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A comparison of the effects of correlated colour temperature and gender on cognitive task performance

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Higher correlated colour temperature ambient lighting, which contains more blue light, has been reported to improve performance on a variety of cognitive tasks. The current investigation compared performance of adults on what/where task switching, go/no-go, and mental rotation tasks when the experimental room was lit by 3500 K standard florescent and 5000 K LED lighting. Results showed that, under higher correlated colour temperature illumination, females (but not males) decreased reaction time by approximately 10% on the task switching task, that males (but not females) showed a reaction time decrease on the go/no-go tasks, and that no effect was observed on the mental rotation task. Our results suggest that higher correlated colour temperature illumination improves reaction time performance on certain attention/executive function tasks, but that that improvement is gender specific.

1. Introduction

It is well known that light affects human physiology beyond vision. Exposure to different kinds of light can lead to changes in circadian rhythm, mood, and cognitive abilities. These non-visual effects of light are even present in some blind individuals,[1] suggesting that they are independent of the image-forming visual system.

Our understanding of the mechanisms by which light impacts these non-visual processes has greatly increased with the recent discovery of a third type of photoreceptor cell in the retina.[2,3] These intrinsically photosensitive retinal ganglion cells (ipRGCs) express the photopigment melanopsin and send signals to non-visual regions of the brain.[2] Light from these cells initially stimulates brain structures related to alertness, such as the thalamus and hypothalamus, before filtering out into cortical areas, reaching full saturation after approximately 20 min of exposure.[4] The ipRGCs are most sensitive to short-wavelength light emitted in the blue region of the visible spectrum, at approximately 490 nm.[5,6] The ipRGC system has a direct effect on circadian rhythms,[7] helping to regulate when the body feels tired or awake by modulating melatonin secretion.

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Recent attention has turned to the ways in which stimulation of the ipRGCs by artificial lighting impacts cognitive abilities, specifically following exposure to light of various correlated colour temperatures (CCT). Studies in settings from the laboratory to the office environment suggest that exposure to cooler correlated colour temperature light results in improvements in mood and alertness,[8,9] as well as cognitive domains such as sustained attention, detection, working memory,[8,10–12] and task switching.[13]

However, the full scope of these effects is not well understood, with previous studies suggesting that the presence of these effects largely depends on factors such as type of task and level of task difficulty,[10,14] as well as the time of day and season.[15] As such, understanding the extent to which light exposure impacts cognition requires further examination. Given the variety of settings, from classrooms to workspaces, where the right environment is critical to performance, it is important to better understand which types of tasks benefit from exposure to cooler CCT lights and what parameters support the best outcomes.

In order to clarify the existing findings on the cognitive effects of illumination, the present study used a mixed design where experimental participants were tested twice, first with illumination by standard fluorescent 3500 K office lighting (warm) and later with illumination by a 5000 K (cool) LED fixture. Control participants were tested twice in the same setting with the 3500 K source. Participants were tested individually at 9:00 a.m. or 10:00 a.m. during weekdays. Assessments of mental rotation, sustained attention in a go/no-go task, and cognitive control in a task switching task were administered in order to determine if the effects are general or task specific. Lastly, both males and females were tested to determine if gender influenced any illumination effects.

2. Method

Participants were 40 undergraduate students (21 females) enrolled in the Department of Psychological and Brain Sciences at the University of Massachusetts Amherst. Participant ages ranged from 18 to 26 years, with an average age of 20.5 years. Fifty-eight per cent of participants identified as Caucasian, 20.9% as Asian, 9.3% as African American, 2.3% as Hispanic, and 2.3% as Pacific Islander. Students received department extra credit as compensation for their participation. Participants were excluded who had a history of psychological or neurological disorders, did not have normal or corrected-to-normal vision, had recently travelled across time zones, were taking psychotropic medication, or had consumed caffeine or smoked cigarettes the morning of testing. All study procedures were approved by the University of Massachusetts Amherst Institutional Review Board.

2.1 Apparatus

A small, windowless laboratory room was used to test participants. The room was 2.3 m high with dimensions 2.6 m × 2.2 m. The ceiling consisted of white, 0.6 m × 0.6 m (2′ × 2′), mineral board tiles and the walls were painted off-white. A table (1.5 m × 0.76 m, 0.76 m high) sat against one wall and was covered with a white sheet. White was chosen for the walls, ceiling, and table so as to reflect the light from the luminaires without glare. A laptop computer, a 15.5″ Dell Inspiron 1501, sat on the table facing a single chair. Participants were seated such that their eyes were approximately 64 cm from the laptop monitor.

There were four luminaires in the ceiling, two fluorescent and two LED. See Figure 1 for a representation of the laboratory setup and the positions of the light sources. The two fluorescent fixtures, 1.21 m × 0.3 m (4′ × 1′),

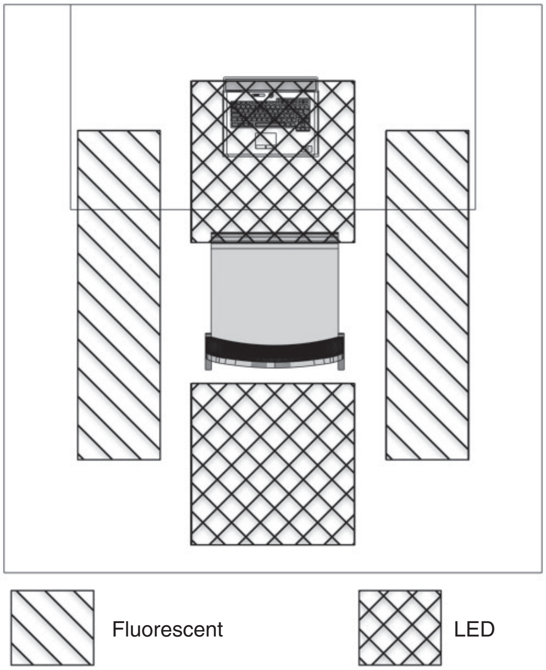

Figure 1. Schematic plan of the test room showing the location of the participant's chair, the 3500K fluorescent and the 5000 K LED light sources

were positioned above the desk separated by 0.6 m. The fluorescent lamps used were Philips T8 3500 K (measured by a spectrometer to be 3233 K), a frequently used CCT for office lighting, which produced the warm lighting control condition. There were two PLANLED Beetle LED fixtures, 0.6 m^2, positioned in between the fluorescent fixtures, centred in the ceiling above the desk. The LED fixtures are tunable along the blackbody curve and were set to 5000 K (measured as 4858 K) to produce the cool correlated colour temperature lighting for the experimental condition; 5000 K was chosen for the experimental condition to be a meaningful jump in CCT from the baseline condition while still within the range of what participants might regularly encounter in places like the workspace or classroom.

The spectra of the fluorescent and LED lights, taken pointing at the source, along with the melanopsin response function, $N_z(\lambda)$,[16] are presented in Figure 2(a), while Figure 2(b) shows the spectral distribution weighted by $N_z(\lambda)$.

The brightness of the LED lights was set such that the illuminance at participant eye level was the same for both lighting conditions. Illuminance with the lights and laptop on was measured at participant eye level with a LX1330B digital light meter to be 350 lux. Illuminance measurements taken at the work-plane were 715 lux and 689 lux for the fluorescent and LED lights, respectively. These illuminance levels are slightly greater than the required illumination levels for office spaces as designated by the Occupational Safety and Health Administration,[17] but is an appropriate level for detailed work (See The Lighting Handbook,[18] for tables of recommended illuminance for various workspaces and activities). The placement of the LED lights was chosen to minimize any spatial variation in the light field at table height. Differences in light intensity across the table were minimal, less than 14 lux as compared to the 670 lux average across the table.

Since the laptop screen illuminance was held constant, its own brightness cannot be the cause of any changes observed. The laptop screen contributed only 25 lux compared to the 325 lux provided by the luminaires, less than 10% of the light incident on the participant, and is therefore negligible. Furthermore, throughout both computer tasks, the image on the screen was a white background with a black letter appearing on the screen, and so the screen did not change colour during the study. Thus, there was a negligible change in colour or melanopic equivalent illuminance throughout the tasks. The task switching and go/no-go tasks were programmed using E-Prime Version 1.2.

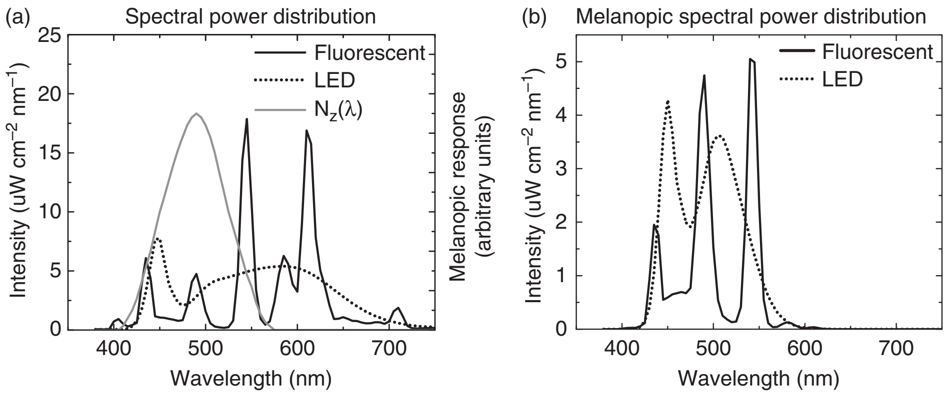

Figure 2. (a) Spectral power distribution incident on the cornea from the LED and fluorescent lights when directed at the source (dashed and solid lines respectively, left axis) along with the melanopic response function, $N_z(\lambda)$ (grayed line, right axis). (b) The melanopic spectral power distribution of the LED (dashed) and fluorescent (solid) lights. The area under the curves represents the level of stimulation of the ipRGCs

Table 1. Effective illuminance for human photopigments for each lighting condition

	Effective Illuminance (lux)	
Photopigment	LED 5000 K	Fluorescent 3500 K
S Cone (blue)	529.87	289.97
ipRGC	552.79	352.78
Rod	592.26	451.33
M Cone (green)	653.44	600.84
L Cone (red)	670.07	693.19

In order to compare the impact of the lights with different spectral distributions, a set of five measures of effective illuminance, one for each of the photoreceptive cells, is calculated based upon the response curves presented by Lucas *et al.*[16] Of particular interest for human cognition is the value of the equivalent melanopic illuminance, as this is the stimulation of the ipRGCs by the light. The effective illuminance perceived by each type of photocell for both the 5000K LED lights and 3500K fluorescents are presented in Table 1.

Although the LED and fluorescent lights have different spectral distributions, the M and L cones perceive similar values, within 50 lux, while the S cone and ipRGCs perceive values that vary by more than 200 lux. This makes sense because the S cone and ipRGCs are more sensitive in the blue portion of the spectrum and the LED lights are at a cooler correlated colour temperature and therefore have more blue light in their spectrum.

We see the ipRGCs are stimulated 1.5× more under the 5000K LED lights than under the 3500 K fluorescents. This agrees well with similar analysis performed using Gall and Bieske's[19] circadian action factor.

2.2 Procedure

The study was conducted between November and March so as to take advantage of participants' decreased exposure to sunlight in order to measure the strongest effects of lighting correlated colour temperature. All testing occurred between 9:00 a.m. and 11:00 a.m. in order to control for the amount of sunlight participants were exposed to. Participants were randomly assigned to either the control or experimental group. Participants were also semi-randomly assigned to testing at either 9:00 a.m. or 10:00 a.m. to ensure equal numbers of control and experimental group members, as well as members of both genders, in each time slot. All participants were walked through the study procedures and consent was obtained. However, participants were not told the true purpose of the study, being instead informed that the study was exploring the effects of delay on cognitive performance. The deception was necessary in order to ensure that participants in the experimental group did not perform better as a result of their expectation that the change in lights would enhance their performance.

After consenting, participants were brought into the testing room and seated at a desk in front of a laptop computer. Participants completed three tasks: the task switching and go/no-go tasks on the computer and the mental rotation task on paper, in a random order. After the baseline assessment was completed, participants were taken out of the testing room to complete a brief demographics questionnaire regarding ethnicity, education level, usual sleep schedule, and alcohol and coffee consumption. At this point, for participants in the experimental condition, the researcher changed the lights in the testing room from the 3500 K fluorescent fixtures to the LED fixture set to 5000 K, unbeknownst to the participant. Participants were brought back into the testing room, where they stayed for the remainder of the study. They then completed Sudoku puzzles as a filler task for 20 min, which served as an adaptation phase. Previous work has shown that 20 min is sufficient for the light exposure to activate multiple relevant brain regions.[4] Finally, all participants completed the three cognitive tasks a second time in a different order than in the initial assessment. These procedures were chosen over a randomized crossover design to eliminate the possibility of carryover effects, as the study took place in a single session and was modelled on similar work done in the field (see Ferlazzo *et al.*[13]for an example of similar procedures).

Following the completion of the tasks, participants were asked what they thought the study was trying to measure, in order to identify whether they were aware that the lights had changed. No participant reported noticing the change in lighting. Finally, participants were fully debriefed and the true purpose of the study was explained.

2.3 Mental rotation test

Stimuli and instructions for this task were taken from Peters *et al.*[20] Each item in the mental rotation test consisted of a target shape and four other shapes, two of which were rotated versions of the target shape. Participants were asked to identify the two rotated versions of the target shape among the four options. After attempting four practice items, participants were given a packet containing 12 items and were given 4 min to complete the test. Participant's score was calculated as the number of correctly identified matches to the target shape out of 12, meaning that a participant needed to correctly identify both answers for each item to be considered correct. A different set of stimuli was used for the test assessment. Which set of stimuli was used in the baseline vs. test assessments was counterbalanced across participants.

2.4 Go/no-go test

Participants saw a white screen on which a black 'M' or 'W' appeared in the centre. Participants were instructed to press the right mouse button upon seeing an 'M' onscreen (a 'go' trial) and to refrain from pressing the button when a 'W' appeared onscreen (a 'no-go' trial). Participants had to press the button to respond within 500 ms of the letter's appearance. The task was composed of 120 trials, presented in random order. The task consisted of approximately 80% 'go' trials and 20% 'no-go' trials. Results were recorded as the number of correct 'no-go' trials, in which the participant successfully inhibited responding, as well as latency on correct 'go' trials.

2.5 Task-switching test

Task components were adapted from Davidson *et al.*[21] The task-switching paradigm consisted of three practice blocks, each with 16 trials, followed by one test block of 64 trials. The practice blocks consisted of only one type of trial. In each trial, either an A or B appeared on either the left or right side of the screen. After the letter appeared, participants had 2 s to respond. Participants were informed that in 'what' trials, they should pay attention to what letter is being displayed and press the left mouse button when they see an A and the right mouse button when they see a B. For 'where' trials, participants were asked to attend to the location of the letter and press the mouse button that corresponded with the side of the screen that the letter appeared on. Finally, they completed a mixed trial test block, in which a voice on the computer either said 'what' or 'where', instructing the participant which rules to follow for that specific trial. The mixed block consisted of 64 trials, 32 of each type, presented in random order.

A trial that followed a trial of the same type was a 'no switch' trial, such as a 'what' trial that followed another 'what' trial. Similarly, a trial was considered a 'switch' trial if it followed the opposite trial type. Along a different dimension, trials were also scored as either congruent or incongruent. A congruent trial consisted of an A on the left side of the screen or a B on the right side of the screen, in which cases the correct button press was the same for both 'what' and 'where' trials. Alternatively, an incongruent trial consisted of an A presented on the right side of the screen or B on the left side, meaning that the correct button press was dependent on the rules of the trial type. Participants' accuracy and reaction time were recorded. To be included in analysis, participants had to demonstrate an accuracy of at least 60% on the mixed trial block.

3. Results

Table 2 shows how the different groups compared on sleep habits, as well as average coffee and alcohol intake. One participant did not provide her average wake time. T-tests did not suggest significant differences between the groups.

All results were analysed with a Light Condition (control, experimental) by Phase (baseline, test) by Gender (male, female) analysis of variance (ANOVA). Start time was not included in the ANOVA as the number of participants at 9:00 and 10:00 was completely balanced across conditions. If light condition differentially altered performance, we would predict significant Phase by Light Condition interaction effects. Furthermore, if the effects of the lighting condition on performance are different for men and women, a significant three-way interaction would be expected.

For main effects of the three independent variables, with the exception of accuracy on the go/no-go task, all ANOVAs and *post hoc*

Table 2. Means and (standard deviation) for various demographic components for participants

	Control	Experimental	
Bed time	00:08 (1 h:09 m)	23:53 (1 h:08 m)	$t(38) = 0.69$, $p = 0.49$
Wake time	08:17 (1 h:14 m)	08:59 (1 h:19 m)	$t(37) = -1.70$, $p = 0.10$
Alcoholic drinks/week	2.95 (4.91)	5.70 (6.76)	$t(38) = -1.47$, $p = 0.15$
Coffee drinks/week	2.05 (4.75)	1.98 (3.50)	$t(38) = 0.06$, $p = 0.96$
Hours slept previous night	7.95 (1.25)	8.48 (1.39)	$t(38) = -1.26$, $p = 0.22$

tests showed a significant main effect of Phase (all $p<0.05$), such that accuracies increased and reaction times decreased from the baseline to test assessments, across lighting conditions. No significant main effects were seen for the Light Condition (all $p>0.05$). Only accuracy on the mental rotation test yielded a significant main effect of Gender, $F(1,36)=8.42$, $p=0.006$, $\eta_p^2=0.19$, such that male participants' scores were consistently higher than those of female participants.

Table 3 shows a summary of participants' performance on the mental rotation test. No significant interactions were found for Phase by Light Condition, $F(1,36)=2.84$, $p=0.10$ or Phase by Light Condition by Gender, $F(1,36)=0.50$, $p=0.48$.

Thirty-eight out of 40 participants provided complete data for the go/no-go task, as experimenter error in the instructions prevented two participants from completing the task correctly. No significant effects were found for accuracy on 'no-go' trials. For reaction time on correct 'go' trials, no significant interaction was found between Phase and Light Condition, $F(1,34)=0.77$, $p=0.39$ (Table 4). However, a significant three-way Phase by Light Condition by Gender interaction was found, $F(1,34)=4.03$, $p=0.05$, $\eta_p^2=0.11$, indicating that the way the lighting condition impacted participants' reaction time performance over time varied by gender. As such, the data were subsequently analysed separately by gender to explore these differences. For female participants' reaction time on correct 'go' trials, no significant Light Condition by Phase interaction was found, $F(1,19)=0.50$, $p=.49$ (Figure 3). For male participants' reaction times on 'go' trials, results showed a significant Light Condition by Phase interaction, $F(1,15)=8.24$, $p=0.01$, $\eta_p^2=0.35$, suggesting that while both groups showed decreased reaction times from the baseline to test assessment, males in the experimental group showed a significantly greater decrease than males in the control group (See Figure 4). Males in the control group reduced their reaction time on average by 2.5% (8.0 ms), whereas those in the experimental group decreased by 9.3% (28.9 ms).

Consider next results of the task switching test. One participant in the control group was removed from all analyses for this task for not meeting the minimum threshold of 60% accuracy on the baseline assessment. Overall, accuracy for all remaining included subjects on the task-switching task was high, with an average of 85.6% correct across conditions and time points. There were no

Table 3. Means and (standard deviations) for performance on the mental rotation test

	Baseline	Test
Control	4.35 (2.25)	6.55 (2.96)
Experimental	5.30 (3.03)	6.15 (3.62)

Table 4. Means and (standard deviations) for reaction time (ms) on correct 'go' trials

	Baseline	Test
Control	319.55 (28.47)	306.82 (30.30)
Experimental	311.77 (39.62)	294.49 (37.10)

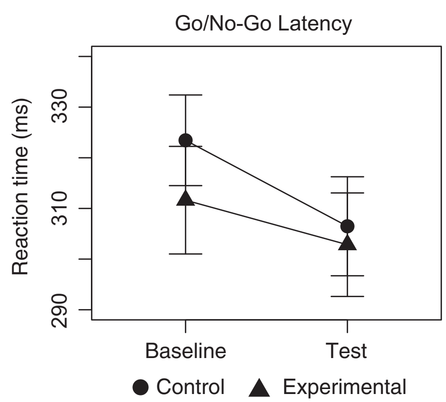

Figure 3. Latency on 'go' trials for female participants on the go/no-go task

significant interactions for Phase by Light Condition, $F(1,35) = 0.49$, $p = 0.49$ or Phase by Light Condition by Gender $F(1,35) = 0.03$, $p = 0.87$ for accuracy on task switching.

For participants included in the analysis, reaction time was analysed for all correct trials. Reaction times were separated into three measures: (1) overall reaction time, (2) reaction time on 'switch' trials, where participants had to rapidly switch between type of trials, and (3) reaction time on incongruent trials, where the correct key press was specific to the trial type.

For overall reaction time, the Phase by Light Condition interaction was not significant, $F(1,35) = 0.15$, $p = 0.71$ (See Figure 5). However, there was a marginally significant three-way interaction of Phase, Light Condition, and Gender, $F(,35) = 3.10$, $p = 0.09$, $\eta_p^2 = 0.08$. For the more challenging 'switch' trials, there was a significant three-way Phase by Light Condition by Gender interaction $F(1,35) = 5.16$, $p = 0.03$, $\eta_p^2 = 0.13$. The Phase by Light Condition interaction was not significant, $F(1,35) = 0.36$, $p = 0.56$. Similarly, for reaction time on incongruent trials, there was a marginally significant Phase by Light Condition by Gender interaction, $F(1,35) = 3.09$, $p = 0.09$, $\eta_p^2 = 0.08$., but no Phase by Light Condition interaction, $F(1,35) = 0.16$, $p = 0.69$.

Given the suggestion in many of the trial types that the effect of Light Condition on performance over time is impacted by gender, follow-up analyses were conducted analysing the results separately for females and males.

As can be seen in Figure 6, female participants in the experimental and control groups performed remarkably similarly in the baseline assessment, with all cell means within 5 ms. While reaction time decreased for both conditions between baseline and test, Figure 6 suggests that those in the experimental group showed a larger decrease in reaction time than participants in the control group. For overall reaction time, analysis of variance showed

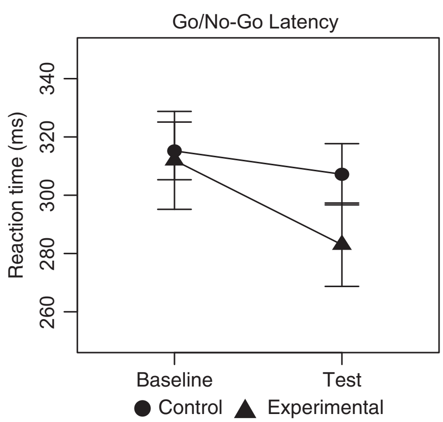

Figure 4. Latency for 'go' trials for male participants on the go/no-go task

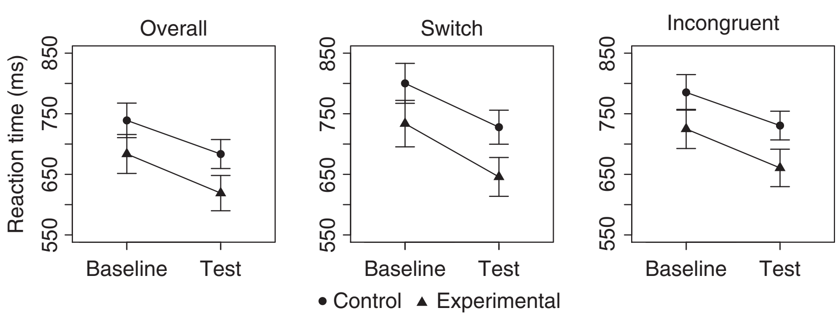

Figure 5. Reaction time performance on the task-switching task

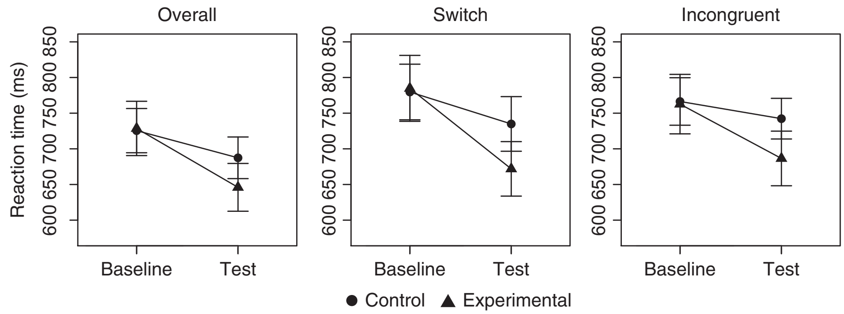

Figure 6. Task switching performance for female participants

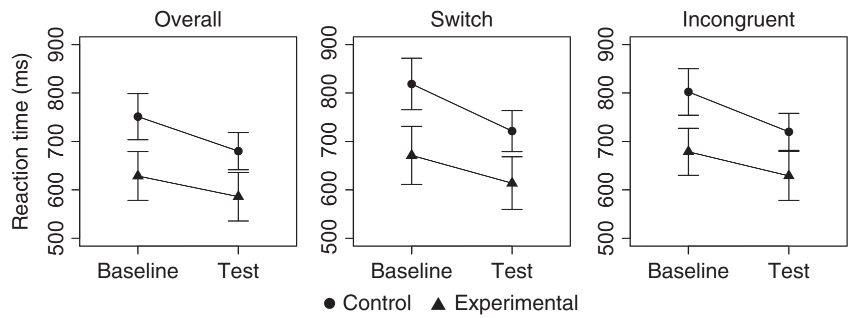

Figure 7. Task switching reaction time performance for male participants. Note the expanded scale compared with Figure 5

a significant Light Condition by Phase interaction, $F(1,18) = 5.25$, $p = 0.03$, $\eta_p^2 = 0.23$. Female participants in the experimental group showed a larger average decrease in reaction time between baseline and test assessments (11.3% or 82.6 ms reduction), compared with those in the control group (5.3% or 38.1 ms reduction).

For 'switch' trials, a significant Light Condition by Phase interaction was found, $F(1,18) = 5.61$, $p = 0.03$, $\eta_p^2 = 0.24$, demonstrating that participants exposed to the cooler CCT light improved in their ability to rapidly switch tasks more than those only exposed to the warmer CCT light in the control condition, with a reaction time decrease of 14.4% (112.9 ms) compared with 5.7% (44.7 ms).

Similarly, for the incongruent trials, there was a significant Light Condition by Phase interaction, $F(1,18) = 4.39$, $p = 0.05$, $\eta_p^2 = 0.20$, again supporting the finding that, while participants in both groups improved on the task between baseline and test assessments, those in the experimental condition demonstrated significantly more reduction in reaction times following their exposure to the cooler correlated colour temperature LED lights (10% or 76.1 ms improvement compared with 3.1% or 24.1 ms).

As seen in Figure 7, male participants in the control and experimental groups started off very differently in the baseline condition, although this difference was not significant, $t(17) = 1.77$, $p = 0.10$. Males in the control group performed comparably to the female participants at baseline, but males in the experimental group showed much faster performance.

Results for overall reaction time showed no Light Condition by Phase interaction, $F(1,17) = 0.59$, $p = 0.45$. When looking at reaction time for 'switch' trials, male participants again showed no interaction effect of Light Condition by Phase, $F(1,17) = 1.05$, $p = 0.31$. Similarly, analysis of reaction time performance on incongruent trials yielded no Light Condition by Phase Interaction, $F(1,17) = 0.60$, $p = 0.45$.

4. Discussion

This study explored whether exposure to cooler correlated colour temperature light can improve participants' cognitive abilities compared with those only exposed to light at a warmer CCT. All analyses showed significant main effects of Phase, indicating that participants improved from baseline to test assessments, across gender, conditions, and tasks. This improvement is expected as participants have likely never been exposed to these tasks at the start of the baseline assessment, but improve with familiarity and practice as they complete the test assessment. Overall, no significant Light Condition by Phase interactions was found. However, for the go/no-go and task-switching tasks, results suggested a three-way interaction with Gender, prompting follow-up analyses focused on males and females separately to explore these differences.

While female participants showed no differences in reaction time decrease between lighting conditions on the go/no-go test, male participants in the experimental group showed a greater, almost three-fold reduction in reaction time compared to male participants in the control group. This mirrors findings from a similar study directed at the cognitive impacts of light, conducted with males only, and showing an improvement of a similar magnitude on a go/no-go task for the experimental condition.[10,11] These findings support the argument that, at least in males, exposure to cooler CCT lighting leads to improvements in sustained attention.

On the task-switching task, female participants in the experimental group showed significantly greater reduction in their speed for switching between tasks than did those in the control group, decreasing their overall reaction times by 44 ms (6%) more than the controls. Because the mean responses of male participants in the two groups were largely different in the baseline assessment, we could not determine what role lighting condition played in any differences seen between males in the two lighting conditions in the test assessment. Nonetheless, Chellappa *et al.*[10] demonstrated a greater improvement on a go/no-go task for male participants exposed to cooler CCT light as opposed to warmer CCT light, but no effect on an executive functioning task, mirroring the results of the present study and suggesting possible gender differences for correlated colour temperature's impact on executive functioning abilities that warrant further scrutiny.

Several previous studies have found gender differences in the way that lighting condition impacts several domains of cognition, including attention[22] problem solving,[23,24] and memory.[25] However, the underlying mechanisms for these gender differences in cognitive effects remain uncertain. Knez[24] demonstrated differences in male and female participants' subjective evaluation of lighting environments of different correlated colour temperature on features such as glare, brightness, and intensity. However, no participants in the present study reported awareness that there was any change in light condition, making it unlikely that their conscious positive or negative evaluation of the different lights impacted their cognitive performance. Studying physiological differences, Cowan *et al.*[26] showed that while men's visual cortex shows much greater activation than women's after exposure to blue light, no difference is seen between the genders in melatonin level following exposure to different brightness levels.[27] Further research is needed to see whether gender differences in physiologic response to light correlate with the demonstrated cognitive effects.

One possible contributing factor is the participants' chronotype. Roenneberg *et al.*[28] found that, towards the end of adolescence, women have a more delayed circadian clock than men, and reach their peak lateness at around 19.5, compared with men at 21. Differences in chronotype have been shown to impact performance across a variety of cognitive tasks, including measures of attention and cognitive flexibility.[29] As the participants in the present study had an average age of around 20 years, it is possible that differences in chronotype contributed to the gender differences seen in how light impacted cognitive performance. Although self-report of participants' average bedtime and wake time were collected, no formal assessment of participant chronotype was made. Future work should look to see whether differences in chronotype might influence men and women's cognitive responses to changes in light correlated colour temperature.

While Ferlazzo *et al.*[13] saw an improvement on accuracy on a mental rotation task for participants' exposed to cool CCT LED light compared with warm CCT halogen light, the present study failed to demonstrate an impact of CCT on mental rotation abilities. However, this is perhaps due to the choice of task. The present study recorded only accuracy, measured in whole numbers from 0 through 12, providing insufficient sensitivity to detect an effect. Perhaps a more sensitive task measuring participants' reaction times would have picked up on smaller performance differences between conditions.

The results of the present study join several others in demonstrating positive effects of cooler correlated colour temperature light on attention in undergraduate students.[13,15,22] Knowing how the lighting environment impacts student attention and performance can inform changes in classrooms and study spaces, helping students reach their full potential.

In summary, the present study provides further evidence that light correlated colour temperature can influence cognitive processes, such that exposure to cooler CCT light can lead to improvement in maintaining attention and transitioning between tasks, with possible differences between genders. Furthermore, effects were found after just a 20-min adaptation to the experimental lighting condition, demonstrating significant differences following limited exposure. Future studies should seek to clarify the precise nature and underlying mechanism behind observed gender differences in perception and reactivity to light CCT. Understanding the ways in which light influences cognition can lead to new practices in lighting environments such as classrooms and workspaces.

Declaration of conflicting interests

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