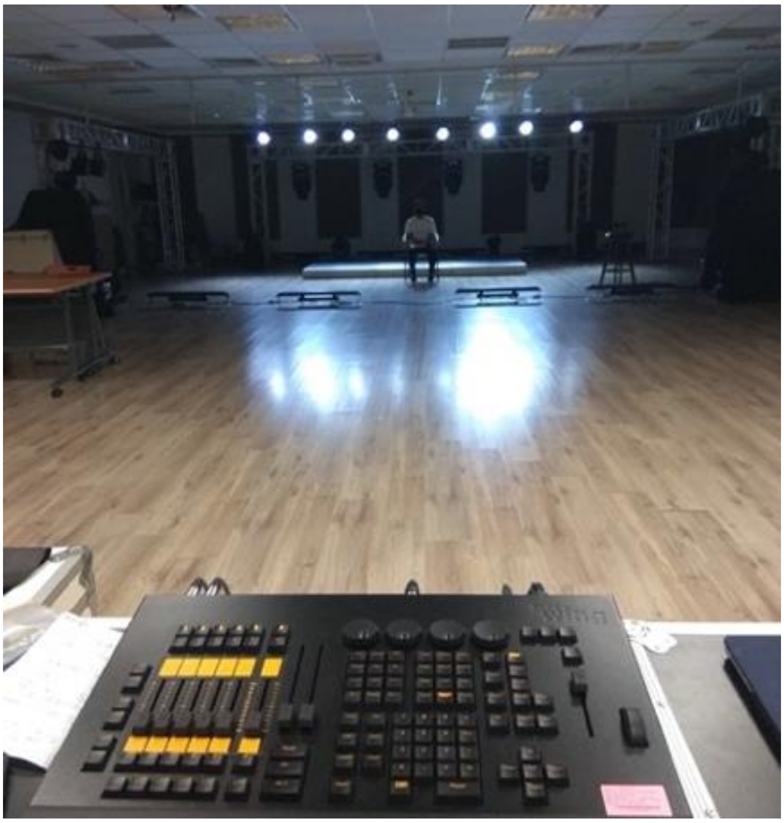

Fig. 2 *The on-site light group and the environment*

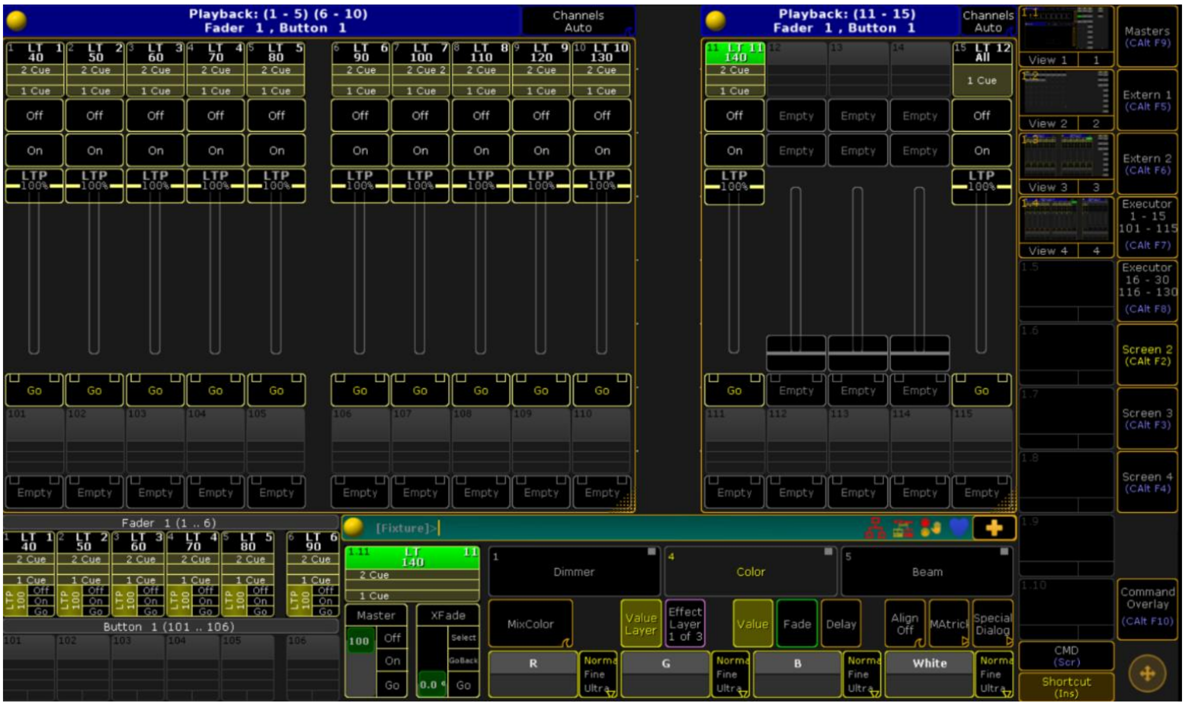

Fig.3 *The control setting software MA2 screen*

After preliminary testing, the beat range and measurement time were adjusted, and the experimental design and method were determined:

（1）BPM Interval and range: the top horizontal row in Fig. 3 showed the set BPM sequence, from 40 on the far left to 140 on the far right. Because if the interval was too large, noteworthy speed nodes may be skipped, and if the interval was too thin, there may be no obvious difference in perception for ordinary people. At present, the sections were set at intervals of 10 BPM, and more detailed measurements can be made in the future. A study in 2013 on music beats noted that beats above 145 BPM may no longer elicit higher arousal [41]. Also, a tempo that is too slow is generally considered less exciting. Therefore, in this study, the flicker test speed was set between 40-140 BPM.

（2）Light color temperature: research has shown that when subjects were exposed to a light color temperature of 6,500°K, people responded more correctly than when exposed to other color temperatures. Therefore, a light source with a color temperature of 6,500°K was recommended when designing tests for human reaction times and errors [5]. Since the light source set in this research was for warning purposes, the light color temperature set by the system was 6,500°K. The incandescent light has high brightness. To avoid causing discomfort to the subjects, this study performed the flash test with eyes closed. In addition, closing the eyes was easy to relax and doze off, but if the light set used could still prevent the user from relaxing easily when the eyes were closed, the lighting design should had a certain warning force.

（3）Subjective scale: the experiment designed a subjective scale, which was divided into two status columns "alertness" and "relaxation" for the subjects to fill in. The scale value range was 1-10, and 10 represented the highest.

（4）Objective numerical value: subjects wore a NeuroSky MindWave single-electrode electroencephalograph to collect eSense data for testing EEG [42] signals. MindWave set eSense has two status indicators that transmit a value per second, one is Attention and the other is Meditation. The eSense Attention should belong to the degree of concentration in the normal working state, but this experiment was designed to feel the environment containing the light source when the eyes are closed, so the Attention value may not be appropriate to use [43]. Since the meditative value in eSense refers to a state of relaxation, the flickering of the white light disrupts the ease of entering a state of relaxation with eyes closed. So lower meditative values should represent a higher state of alertness, which also represents the effect of white light stimulation.

（5）Test environment condition settings: Since the venue space, sound, other light sources, temperature and humidity and other conditions may affect the experimental results, the experiment was finally arranged in a large professional rehearsal classroom (W1001, Department of Popular Music Industry of Southern Taiwan University of Science and Technology) with good isolation conditions, spacious space, silent air conditioning and suitable as a place for lighting control testing. In addition, tests were scheduled during holidays to minimize possible disruption from the neighborhood classes. The experimental site simulated a dark road, so the background light source measured from the subject was about 5.1 Lux. The background light source is a long-bright ceiling lamp 10 meters away from the subject. In addition, the background noise value was approximately 37dB. The room temperature was set to 26 °C.

The purpose of this experiment was to find a beat speed that is both high in alertness and relatively more non-stressful. Therefore, in terms of experimental design, the subjective test feeling value was very important. In this study, the subjective test was divided into alertness and relaxation, and the changes and differences between the two were observed. This research assumes that the best cue frequency was a beat speed that had high alertness and was relatively less oppressive. That said, if there was a beat that achieves a sufficiently high alertness value and a relatively high relaxation value, it may be a more appropriate frequency. Because people and vehicles were likely to drive slowly due to accidents when passing through the warning section, and therefore be exposed to flashing lights for a long time. If certain beat can be less pressure of the already high warning flashes, it may be less irritating. Therefore, on the hand-filled ten-point scale, each test was divided into “alertness” and “relaxation”, and then the relative numerical performance of the two was discussed.

Next is the comparative observation of eSense relaxation values of objective data EEG. It’s important to note that MindWave’s eSense relaxation value is a value when you are still awake, not when you are asleep [39]. Therefore, many brainwave puzzle games designed for sober and relaxed training are expected to allow users to increase the eSense relaxation value, because the high relaxation value it refers to should be beneficial to people's general state. The flicker speeds were explored by comparing statistical analysis of EEG eSense values with each other.

Finally, there was a comparison of subjective and objective data. Here we will discuss the similarities and differences between subjective evaluation, objective values and discuss their possible meanings. The above experimental numerical analysis and discussion will be discussed in **Chapter 4.**

2. Subjects

This study complied with the guidelines of the Ministry of Education, and each subject was tested with informed consent. The age distribution of the subjects was 19-49 years old. 6 males and 6 females, 12 in total. The mean age of the subjects was 23.60±9.0 years. Subject's physical and mental status is normal. Three rounds of testing were performed for each subject, resulting in a total of 36 sets of results. The order of each test was randomized. The control group (continuous light source) and 11 segments of white light with different flashing speeds from 40-140 BPM were randomly played in each session. Subjects were unaware of the frequency order of each playback. The duration of each test segment was 90 seconds. After the flash was over, the subjects opened their eyes, filled out the questionnaire, took a short rest, and then entered the next flash frequency.

IV. Experimental result and discussion

Both the subjective ten-point scale and the MindWave EEG Meditaton value were checked by mean and ANOVA. The mean was compared to observe the state of alertness and relaxation of each segment, while ANOVA was to confirm whether there was a significant difference between the segment and the control group, and whether there was a significant difference between the segments. In the subjective test, 140 BPM was the highest level of alertness, followed by 120 BPM. The feeling of relaxation was roughly in line with expectations, the faster the tempo, the lower it was, and the BPM 140 met the expected minimum value. 120 BPM had a relatively higher degree of relaxation. In the MindWave EEG test, 120 BPM was the highest relaxation value after 90 seconds, and the standard deviation was the smallest. The relaxation value 130 BPM of the EEG test was the lowest.

1. Subjective scales

The questionnaire was divided into 10-point options in two directions: sense of alertness and sense of relaxation. Sensitivity 1 was the least and 10 was the highest. After each test, the subjects opened their eyes and circled the score of the sense of prompting brought by the paragraph and the score of relaxation felt in the paragraph. Because one person filling in the form made mistakes in filling in the list, four questionnaires were not used, so the total number of times was 32. According to the numerical results of each light filled in by the subjects, the mean and standard deviation of alertness were listed in Table 2, and the mean and standard deviation of relaxation were listed in Table 3.

Table 2 presents, as expected, that the faster the tempo, the less relaxed, while the cues generally increased with increasing speed. Although people's subjective perception of speed may not be very accurate, it can be observed from the cue perception values in Table 2 that the subjective cue value roughly increased with the increase of tempo.

Table 2 *Means and standard deviations of alertness on subjective scales*

BPM	Average	Std. Dev	N
Control	3.0000	1.39122	32
40	4.0625	1.26841	32
50	4.0625	1.88265	32
60	4.4375	1.68365	32
70	5.0000	1.52400	32
80	4.0000	1.68485	32
90	4.4375	1.38977	32
100	4.8125	1.97464	32
110	4.8750	1.51870	32
120	5.3125	2.32014	32
130	4.8750	2.45935	32
140	5.9375	2.28512	32

In Table 2, it was worth noting that 80 BPM and 130 BPM were both sudden drop points and then rise again. In addition, 70 BPM was also a sudden increase node, but this experiment hopes to find the best prompt conditions below 140 BPM, so it will not be discussed here. The above nonlinear improvement situation is the focus of the discussion and application in this study. This situation may be related to internal rhythms such as the human body's pulse and deserves further exploration.

In the relative relaxation performance values in Table 3, although the feeling of relaxation generally decreased as the speed increased, the relaxation values of 130 and 140 BPM had a significantly larger decrease, and 120 BPM had only a small decrease compared to 110 BPM. If we compare and observe these two subjective value tables, we can see that among the subjective scale values above 100 BPM, at 130 BPM, the level of alertness was relatively low and the degree of relaxation is not high. Therefore, 130 BPM may not be a good flash speed choice in this speed range. The article pointed out that most electronic dance music tends to have tempos in around 130 BPM [44]. The human characteristics of 130 beats are also values that can be discussed in the future.

Table 3 *Means and standard deviations of relaxation on subjective scales*

BPM	Average	Std. Dev	N
Control	7.1250	2.18130	32
40	6.2500	1.27000	32
50	6.1250	1.86219	32
60	6.3125	1.59510	32
70	5.2500	1.70389	32
80	5.9375	1.81281	32
90	5.8125	1.65466	32
100	5.5000	1.93441	32
110	5.5000	1.60644	32
120	5.3750	2.29656	32
130	4.8750	2.05960	32
140	4.0000	1.96748	32

Table 4 is the between-group ANOVA comparison of each speed of alertness sensation and the long-bright control group in the hand-filled scale. Each beat had a significant p-value (p<.05), that is, every flickering bright light source had a cueing effect.

Table 4 *The between-group significance narrative statistics of the subjective scale (alertness)*

(I) BPM	(J) BPM	Mean difference (I-J)	Std. err.	Sig.	95% confidence interval for the difference	
					Lower limit	Upper limit
Control	40	-1.063*	.339	.004	-1.754	-.371
	50	-1.063*	.414	.015	-1.906	-.219
	60	-1.438*	.421	.002	-2.296	-.579
	70	-2.000*	.291	.000	-2.593	-1.407
	80	-1.000*	.381	.013	-1.777	-.223
	90	-1.438*	.353	.000	-2.158	-.717
	100	-1.813*	.497	.001	-2.826	-.799
	110	-1.875*	.391	.000	-2.672	-1.078
	120	-2.313*	.567	.000	-3.469	-1.156
	130	-1.875*	.531	.001	-2.958	-.792
	140	-2.938*	.548	.000	-4.055	-1.820

** The correlation is significant at the .05 level (single-tailed)

Table 5 is the ANOVA comparison between each speed of the sense of relaxation and the long-bright control group. As shown in table 4, almost every speed reached p-value significance (p<.05, except for 40 and 60 BPM), i.e., the beat light was significantly less relaxing than the steady light source.

In Table 5, when flashing speed exceeded 50 BPM, it had a significant impact on relaxation. 40 bpm was too slow and easy to understand, but why there was no significant relaxation difference between only 60 BPM and the long phase ratio？It's worth noting that 60 bpm is equivalent to one second. Whether 60 BPM, as a benchmark for timing, has special meaning to human senses, may be further explored in the future.

Table 5 *The between-group significance narrative statistics of the subjective scale (relaxation)*

(I) BPM	(J) BPM	Mean difference (I-J)	Std. err.	Sig.	95% confidence interval for the difference: Lower limit	95% confidence interval for the difference: Upper limit
Control	40	.875	.462	.067	-.067	1.817
	50	1.000*	.435	.029	.112	1.888
	60	.813	.463	.089	-.132	1.757
	70	1.875*	.359	.000	1.144	2.606
	80	1.188*	.408	.007	.356	2.019
	90	1.313*	.443	.006	.409	2.216
	100	1.625*	.531	.005	.542	2.708
	110	1.625*	.483	.002	.640	2.610
	120	1.750*	.627	.009	.471	3.029
	130	2.250*	.570	.000	1.088	3.412
	140	3.125*	.595	.000	1.911	4.339

** The correlation is significant at the .05 level (single-tailed)

2. MindWave EEG Meditation Values

When eyes are closed but still awake, a lower Meditation value for MindWave can indicate less relaxation. In this study, ANOVA test was used to test between-group comparisons, as well as the values of the mean and standard deviation. Generally looking at the average MindWave EEG Meditation (Table 6 to 11), it can be found that the result of relaxation is roughly the same as the subjective scale, with the increase of frequency, there is a gradual tendency to be unable to relax (disturbed by the influence of cues). The average value of eSense Meditation, which gradually decreased as the flicker frequency increases, was not as smooth as the relaxation of the subjective scale but had some ups and downs. This may mean that people have a special response to certain beat speeds. This may also be related to human heartbeat and internal rhythm, and subsequent research may further explore the relationship between them.

Different from the subjective perception of a whole paragraph because the EEG state was likely to have observable changes as the seconds progress, this experiment divided the electroencephalograph data into stages every 15 seconds. Comparisons were made between 15 seconds (Table 6), 30 seconds (Table 7), 45 seconds (Table 8), 60 seconds (Table 9), 75 seconds (Table 10), and 90 seconds (Table 11) after exposure to an incandescent light source.

Table 6 shows 15-second eSense Meditation means, standard deviations, and counts. In the first 15 seconds, the objective relaxation value (Meditation) generally showed a gradually decreasing trend as the beat gets faster, except for 60 BPM and 80 BPM, where there were two small rebounds of relaxation. It is worth noting that 60 BPM, as a second speed, makes the subjects feel even more relaxed than 50 BPM when filling in the scale by hand (refer to Table 3 and Table 5). In the first 15 seconds of the eSense value, the relaxation value of 60 BPM was also higher than 50 BPM. The meaning of 60 BPM and 80 BPM may need to be further observed in the future.

The slower observation results were not the focus of this study and will not be discussed here. However, although the value of 80 BPM in the entire test was the high point in the small range, its standard deviation value was also particularly high, indicating that this speed had large individual differences among subjects, and a larger group test may be needed. Only then can the observation results be further confirmed. 120 BPM gave a relatively low standard deviation here.

Table 6 *15-second eSense Meditation mean, standard deviation and count*

BPM	Average	Std. Dev	N
Control	64.3815	18.79390	36
40	60.3852	11.78850	36
50	56.4630	11.43618	36
60	60.3519	13.10028	36
70	57.9630	11.80397	36
80	62.0556	16.49038	36
90	58.4148	11.74650	36
100	58.4037	11.88543	36
110	58.7704	12.10664	36
120	56.5556	10.70529	36
130	55.8741	12.93893	36
140	53.0148	12.29313	36

At 30 seconds in Table 7, 60 BPM and 80 BPM still had relatively relaxed values compared to their previous intervals (50 BPM and 70 BPM), but the magnitude of the difference tended to slow down. Additionally, there were more relaxed highs at 70 and 100 BPM. Compared to 15 seconds, the relaxation value gradually moved upward between 60 and 80 BPM, including the 70 BPM node (note that individual differences among subjects were larger than 100 BPM). 120 BPM still gave a relatively low standard deviation here.

Table 7 *30-second eSense Meditation mean, standard deviation and count*

BPM	Average	Std. Dev	N
Control	67.4778	15.47041	36
40	61.2815	9.42863	36
50	57.1463	9.04180	36
60	58.3407	10.69484	36
70	60.0667	12.36006	36
80	61.1741	15.25859	36
90	56.6111	11.53120	36
100	59.1056	9.29054	36
110	57.3537	10.14792	36
120	56.4852	9.90791	36
130	55.8074	11.72919	36
140	54.3444	11.12289	36

At 45 seconds (Table 8), there was still an upward trend between 60 BPM and 80 BPM with high standard deviations, and 100 BPM was still a higher node. It can be noticed that although 120 BPM at this time was not higher than 110 BPM, it was very close, with a smaller standard deviation. So far, every 15 seconds later, the value gradually fluctuates with about 20 BPM as an interval and goes back to high and low.

Table 8 *45-second eSense Meditation mean, standard deviation and count*

BPM	Average	Std. Dev	N
Control	68.2346	16.47035	36
40	61.4111	10.16708	36
50	56.8148	6.99869	36
60	58.3481	9.77426	36
70	60.1074	13.11289	36
80	62.5457	14.97629	36
90	55.1358	10.83326	36
100	58.4136	9.40496	36
110	56.8469	9.32308	36
120	56.3765	8.29160	36
130	55.8667	10.87187	36
140	54.4593	11.15324	36

At 60 seconds (Table 9), the situation of average was roughly the same as at 45 seconds. However, it can be observed that 120 BPM has a particularly low standard deviation value for the first time and was the lowest value from above 60 BPM. This means that after one minute of flashing, most subjects showed an average state of mental relaxation at 120 BPM.

Table 9 *60-second eSense Meditation mean, standard deviation and count*

BPM	Average	Std. Dev	N
Control	67.4417	16.60662	36
40	60.3028	10.17847	36
50	56.7667	5.60811	36
60	57.6491	10.48086	36
70	60.5574	13.02866	36
80	62.2611	14.00035	36
90	55.8102	10.91966	36
100	58.9574	9.29963	36
110	56.7065	8.67909	36
120	56.1769	6.78287	36
130	55.5102	10.15827	36
140	54.8435	9.77641	36

The average after 75 seconds (Table 10), 120 BPM exceeded 110 BPM for the first time. The standard deviation was still the smallest above 60BPM. It can be observed that the stability of 120 BPM gradually appeared. This situation continues until 90 seconds later (Table 11). The average value of 120 BPM reached a higher value by 90 seconds, with a larger gap from 130 BPM.

Table 10 *75-second eSense Meditation mean, standard deviation and count*

BPM	Average	Std. Dev	N
Control	67.0126	16.00311	36
40	60.7844	10.00378	36
50	57.2326	5.24156	36
60	57.5148	10.43167	36
70	61.0881	11.92280	36
80	61.8059	12.53504	36
90	55.5941	11.10532	36
100	58.8422	9.10929	36
110	56.2422	8.09600	36
120	56.4467	6.26107	36
130	55.3230	9.86773	36
140	55.2185	10.15150	36

Table 11 *90-second eSense Meditation mean, standard deviation and count*

BPM	Average	Std. Dev	N
Control	66.6784	15.14869	36
40	59.7099	9.21069	36
50	56.8864	5.77263	36
60	57.7852	10.75725	36
70	60.8370	12.18085	36
80	61.6951	11.60768	36
90	55.7704	10.80088	36
100	58.6019	8.67401	36
110	56.7463	7.88675	36
120	56.8827	6.06696	36
130	54.9494	9.34080	36
140	55.8654	10.08451	36

From the average value of each segment, the following phenomena worthy of observation can be found. After 90 seconds (Table 11), the Meditation value bottoms out at 130 BPM, not 140 BPM. 130 BPM may be a beat that makes people's brain nerves less relaxed, although subjectively judged, faster 140 BPM had a more unrelaxed feeling. Around 130 BPM was also a commonly used tempo value for some electronic dance music, such as Trap Music, which claims to be addictive. Does BPM130 have cranial nerve compression, but there is no subjective pressure of faster speed, so it also becomes the support of a certain rhythm atmosphere? This is also a point worth observing.

The comparison between ANOVA groups (Table 12) showed that when the number of seconds reached more than 30 seconds, almost each segment of flashing white light was significantly more incapable of relaxation than the long-bright control group ($p<.05$). Echoing the high standard deviation values presented in Table 6-11, there were no significant performances at 80 BPM from 15-90 seconds. In addition, since the need for high alertness was the primary condition (refer to Table 2), the overall performance obtained at 80 BPM were not good enough.

Table 12 *Significant descriptive statistics between eSense Meditation values and controls*

		15 sec		30 sec		45 sec		60 sec		75 sec		90 sec	
(I) BPM	**(J) BPM**	Mean Diff.(I-J)	Sig.[b]	Mean Diff.(I-J)	Sig.[b]	Mean Diff.(I-J)	Sig.[b]	Mean Diff.(I-J)	Sig.[b]	Mean Diff.(I-J)	Sig.[b]	Mean Diff.(I-J)	Sig.[b]
Control	**40**	3.996	.121	6.196*	.009	6.823*	.014	7.139*	.014	6.228*	.020	6.969*	.004
	50	7.919*	.016	10.331*	.001	11.420*	.001	10.675*	.001	9.780*	.001	9.792*	.001
	60	4.030	.305	9.137*	.008	9.886*	.007	9.793*	.010	9.498*	.008	8.893*	.011
	70	6.419	.052	7.411*	.004	8.127*	.003	6.884*	.008	5.924*	.015	5.841*	.009
	80	2.326	.506	6.304	.067	5.689	.116	5.181	.143	5.207	.114	4.983	.093
	90	5.967	.096	10.867*	.000	13.099*	.000	11.631*	.000	11.419*	.000	10.908*	.000
	100	5.978	.059	8.372*	.008	9.821*	.004	8.484*	.006	8.170*	.008	8.077*	.007
	110	5.611	.091	10.124*	.000	11.388*	.000	10.735*	.000	10.770*	.000	9.932*	.000
	120	7.826*	.020	10.993*	.001	11.858*	.000	11.265*	.001	10.566*	.001	9.796*	.002
	130	8.507*	.018	11.670*	.000	12.368*	.000	11.931*	.000	11.690*	.000	11.729*	.000
	140	11.367*	.001	13.133*	.000	13.775*	.000	12.598*	.001	11.794*	.001	10.813*	.001

** The correlation is significant at the .05 level (single-tailed)

Another concern of this study was that although the faster the speed, the more likely it is to attract attention, but after a certain speed, long-term use may cause fatigue, which may not be the best choice. It can also be an uncomfortable oppression for people who are on the scene and aren't leaving anytime soon.

3. Comparison of subjective and MindWave EEG Meditation values

This study on the flashing rhythm of the warning light was based on the investigation and analysis of people's usage experience. The analysis was mainly based on subjective hand-filled scales and MindWave eSense values. The MindWave eSense values of the single-electrode electroencephalograph include Attention and Meditation. Since the Attention value is not suitable for continuous eyes-closed measurement, it was excluded. Compared with the subjective feeling of "relaxation", the Meditation value of eSense can be used as an objective basis for stress perception. In addition, people's situational memories are not necessarily accurate. During the test process, the test values filled in by the test subjects in each paragraph may not be relatively accurate, and they are often affected by the comparison of the relationships between the randomly ordered values at that time. Therefore, EEG feedback may be relatively more objective, and possible regularities or characteristics that change over time can be observed. However, the “alertness” filled in subjectively is an important basis for the degree of warning felt by the subjects. To sum up, below we will cross-compare and discuss the eSense Meditation value after 90 seconds with the hand-filled “relaxation” and “alertness” values.

As can be seen from the comparison in Table 13, the subjective warning level of 120 BPM was only slightly lower than 140 BPM, and it was also one of the two groups that exceeds 5 in this test. In the subjective relaxation level, 120 BPM was obviously higher than 140 BPM. The eSense Meditation value was not only higher than 140 BPM, but also the highest value above 110 BPM. It is worth noting that the standard deviation of the 120 BPM Meditaion value was the smallest one from 40 BPM - 140 BPM except 50 BPM. The significance of this part may reflect the discussion about 120 BPM in Chapter 2.2, that is, 120 BPM may be a meaningful rhythm for the human body. Compared with 120 and 140 BPM, 130 BPM, as a fast beat higher than 120, was a beat with low subjective warning, low objective eSense Meditation value and scattered values. The above characteristics were in line with our expectations, that is, the faster the beat was not necessarily the better it can capture people's attention, but it may be limited by fluctuations and high points caused by fatigue after a certain period of time.

Table 13 *"Alertness", "relaxation" of hand-filled relaxation scale and eSense Meditation value after 90 seconds*

BPM	Subjective alertness		Subjective relaxation		eSens Meditation	
	Average	**Std. Dev.**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**
Control	3.0000	1.39122	7.1250	2.18130	66.6784	15.14869
40	4.0625	1.26841	6.2500	1.27000	59.7099	9.21069
50	4.0625	1.88265	6.1250	1.86219	56.8864	5.77263
60	4.4375	1.68365	6.3125	1.59510	57.7852	10.75725
70	5.0000	1.52400	5.2500	1.70389	60.8370	12.18085
80	4.0000	1.68485	5.9375	1.81281	61.6951	11.60768
90	4.4375	1.38977	5.8125	1.65466	55.7704	10.80088
100	4.8125	1.97464	5.5000	1.93441	58.6019	8.67401
110	4.8750	1.51870	5.5000	1.60644	56.7463	7.88675
120	5.3125	2.32014	5.3750	2.29656	56.8827	6.06696
130	4.8750	2.45935	4.8750	2.05960	54.9494	9.34080
140	5.9375	2.28512	4.0000	1.96748	55.8654	10.08451

4. Recommended tempo for this study: 120 BPM

According to **2.2 Prefferred Tempo**, people may have preferences for certain speeds, the test results of the prompting power of the flashing speed may not increase linearly and steadily, but may have sudden highs or lows near certain speeds. In addition, as time goes by, the light source that continuously flashes at high speed may cause perceptual fatigue and reduce the level of perception in the later period. Since vision and hearing are the perception systems of the human body, if a beat that has a high level of cue and is relatively calmer, it may be a good design reference for visual light stimulation. Taken this point into consideration, 120 BPM can be seen as a very suggestive, unstressed flickering rhythm. In this study, from both the subjective scale and EEG values, 120 BPM has a high promptness and a relatively less sense of pression. In addition, when the Meditation value of MindWave eSense reaches 75 seconds and 90 seconds, which were longer seconds, the average EEG Meditation of 120 BPM was the highest one above 110 BPM. Also, the standard deviation of 120 BPM Meditation was the smallest one above 90 BPM, and the degree of dispersion was the smallest. This study infers that 120 BPM, which was exactly half a second, may be related to the real-world time unit, and may be a fast tempo that was sufficiently prompt for psychological feelings, but makes people feel less oppressive. In addition, the characteristics of the 80 BPM value found in **Chapter 4.2** may also be related to the human body's preferred tempo. Due to the various rhythms that people have, such as heartbeat, brain waves, natural frequencies of organs, etc., subtle frequency differences in external stimulation are enough to cause very different effects. This part of 80 BPM needs to be further explored in future related research.

V. Conclusion

The purpose of this study was to find a flicker rate for warning light sources suitable for longer exposures. The target speed needed to be highly suggestive and relatively less oppressive. The test frequency was between 40-120 BPM. On a subjective scale, the 120 BPM average had a more relaxed character on beats with high reminders. The average value of MindWave EEG Meditation at 120 BPM was the highest above 110 BPM, the standard deviation was obviously the smallest above 90 BPM, and the degree of dispersion was the smallest. In addition, consistent with some previous studies on human perception of sound beats, subjects had a clear rhythm preference for the performance of 120 BPM in the visual light flicker frequency. Such results support that 120 BPM belongs to the existing resonance beat of human beings and was also the preferred frequency in some cases. The conclusion is that when the incandescent light source was flickering at 40-140 BPM, 120 BPM may be more suitable for long-term use, because it has enough prompted force and relatively less pressure. For future research planning, since incandescent light sources have been banned or will be banned in some countries and regions, follow-up research will use other feasible light sources for testing. And consider close-range portable devices, such as mobile phone light sources, to test people's sense of prompting to the light flash beat, and whether there is similar feedback under different light source settings. Besides, a heart rate monitor and finer classification values can be incorporated to detect the subject's body pressure value for a longer period, as well as to make a finer division of the speed, and to further consider more detailed lighting and multimedia design, so that users can have a better feeling and effect.

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