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Illuminating the Effects of Dynamic Lighting on Student Learning

Michael S. Mott[1], Daniel H. Robinson[2], Ashley Walden[1], Jodie Burnette[1], and Angela S. Rutherford[1]

Abstract

Light is universally understood as essential to the human condition. Yet light quality varies substantially in nature and in controlled environments leading to questions of which artificial light characteristics facilitate maximum learning. Recent research has examined lighting variables of color temperature, and illumination for affecting sleep, mood, focus, motivation, concentration, and work and school performance. This has resulted in artificial light systems intended to support human beings in their actualization through dynamic lighting technology allowing for different lighting conditions per task. A total of 84 third graders were exposed to either focus (6000K-100fc average maintained) or normal lighting. Focus lighting led to a higher percentage increase in oral reading fluency performance (36%) than did control lighting (17%). No lighting effects were found for motivation or concentration, possibly attributable to the younger age level of respondents as compared with European studies. These findings illuminate the need for further research on artificial light and learning.

Keywords

education, social sciences, literacy, curriculum, educational research, teacher, achievement

The Effects of Lighting on Humans in General

The human evolution is shaped by light. In the course of evolution, human beings have adapted and developed an internal clock that under natural light conditions is synchronized to the earth's 24-hr light–dark rotational cycle (Czeisler et al., 1999). Research reveals the mechanism for how light is essential for human functioning (Boyce, Hunter, & Howlett, 2003). Light is a strong enabler for visual performance (Grangaard, 1995), regulates a large variety of bodily processes such as sleep and alertness (Dijk & Cajochen, 1997; Takasu et al., 2006; Viola, James, Schlangen, & Dijk, 2008; Wright, Hull, Hughes, Ronda, & Czeisler, 2006), is essential for cognition and mood (Taras, Potts-Datema, & Pearson, 2005; Veitch & McColl, 2001), enables production of important hormones such as melatonin and cortisol (Dijk & Cajochen, 1997; Leproult, Colecchia, L'Hermite-Baleriaux, & Van Cauter, 2001), and is essential for a healthy rest–activity pattern (Wurtman, 1975).

Lights of different wavelengths also affect blood pressure, pulse, respiration rates, brain activity, and biorhythms. The role of lighting in our daily lives is essential to operate ideally in every environment. Thus, lighting directly influences every dimension of human existence. Tanner reiterated, "Light is the most important environmental input, after food and water, in controlling bodily functions" (as cited in Wurtman, 1975).

Since the industrial revolution, people spend more and more time indoors while artificial lighting has shown the power to at least partially compensate for the processes that stabilize the body, mind, and emotions (Knez, 1995; Mishima, Okawa, Shimizu, & Hishikawa, 2001; Takasu et al., 2006; Tanner, 2008; Viola et al., 2008). In the following, we elaborate a bit more on the proven effects that artificial light has on human functioning.

Sleep is one of the most basic physical requirements for human functioning. Amount and quality of lighting invariably affect the degree and quality of sleep in humans and regulates our biological clocks. In 2002, Berson, Dunn, and Takao (2002) identified a new nonimage-forming photopigment residing within a cell type in the retina of the eye. Sleep consolidation is optimal when sleep timing coincides with the period of melatonin secretion (Dijk & Cajochen, 1997). People who sleep during their melatonin peak (as in normal, that is, well-synchronized, people) are reported to have a longer total sleep time and less wakefulness after sleep onset as compared with people who schedule their

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wakefulness during the melatonin peak (nonsynchronized people; Wright et al., 2006). Moreover, the same study indicates that cognitive performance (i.e., learning) was better in a synchronized group of people, whereas learning was impaired in a nonsynchronized group of people. This indicates that proper alignment between sleep–wakefulness and biological (internal circadian) time is crucial, not only for sleep quality but also for enhancement of cognitive performance.

Lighting plays an important role in evoking emotions. Lighting can be used to make an architectural space more aesthetically pleasing or it can create an atmosphere in that space; both affect people's emotions. In addition, the user's well-being can be directly influenced by light. Brightness, color, direction, contrast, and time are parameters used to create lighting conditions that address this.

Nevertheless, concerning the relationship between lighting and mood/cognition, research has not shown consistent results. In a study by Knez (1995), two experiments were performed to analyze the effects of color temperature and illumination levels on mood and cognitive performance tasks including long-term recall, free recall, and performance appraisal between males and females. After each experiment, a test to measure each participant's mood was administered. The results showed that females performed better in warm white lighting environments, whereas males performed better on cognitive tasks in cool white lighting. Both males and females perceived and responded differently in evaluating the illumination levels and color index of the lighting, and therefore each gender's mood was affected differently. Positive mood measures showed no increase in mood in both genders; however, the cooler lighting had a more negative effect on females' moods. Thus, females' performance on cognitive tasks decreased under cooler lighting (Veitch & McColl, 1994).

Because physiological changes occur when humans are exposed to light, mood and cognition can be affected indirectly and variably. In addition, according to Veitch and McColl (2001), lighting's cognitive and mood-related effects on people have noteworthy implications: (a) better performance on cognitive related tasks in the workplace or academic environment and (b) overall improved quality of life and well-being. Visual perception strength and adequate sleep could have a considerable impact on cognitive abilities such as concentration and memory. Mood may also determine the sharpness of these cognitive abilities. Mood can be influenced by the quality and amount of lighting (Veitch & McColl, 2001; inter alia Beauchemin & Hays, 1996; Benedetti, Colombo, Barbini, Campori, & Smeraldi, 2001). For instance, light therapy has proven a successful treatment for those with seasonal affective disorder (SAD) and other nonseasonal mood-related disorders such as depression and eating disorders (Veitch & McColl, 1994; Spiegel, Tasali, Penev, & Van Cauter, 2004; Van Cauter, Leproult, & Plat, 2000).

Effects for Lighting and Learning

Because lighting profoundly affects numerous levels of human functioning such as vision, circadian rhythms, mood, and cognition, its implicit effects on learning and classroom achievement cannot be dismissed. Several studies have addressed how the quality and color of lighting can either impair or enhance students' visual skills and, thus, academic performance. Visual impairments alone can induce behavioral problems in students, and the level of concentration and motivation in the classroom. Cheatum and Hammond (2000) estimated that around 20% of children who enter the school encounter visual problems (e.g., problems with focusing, eye tracking, training, lazy eye, and trabismus). Among elementary school children, 41% have experienced trouble with tracking, 6% have refractive errors, and 4% have strabismus (Koslowe, 1995, as cited in Cheatum & Hammond, 2000). The same study suggests that "the inability of visual tracking is also thought to be the cause of behavioral problems and being illiterate" (Cheatum & Hammond, 2000, p. 6).

Winterbottom & Wilkins (2009) suggested that certain features of lighting can cause discomfort and impair visual and cognitive performance. These features include "imperceptible 100 Hz flicker from fluorescent lighting and glare induced by 1) daylight and fluorescent lighting, 2) interactive whiteboards (IWBs) and dry-erase whiteboards (DWBs)" (Winterbottom & Wilkins, 2009, p. 8). The purpose of his study was to determine the degree and magnitude to which students are subjected to the above stated lighting inefficiencies in the classroom. The 100 Hz flicker from fluorescent lighting was displayed in 80% of the 90 U.K. classrooms used for the study. Other general lighting issues were that many of the classrooms had "an unnecessarily inefficient form of fluorescent lighting that has been shown to cause headaches and impair visual performance," some were "over-lit with excessive fluorescent lighting and excessive daylighting," and finally, "glare from IWBs and DWBs is common. Pattern glare from Venetian blinds is a possibility" (Winterbottom & Wilkins, 2009, p. 9).

A study by Ott (1976) revealed that cool white fluorescent lighting in classrooms can drastically improve the behavior of students who are hyperactive or have learning disadvantages. Four "windowless" classrooms containing first graders in Sarasota, Florida, were observed. Two of the classrooms had standard fluorescent lighting, and the other two had the new full-spectrum fluorescent lighting installed. Cameras were set up in each room to take snapshots of the students throughout the day. Results proved that the students in the full-spectrum lit classrooms were able to pay attention better, which led to improved performance. Ott concluded that "hyperactivity is partly due to a radiation stress condition," and that when the exposure to the radiation from the lighting was minimized, behavior and performance improved.

Another study (Grangaard, 1995) measured how "color and light" had an effect on 11 six-year-old students'

on-task and off-task behaviors and their blood pressure measurements. The children went through three phases of testing each of which lasted 10 days. During this time, the students were videotaped for 15-min intervals at the same times each day and their blood pressure was also measured each day. The results revealed that a decrease appeared in the children's blood pressure during the second phase in the experimental classroom with blue walls and full-spectrum lighting, and a gradual 1% increase occurred on returning to the original classroom setup with cluttered white walls and plain white fluorescent lighting in the third phase. The results also unearthed that the six-year-olds exhibited a dramatic decline in off-task behaviors in the second phase as compared with the first. In the first phase, a total of 390 off-task behaviors were measured as opposed to a total of 310 in the second phase, a 22% decrease. The author concludes that "the enhancement of human performance requires the optimum environment" and that "educators must recognize the fact that surroundings are never neutral."

A study by Tanner (2008) reiterates the idea that the physical design of schools can effect student achievement. One of the areas of design discussed was lighting. The author relates evidence from other studies that have shown that lighting affects human physiological functions, health, development, and performance. Regression models were used to help determine the relationships between school design elements and student performance. The overall outcome expressed variances in achievement when compared with controlled and noncontrolled design elements in schools, including lighting.

Heschong et al. (2002) examined second- through fifth-grade students' math and reading test results to determine whether the effects of daylighting in the schools had an impact on student performance. Three different school districts across the nation were chosen to participate in this study. Each school districts' lighting conditions were categorized into several sets of data. A multivariate regression analysis was used to differentiate the highly variable data for each school district. The statistical evidence revealed that school buildings with the greatest capacity for daylight, such as those "with increased window and skylight areas," had a noteworthy effect on students' performance and behavior. Within the different school districts, the findings were consistent.

Different types of lighting can play different roles in enhancing classroom performance such as improving vision (and perhaps affecting concentration, and motivation), behavior, and academic achievement. For example, cool white fluorescent lighting is recommended to aid in reading speed and accuracy and attentiveness or focus. However, warm white lighting can assist in helping adults to work together and to minimize conflict (Baron, Rea, & Daniels, 1992).

In addition, recent research addressing artificial light in school environments has investigated light effects for student achievement (Wolhfarth, 1986), motivation, concentration, and cognition. The current study further examined effects of lighting on motivation and concentration revealed by Sleegers et al. (2012) and extended to include a measure of reading accuracy and rate.

Defining Oral Reading Fluency (ORF)

In the most recent edition of the *Handbook of Reading Research*, Rasinski, Reutzel, Chard, and Linan-Thompson (2011) provided the following definition of fluency— "a characteristic of reading that occurs when readers' cognitive and linguistic systems are developed to the extent that they can read with sufficient accuracy and rate to allow for understanding the texts and reflecting its prosodic features" (p. 287). Many researchers (Kuhn & Rasinski, 2011; Rasinski, 2011; Rasinski et al., 2011) describe the main components of fluency as automaticity in word recognition (which includes accuracy) and prosody. According to Rasinski and Samuels (2011), automaticity is the "ability of readers to decode words not just accurately but effortlessly or automatically" (p. 95). When readers can read with automaticity, they can devote more cognitive energy to comprehending the text and less to decoding individual words. The other component of fluency is prosody. Kuhn and Rasinski (2011) defined prosody as the "melodic elements of language that, when taken together, constitute expressive reading" (p. 278). That is, the reader is able to automatically recognize words while providing the appropriate expression implied by the text (e.g., intonation, stress, and timing) so that the "oral reading of written text takes on the quality of fluent speech" (Kuhn & Rasinski, 2011, p. 278).

For many years, ORF has typically been assessed through the use informal reading inventories (IRIs). IRIs are designed to determine the percentage of words a reader can read correctly in a passage within 1 min. However, IRIs only provide information about the reader's ability to decode accurately, not automatically. Measuring word accuracy provides information to classify a text as being on a reader's independent, instructional, or frustration reading level. Research (Rasinski, Reutzel, Chard, & Linan-Thompson, 2011) does support that comprehension of text declines as the number of words decoded accurately declines. Another method of measuring ORF is to determine the reading rate. Reading rate assessment tools actually measure automaticity with the assumption that readers decoding text rapidly coincides with automatic recognition of words. Curriculum-based measurement (CBM) is a more recent attempt to measure ORF. These measures define ORF by the number of words read accurately in grade level text in 1 min (Rasinski et al., 2011). CBM tools have been found to correlate with other measures of reading achievement, such as reading comprehension (Fuchs, Fuchs, Hosp, & Jenkins, 2001; Good, Simmons, & Kame'enui, 2001; Marston, 1989; Rasinski et al., 2005, as cited in Rasinski et al., 2011). Measuring prosody is more difficult to measure because it is

not as easily quantified. Rubrics have been developed and can be used to measure prosody. However, these are typically more appropriate for classroom teacher use to inform classroom instruction (Rasinski et al., 2011).

ORF: A Bridge to Reading Comprehension

Pikulski and Chard (2005) described fluency as the bridge between phonics and comprehension. That is, fluency links to phonics via the automatic recognition of words with little cognitive energy expended by the reader. Also, fluency links to comprehension via prosodic reading where text is read with expression. For decades, educational research concerning literacy skills has focused on how ORF correlates with overall reading ability, including reading comprehension. LaBerge and Samuels (1974) introduced the theory of automatic information processing in reading where they argued that surface-level processing of words should occur automatically with little cognitive effort so that readers could concentrate on comprehension. In fact, they described the notion that poor comprehension could be traced to a reader's lack automaticity. Stanovich (1980) extended this theory in stating that good and poor readers could be characterized by how automatically they recognized words. In addition to the automaticity issue, prosody also correlates to good comprehension (Rasinski, 2004, 2010; Wright, Sherman, & Jones, 2004). These researchers provide evidence of how fluency bridges the gap between phonics and comprehension.

Because fluency is an important part of reading instruction and is a major factor in developing reading comprehension, it is important to note the relationship between oral and silent reading fluency. Although fluency is typically thought of as occurring orally, fluency also extends to silent reading. Fluency should manifest itself in silent reading parallel to ORF because one would infer that the manner in which an individual reads orally would translate into how the same individual reads silently. Research does support that ORF and silent reading comprehension correlate on silent reading assessments (Deno et al., 1982; Rasinski, Padak & Logan, 1991, as cited in Rasinski & Samuels, 2011).

ORF is important to developing overall reading as without a sufficient level of competence in lower level reading skills such as "word recognition," one's capability to perform higher level skills required to comprehend text will be hampered. This theory is based on the premise that *constructing meaning* is the primary goal of reading. Thus, efficient ORF skills are necessary for a solid foundation for comprehension and overall reading ability (Fuchs et al., 2001).

In addition to concentration and motivation, the current study examines ORF in an effort to determine artificial lighting effects on learning as measured via a reliable and valid highly prevalent norm-referenced assessment utilized in the authentic setting of classrooms. The conceptual framework for this study juxtaposes prior research with this study (see Figure 1 for a summary of the conceptual framework of the study in relation to previous research).

Dynamic Lighting in the Classroom

Artificial Lighting Design and Specifications[1]

Light illumination intensity and color temperature are two main variables in lighting systems used for artificial lighting indoors. Light intensity is measured via "lux," and typically, 500 lux horizontally on the workplane is the minimum used to create enough illumination for teachers and students to see given the lack of natural light available in classrooms. Color temperature, as measured in Kelvin, refers to the quality of light hue and runs from "cool" (blue and white) to "warm" (red and yellow) along the radiation spectrum of light. Each lighting fixture (or panel) contains three lamps, with the two outer lamps generating a "cool color temperature" and the single inner lamp producing a "warm color temperature." The lamps within the lighting panel are incrementally "decreased (dimmed)/increased in light output per selected scene [setting] to create the light effect per scene." Furthermore, the luminaries consist of a diffuser plate to mix the colors and to prevent direct view in the lamps.

Settings

As previously outlined, sound scientific research exists on the topic of lighting and its effects on humans, including sleep patterns, vision, learning and cognitive development, mood (which affects motivation and concentration), and finally ORF. Based on this research, the authors conducted the current study utilizing a lighting system, *SchoolVision*,[1] specifically designed for schools. SchoolVision is an intended "teaching tool" created to positively influence school performance, aiding via desirable behavior during the different tasks like being focused during tests, being cooperative or creative during art sessions, or reducing restlessness when children are too excited for the instruction. Based on research that attests to the relationship of lighting quality and color temperature to the body and mind, four distinct light settings were engineered within this dynamic classroom lighting system (see Figures 2 and 3).

These four settings consist of *normal, focus, energy*, and *calm*, and they are designed to correspond with various classroom activities. These settings can be selected by the teacher "via [a] control panel." The *normal* setting can be used "for regular classroom activities," whereas the *focus* setting can be employed "when children have to concentrate, such as for tests." *Energy* is a setting designed for use during times of day when students experience a reduction in energy, usually "in the morning and after lunch." Finally, the *calm* setting is designed for group activities requiring cooperation or supporting the students to settle down when students are "overactive." Results of previous experimental

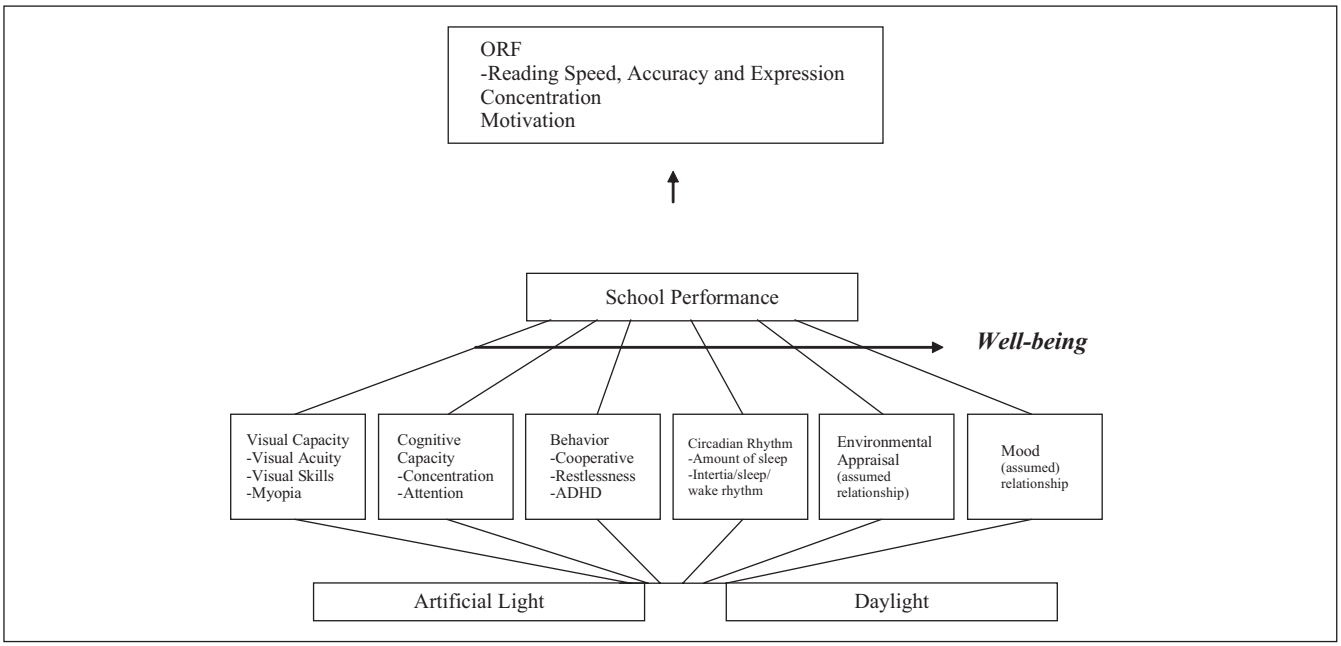

Figure 1. Conceptual framework of the study
Note: ORF = oral reading fluency. ADHD = attention deficit hyperactivity disorder. The figure places previous research and theoretical rationale in juxtaposition to the current Mott, Robinson, Walden, Burnette, and Rutherford study. The Mott et al. study shares the theoretical rationale and incrementally adds to previous research by examining oral reading fluency as measured via the AIMSweb validated norm-referenced assessment.

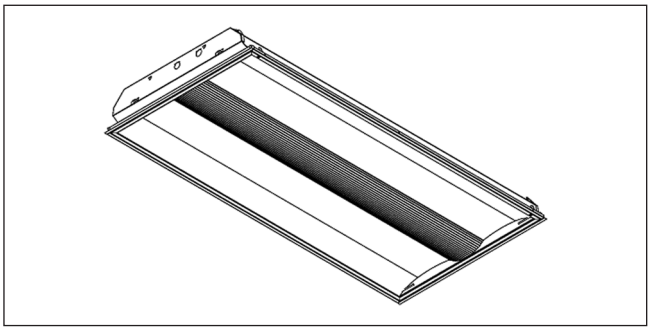

Figure 2. Light fixture

studies using SchoolVision have proven the system an effective and energy-efficient learning aid. Consequently, the current study sought to identify effects for SchoolVision focus light setting as it relates to concentration, motivation, and ORF.

Objectives

The objective of the current study was to evaluate an artificial lighting system with four discrete settings (focus, energy, calm, and normal) designed for the classroom environment. Subobjectives were to incrementally examine the lighting system "focus" setting effect on student concentration and motivation and to extend the previous body of

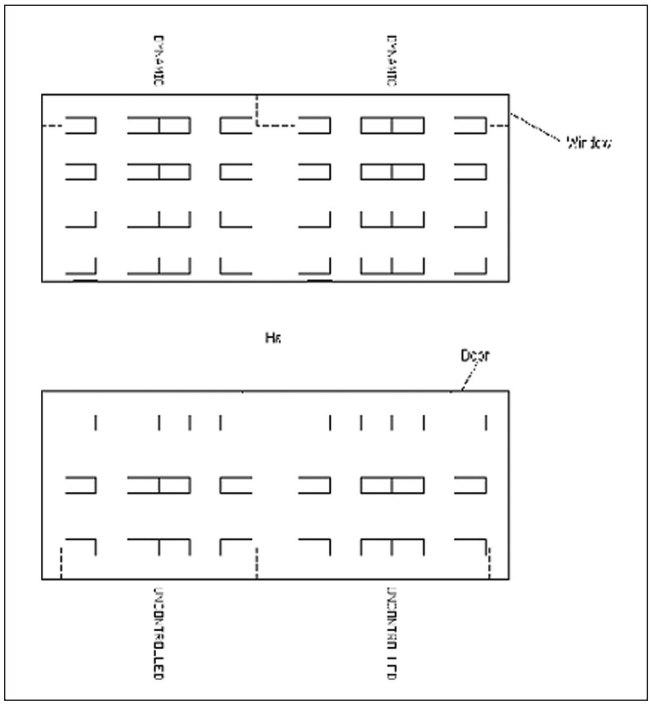

Figure 3. Lighting layout

research from the Netherlands, Germany, and Great Britain (Sleegers, 2012) to discern possible effects on student ORF performance.

Participants, Method, and Instrumentation

In all, 84 Grade 3 children, ages 7 to 8, in four different classrooms from a public school in the midsouth region of the United States participated. In a quasi-experimental design, the four classrooms were randomly assigned, two to each condition, to either "focus" or "normal" light conditions. "Focus" lighting consisted of 1000 lux with a temperature of 6500 K (see Figure 3). It consisted of a Modified Softrace with three T5HO lamps: two 17000 K Activiva Active and one 2700 K, with one 1-lamp DALI ballast, one 2-lamp DALI ballast, and one DMBC320–DALI-NA controller. Focus light setting for the treatment group was utilized during all "fluency" instruction; however, the other three settings (calm, energy, and normal) were utilized at the teachers' discretion.

Normal lighting consisted of 500 lux with a temperature of 3500 K (lens troffer 2 by 4 two-lamp T8 fluorescent fixtures; see Figure 3). Readings were taken in the center, front, and corners of the room, and then the average maintained light levels were computed based on those various readings. The photometrics of both lighting conditions and the various scenes were known. The layout was designed to ensure that IES criteria were met for classroom lighting. Due to the fact that windows were small and in some cases were blocked, the daylight contribution was minimal, and teachers were instructed to draw the blinds during the study, thus mitigating weather and atmospheric conditions during the study.

Students participated in either treatment or normally lit classrooms for the full calendar year. Normal lighting was used for all testing to ensure equivalent test conditions, although it could be argued that this may have disadvantaged the focus lighting children as they experienced a different environment from acquisition to testing, whereas the normal lighting children experienced the same environments. Repeated measures were used with three instruments at the beginning (September), middle (January), and completion (May) of the study using ORF—a key index of reading comprehension, and motivation and concentration.

AIMSweb CBM Test of ORF

ORF was assessed with the AIMSweb (Good et al., 2001; Kame'enui, Simmons, Good, & Harn, 2001) validated measure to explore possible effects for the focus light setting on reading performance. AIMSweb ORF is a CBM, meaning the test items are in alignment with classroom fluency instruction consisting of teaching the students how to read with accuracy, speed, and expression. Christ and Silberglitt (2007) evaluated benchmark AIMSweb ORF scores for 8,200 students in Grades 1 through 5 from five rural and suburban school districts in the upper Midwest using AIMSweb scores for three of the probes. The data were collected during eight consecutive school years. Each of the three ORF benchmark scores was the median of the other five probes indicating strong comparative validity technical characteristics.

Motivation Questionnaire

Student motivation was evaluated with an instrument adapted from Pintrich and DeGroot (1990) specifically for the Grade 3 students in the midsouthern region of the United States. The researchers adjusted motivation questions so that Grade 3 students responded with assurance. Items were pilot tested by the researchers. Sample items included the following:

1. I do schoolwork because I enjoy it.
2. I know I can learn the material in class.
3. Getting good grades is important to me.

Students answered the motivation items individually in a relaxed and quiet environment in the hallway or corner of their classroom as recommended by Fink and Kosecoff (1985).

d2 Test of Concentration

The d2 Test of Concentration (Brickenkamp & Zilmmer, 2010) was used to explore effects for focus lighting on student ability to concentrate, a key component to learning. The d2 Test measures processing speed, rule compliance, and performance, allowing for an estimation of individual attention and concentration ability. Test takers respond to prompts requiring them to strike through various symbols according to a variety of rules. The test can be administered in approximately 8 min. Reliability and the validity are well supported (Brickenkamp & Zilmmer, 2010) with internal consistency above .90 (Cronbach's α) and construct and comparative validity established in Europe and the United States.

Results and Discussion

A mixed-model ANOVA was conducted on each of the three dependent measures using lighting as a between-participants factor and testing occasion as a within-participants factor. Huynh–Feldt adjustments resulted in no changes for statistically significant effects, indicating no violations of the sphericity assumption. For our purposes, we were only interested in the lighting by testing occasion interaction effect on each of the three measures. We found such an effect for ORF. An examination of slopes revealed the nature of the interaction effect. Although students in the lighting group initially scored slightly lower (M = 94) than those in the control group (M = 103) before treatment began, by midsemester their performance had increased at a greater rate (by 34 points on average) compared with the control group (by 18 points on average). Increasing the quality of artificial light positively affected students' ORF performance, a key component of reading comprehension and the reason for reading.

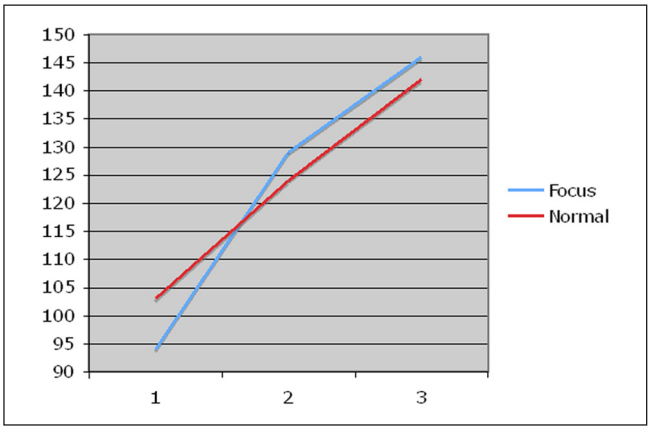

Figure 4. ORF results
Note: ORF = oral reading fluency. WCPM = words read correctly per minute. The nationally standardized ORF percentile scores for Grade 3 students are 107 WCPM at the 50th percentile, 137 WCPM at the 75th, and 162 at the 90th (Hasbrouk & Tyndale, 2005). The participants in this study could, therefore, be viewed as "average" as compared with the rest of the nation. Thus, the important finding here is the difference in growth between nonlighting and lighting participant scores.

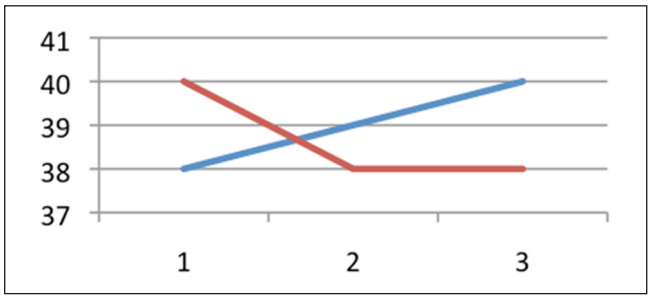

Figure 5. Motivation results

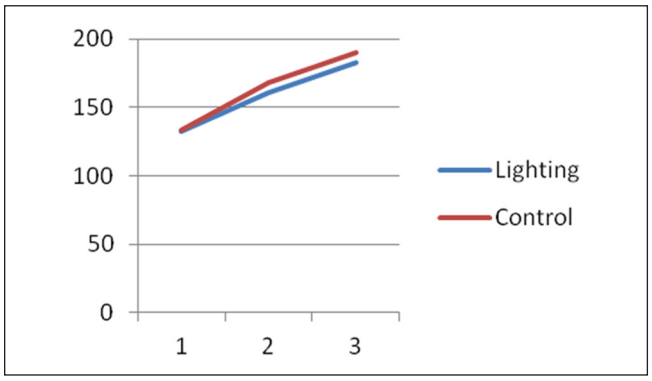

Figure 6. Concentration results
Note: Repeated measures ANOVA test for the effect of concentration was not significant, $F(2, 1.84) = 225.4$, mean standard error = 1203.5, $p = .08$.

For concentration and motivation, we found no lighting by testing occasion interaction effects. In the following, we discuss the different research outcomes more elaborately.

ORF

Although prior research (Schulte-Markwort, 2011) has revealed effects for focus lighting on ORF when students take exams, the current study found a focus lighting effect *during teaching and learning* for ORF during the school year with control and treatment groups tested in normal light conditions. This effect was revealed in an interaction of lighting by testing occasion, $F(2, 154) = 9.86$, mean standard error = 116.35, $p < .001$, providing evidence that focus light setting as an instructional technology improved the reading performance of the experimental group at a rate greater than the improvement experienced by the control group. Such a finding (see Figure 4), in light of previous research on lighting effects for well-being (mood, concentration, focus, motivation and cognition), reading speed (Schulte-Markwort, 2011), and reading performance (Heschong, 2002) behooves educational researchers to examine lighting effects on reading comprehension as well as other academic content learning in authentic classroom settings.

Motivation and Concentration

Although previous research found effects of lighting on motivation (Knez, 1995), our study found no lighting effects on either motivation or concentration, Fs < 1. It is important to note that, although statistically nonsignificant, motivation did descriptively increase for the experimental group, whereas it decreased for the control group (see Figures 5 and 6). Whereas students in Europe are familiar with the d2 Test of Concentration, students in the United States in the current study were not familiar with this test. In addition, the test is designed for age 9 and above, and the average age for the students in this study was closer to 8 than to 9 based on age requirements for admittance into the third grade. Perhaps when using the d2 Test of Concentration, for ages under 9, an abbreviated version could be used to address possible validity issues due to any developmental challenges.

Limitation

Despite its encouraging findings for ORF, this study had a few limitations. First, due to the quasi-experimental design where classrooms, rather than students, were randomly assigned to conditions, we could not control for teacher effects. However, we did use a repeated-measures design where preexisting differences among students were assessed for each measure. Second, as mentioned previously, all students were tested in a normal lighting environment. This possibly placed focus lighting students at a disadvantage due to encoding specificity (Tulving & Thomson, 1973). Third, we only used one measure for each of the three dependent variables. Our failure to find differences on two of the measures

may have been simply due to poor measures. Future studies should consider other ways of measuring student outcomes, such as behavioral observations. Finally, as with any experimental study, it is possible that students and teachers were aware of the study and conformed by exerting more or less effort depending on their perceptions of the desired outcomes. These threats to internal validity could be addressed in future studies by eventually eliminating novelty of treatment effects (e.g., entire schools would have focus lighting for a few years).

Conclusion

Light qualities of illumination and color temperature were found to influence student gains in reading. Artificial light settings vary greatly in classrooms leading to important questions of how educational and industrial designers, and constituents in the educational process select lighting for optimizing teaching and learning. The current study found an effect of focus lighting on student oral reading performance, indicating a need for further evaluation of the effects of illumination level and color temperature variables on more student learning outcomes.

Declaration of Conflicting Interests

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Note

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References

Baron, R. A., Rea, M. S., & Daniels, S. G. (1992). Effects of indoor lighting (illuminance and spectral distribution) on the performance of cognitive tasks and interpersonal behaviors: The potential mediating role of positive affect. *Motivation and Emotion*, *16*, 1-33.

Beauchemin, K. M., & Hays, P. (1996). Sunny hospital rooms expedite recovery from severe and refractory depressions. *Journal of Affective Disorders*, *40*, 49-51.

Benedetti, F., Colombo, C., Barbini, B., Campori, E., & Smeraldi, E. (2001). Morning sunlight reduces length of hospitalization in bipolar depression. *Journal of Affective Disorders*, *62*, 221-223.

Berson, D. M., Dunn, F. A., & Takao, M. (2002). Phototransduction by retinal ganglion cells that set the circadian clock. *Science*, *295*, 1070-1073.

Boyce, P., Hunter, C., & Howlett, O. (2003). *The benefits of daylight through windows*. New York, NY: Lighting Research Center of Rensselaer Polytechnic Institutes.

Brickenkamp, R., & Zilmmer, E. (2010). *The d2 test of concentration*. Cambridge, MA: Hogrefe.

Cheatum, B. A., & Hammond, A. A. (2000). *Physical activities for improving children's learning and behavior: A guide to sensory and motor development*. Champaign, IL: Human Kinetics.

Christ, T. J., & Silberglitt, B. (2007). Estimates of the standard error of measurement for curriculum-based measures of oral reading fluency. *School Psychology Review*, *36*, 130-146.

Czeisler, C. A., Duffy, J. F., Shanahan, T. L., Brown, E. N., Mitchell, J. F., Rimmer, D. W., & . . .Kronauer, R. E. (1999). Stability, precision, and near 24-hour period of the human circadian pacemaker. *Science*, *284*, 2177-2181.

Dijk, D. J., & Cajochen, C. (1997). Melatonin and the circadian regulation of sleep initiation, consolidation, structure, and the sleep EEG. *Journal of Biological Rhythms*, *12*, 627-635.

Fink, A., & Kosecoff, J. (1985). *How to conduct surveys: A step-by-step guide*. Beverly Hills, CA: SAGE.

Fuchs, L. S., Fuchs, D., Hosp, M. K., & Jenkins, J. R. (2001). Oral reading fluency as an indicator of reading competence: A theoretical, empirical, and historical analysis. *Scientific Studies of Reading*, *5*, 239-256.

Good, R. H., Wallin, J., Simmons, D. C., Kame'enui, E. J., & Kaminski, R. A. (2002). *System-wide Percentile Ranks for DIBELS Benchmark Assessment* (Technical Report 9). Eugene, OR: University of Oregon.

Grangaard, E. M. (1995). *Color and light effects on learning*. Retrieved from ERIC Database. (ED382381)

Heschong. (2002). Daylighting makes a difference. *Educational Facility Planner*, *37*, 5-14.

Heschong, L., Wright, R. L., Okura, S., Klein, P. D., Simner, M., Berman, S., & Clear, R. (2002). Daylighting impacts on human performance in school. *Journal of Illuminating Engineering Society*, *31*, 101-114.

Kame'enui, E. J., Simmons, D. C., Good, R. H., & Harn, B. A. (2001). The use of fluency-based measures in early identification and evaluation of intervention efficacy in schools. In M. Wolf (Ed.), *Time, fluency, and dyslexia* (pp. 307-331). New York, NY: York.

Knez, I. (1995). Effects of indoor lighting on mood and cognition. *Journal of Environmental Psychology*, *15*, 39-51.

Koslowe K, Bergwerk K, Yinon U, Merrick. (1995). Ocular findings in Rett Syndrome. *Journal of Behavioral Optometry, 20*, 151-153.

Kuhn, M. R., & Rasinski, T. V. (2011). Best practices in fluency instruction. In L. Morrow, & L. Gambrell (Eds.), *Best practices in education* (4th ed., pp. 276-294). New York, NY: Guilford.

LaBerge, D., & Samuels, S. A. (1974). Toward a theory of automatic information processing in reading. *Cognitive Psychology*, *6*, 293-323.

Leproult, L. R., Colecchia, E. F., L'Hermite-Baleriaux, M., & Van Cauter, E. (2001). Transition from dim to bright light in the morning induces an immediate elevation of cortisol levels. *Journal of Clinical Endocrinology & Metabolism*, *86*, 151-157.

Marston, D.B. (1989). A curriculum-based measurement approach to assessing academic performance: What is it and why do it? In M.R. Shinn (Ed.), *Curriculum-based Measurement: Assessing special children (pp. 18-78)*. New York: The Guiliford Press.

Mishima, K., Okawa, M., Shimizu, T., & Hishikawa, Y. (2001). Diminished melatonin secretion in the elderly caused by insufficient environmental illumination. *Journal of Clinical Endocrinology & Metabolism*, *86*, 129-134.

Ott, J. N. (1976). Influence of fluorescent lights on hyperactivity and learning disabilities. *Journal of Learning Disabilities*, *9*, 22-27.

Pikulski, J. J., & Chard, D. (2005). Fluency: Bridge between decoding and reading comprehension. *Reading Teacher*, *58*, 510-519.

Pintrich, P., & DeGroot, E. (1990). Motivational and self-regulated learning components of classroom academic performance. *Journal of Educational Psychology*, *82*, 33-40.

Rasinski, T. V. (2004). *Assessing reading fluency*. Honolulu, HI: Pacific Resources for Education and Learning. Retrieved from http://www.prel.org

Rasinski, T. V. (Ed.). (2010). *The fluent reader: Oral and silent reading strategies for building word recognition, fluency, and comprehension*. New York, NY: Scholastic.

Rasinski, T. V. (2011). Teaching reading fluency. In T. Rasinski (Ed.), *Rebuilding the foundation: Effective reading instruction for 21st century literacy* (pp. 181-198). Bloomington, IN: Solution Tree.

Rasinski, T. V., & Padak, N. (2005). *Three Minute Reading Assessments: Word Recognition, Fluency, and Comprehension for Grades 1-4.* New York, NY: Scholastic.

Rasinski, T.V., Padak, N., & Logan, J. (Eds.) (1991). *Reading is Knowledge.* Pittsburg, KS: College Reading Association.

Rasinski, T. V., Reutzel, D. R., Chard, D., & Linan-Thompson, S. (2011). Reading fluency. In M. Kamil, P. D. Pearson, E. B. Moje, & P. Afflerbach (Eds.), *Handbook of reading research* (*Vol. 4*, pp. 286-319). New York, NY: Routledge.

Rasinski, T. V., & Samuels, S. J. (2011). Reading fluency: What it is and what it is not. In S. J. Samuels & A. E. Farstrup (Eds.), *What research has to say about reading instruction* (pp. 94-114). Newark, DE: International Reading Association.

Spiegel, K., Tasali, E., Penev, P., & Van Cauter, E. (2004). Brief communication: Sleep curtailment in healthy young men is associated with decreased leptin levels, elevated ghrelin levels, and increased hunger and appetite. *Annuals of Internal Medicine*, *141*, 846-850.

Stanovich, K. E. (1980). Toward an interactive-compensatory model of individual differences in the development of reading fluency. *Reading Research Quarterly*, *16*, 32-71.

Takasu, N. N., Hashimoto, S., Yamanaka, Y., Tanahashi, Y., Yamazaki, A., Honma, S., & Honma, K. (2006). Repeated exposures to daytime bright light increase nocturnal melatonin rise and maintain circadian phase in young subjects under fixed sleep schedule. *American Journal of Physiology—Regulatory, Integrative and Comparative Physiology*, *291*, 1799-1807.

Tanner, K. C. (2008). Explaining relationships among student outcomes and the school's physical environment. *Journal of Advanced Academics*, *19*, 444-471.

Taras, H., Potts-Datema, W., & Pearson, H. (2005). Sleep and student performance at school. *Journal of School Health*, *75*, 248-254.

Tilving, E., & Thomson, D. M. (1973). Encoding specificity and retrieval processes in episodic memory. *Psychological Review, 80*, 352-373.

Van Cauter, E., Leproult, R., & Plat, L. (2000). Age-related changes in slow wave sleep and REM sleep and relationship with growth hormone and cortisol levels in healthy men. *Journal of the American Medical Association*, *284*, 861-868.

Veitch, J. A., & McColl, S. L. (1994). Full-spectrum fluorescent lighting effects on people: A critical review. In J. A. Veitch (Ed.), *Full-spectrum lighting effects on performance, mood, and health* (IRC Internal Report No. 659, pp. 53-111). Ottawa, ON: National Research Council of Canada, Institute for Research in Construction.

Veitch, J. A., & McColl, S. L. (2001). A critical examination of perceptual and cognitive effects attributed to full-spectrum lighting. *Ergonomics*, *44*, 255-279.

Viola, A. U., James, L. M., Schlangen, L. J., & Dijk, D. J. (2008). Blue-enriched white light in the workplace improves self-reported alertness, performance and sleep quality. *Scandinavian Journal of Work, Environment & Health*, *34*, 297-306.

Winterbottom, M. & Wilkins, A. (November 2008). Lighting and discomfort in the classroom. *EARLI Practice-Based and Practitioner Research Conference on Learning and Instruction.* Bergen, Norway.

Wohlfarth, H. (1986). *Color and Light Effects on Students' Achievement, Behavior and Physiology.* Edmonton, Alberta: Planning Services Branch, Alberta Education.

Wright, G., Sherman, R., & Jones, T. B. (2004). Are silent reading behaviors of first graders really silent? *Reading Teacher*, *57*, 546-553.

Wright, K. P., Jr., Hull, J. T., Hughes, R. J., Ronda, J. M., & Czeisler, C. A. (2006). Sleep and wakefulness out of phase with internal biological time impairs learning in humans. *Journal of Cognitive Neuroscience*, *18*, 508-521.

Wurtman, R. J. (1975). The effects of light on the human body. *Scientific American,* 233, 68-77.

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