Shining New Light on the Hawthorne Illumination Experiments

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Objective: This study provides an historical and statistical analysis of archival data from the Hawthorne illumination experiments.

Background: Previous accounts of the illumination experiments are fraught with inconsistencies because they have been based on secondary sources. The general consensus has been that variations in light levels had no effect on worker productivity at Hawthorne. All reports and data were thought to have been destroyed, but an archive at Cornell University was found to contain copies of the original documentation and much of the data from all three illumination experiments. Conclusions were originally drawn from visual comparisons of productivity graphs, and the data have never been properly statistically analyzed.

Method: Archival reports, notes, photographs, and letters on the experiments were consulted. Productivity data were extracted from the tables and graphs in the reports and statistically analyzed for each experiment.

Results: Previously unpublished details of the illumination experiments emerged. An effect of lighting on productivity was found in the first treatment sequence for the first experiment, but this finding was not confirmed in the second sequence or in the second and third experiments.

Conclusion: Experimental results provided inconsistent evidence of an association between light levels and productivity. All three experiments were found to be seriously flawed.

Application: This study challenges popular accounts of the "Hawthorne effect," and the shortcomings of these experiments also have implications for the design of field studies.

Keywords: lighting, illumination, productivity, Hawthorne effect

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INTRODUCTION

History of the Illumination Experiments

In 1923, General Electric (GE) funded the Committee on Industrial Lighting (CIL) division of the National Research Council with a $50,000 award to scientifically prove to skeptical factory management executives that more lighting would increase productivity (Wrege, 1976). Thomas Edison was the honorary chairman of the CIL, and the 50th anniversary of Edison's invention of the incandescent bulb was to be celebrated in 1929. Positive results showing that supplemental artificial illumination improved industrial productivity would have been apt for this celebration. A finding that productivity was increased by supplemental artificial illumination would also have increased electric company revenues (C. D. Wrege, personal communication, March 13, 2010).

Three series of industrial illumination experiments were planned and conducted at the Hawthorne Works of Western Electric Company in Cicero, Illinois, from 1924 to 1927. CIL chairman Dugald Jackson, head of the Electrical Engineering Department at the Massachusetts Institute of Technology (MIT), managed the illumination experiments at the Hawthorne Works and assigned a researcher, Charles Snow, to conduct the actual tests and write up the reports. Higher-output Type C lamps were tested, and the supplemental artificial light fixtures selected for testing were glassteel diffusers that had been patented by Ward Harrison, an illuminating engineer at the National Lamp Works of GE, with the hopes that this design would become a worldwide industry standard fixture. The expected results were that additional artificial illumination would increase worker productivity.

Results from the first experiment did not appear to show the expected productivity increase with the supplemental artificial illumination, and in

1925, the National Electric Lighting Association raised more than $90,000 for an industrial lighting campaign to counter the potentially adverse effects should the experimental results ever become public (Anonymous, 1925). To the dismay of GE and the CIL, it was concluded at the end of all three experiments that lighting had no effect on worker productivity (Snow, 1927c). A final report on the illumination experiments was never published because of the unfavorable findings (Gillespie, 1991; Wrege, 1986). Snow left the Hawthorne Works after April 11, 1927; resigned from MIT in 1928 and joined Western Electric Company. On December 19, 1928, Hawthorne superintendent George Pennock ordered the destruction of all data from the illumination experiments (Mallach & Smith, 1977). The illumination data that had been regularly sent to MIT were also destroyed.

Accounts of the Illumination Experiments

Without access to the original data, subsequent accounts of the illumination experiments have been based on secondary sources and anecdotal accounts, and a statistical analysis of the data has not been possible. Researchers (Hart, 1943; Landsberger, 1958; Merrett, 2006; Parsons, 1974; Sonnenfeld, 1985) primarily relied on Mayo (1933) and Roethlisberger and Dickson (1939) for descriptive accounts and findings on the illumination experiments. However, as Hawthorne historian Gillespie (1991) points out, Mayo and Roethlisberger and Dickson “did not have access to any of the participants in the lighting tests or to the reports that had been drafted but left unpublished” (p. 38). Their accounts were based on Snow’s (1927c) brief technical article and a memorandum from Dugald Jackson that lacked any hard data (Parsons, 1974).

Confusion With Other Hawthorne Experiments

To further add to the confusion in subsequent accounts, other experiments (e.g., a supervision experiment) had been conducted in addition to the illumination experiments, and these additional experiments have been incorrectly described as a part of the three illumination experiments conducted by Snow. During the third illumination experiment, a research assistant of Snow’s, Homer Hibarger, undertook a separate “special illumination test” (sometimes referred to as the “Moonlight Test”). This special test had two women perform relay assembly work for a 1-week period in baseline conditions and then work in low-light-level conditions (0.39 fc to 1 fc, or 4.20 lux to 10.76 lux) for a day. Hibarger (1927) concluded from the study that “the test was successful, demonstrating as it did the possibility of maintaining a uniform output under greatly reduced illumination intensities” (p. 5). Results from this special test possibly added to the disappointment from the illumination experiments because it showed that more lighting was not necessary for this manual task.

Toward the end of the third illumination experiment, Hibarger started an experiment focusing on human relations known as the “relay assembly test room experiment.” The first published statistical analysis on Hawthorne was on this relay assembly test room experiment (Franke & Kaul, 1978). Later statistical analyses have all been on the relay assembly test room experiment (Bloombaum, 1983; Jones, 1992; Pitcher, 1981; Schlaifer, 1980). More recently, Levitt and List (2011) claim to have uncovered the original data from the illumination experiments and conducted a statistical analysis to verify the elusive Hawthorne effect. A close review of their study reveals that critical details of the illumination experiments were glossed over. Table 1 presents a chronological history of research pertaining to the Hawthorne studies and shows that the relay assembly test room experiment has been the focus of analyses conducted to date. None of the studies in Table 1 presents a comprehensive analysis of the results from the three illumination experiments.

All Was Not Lost

Fortunately, it transpires that a number of records pertaining to the Hawthorne illumination experiments escaped destruction because Snow had made personal carbon copies of his work and kept these along with some of his original documents, and these personal records were not destroyed during the purge in 1928. In 1957, Charles Wrege, a historian-archivist of

TABLE 1: Brief Chronology of Hawthorne Studies Publications

Author(s)	IE	RATR	HR	Comments
Snow (1927c)	x			Summarizes illumination experiments. Very little quantitative data provided.
Mayo (1933)	x	x	x	Summarizes illumination experiments. No quantitative data provided.
Whitehead (1938)		x		No mention of illumination experiments.
Roethlisberger and Dickson (1939)	x	x	x	Summarizes illumination experiments. No quantitative data provided.
Hart (1943)			x	Incorrectly credits Roethlisberger and Dickson (1939) with illumination experiments. Associates RATR with illumination experiments.
Carey (1967)			x	Mentions illumination experiments but does not provide details.
Landsberger (1958)	x	x	x	Provides an account of illumination experiments, but most of it is a repeat of Roethlisberger and Dickson (1939).
Parsons (1974)		x		No details on illumination experiments provided. Was aware that conclusions drawn from illumination experiments were unsubstantiated (i.e., no quantitative data).
Wrege (1976)	x			A very thorough account of illumination experiments and how they were developed. Based on primary sources provided by Snow. No quantitative data provided, however.
Franke and Kaul (1978)		x		First statistical analysis on RATR. Mentions illumination experiments but does not provide details.
Schlaifer (1980)		x		Another statistical analysis on RATR. No details on illumination experiments provided.
Pitcher (1981)		x		An analysis of RATR. No details on illumination experiments provided.
Bloombaum (1983)		x		Another statistical analysis on RATR. No details on illumination experiments provided.
Sonnenfeld (1985)	x	x	x	Includes a paragraph on illumination experiments with very vague details. Details are mixed up with the later experiments conducted at Hawthorne.
Jones (1990)		x		Another statistical analysis on RATR. Mentions illumination experiments but does not provide details.
Gillespie (1991)	x	x	x	A historical perspective on Hawthorne. Provides accurate details on illumination experiments, such as the lighting period dates and the lighting treatments.
Jones (1992)		x		Another look at RATR. No details on illumination experiments provided.
Merett (2006)	x			Repeats same details provided by Roethlisberger and Dickson (1939) regarding illumination experiments.
Levitt and List (2011)	x			Three departments are mentioned, but only two of them are actually named; inspection department is not mentioned. Substantial information, such as the design of the illumination experiments (e.g., test groups, control groups, lighting treatments), is not provided. Several critical oversights include the following: Saturdays were shorter workdays; one of the groups in the first experiment was a control group; halfway through the first experiment, there was an intervention to reduce glare.

Note. IE = illumination experiments from 1924 to 1927; RATR = relay assembly test room experiment from 1927; HR = human relations experiments from 1927 to 1932.

management history, as part of his doctoral dissertation at New York University, tracked down Snow and inquired about the existence of records from the illumination experiments. Wrege was able to borrow Snow's personal copies of the records to complete his dissertation. After the completion of his dissertation in 1961, Wrege received the personal copies as a gift from Snow. The items from Snow included log notes, photos, and the draft manuscripts of the reports of all three illumination experiments with appendices. These items were donated in 1980 to the Kheel Center for Labor-Management Documentation and Archives in the M. P. Catherwood Library at Cornell University by Wrege, where they are housed in Collection No. 5167. Despite this scholarly windfall, it seems that the existence of these documents has been generally unknown to researchers.

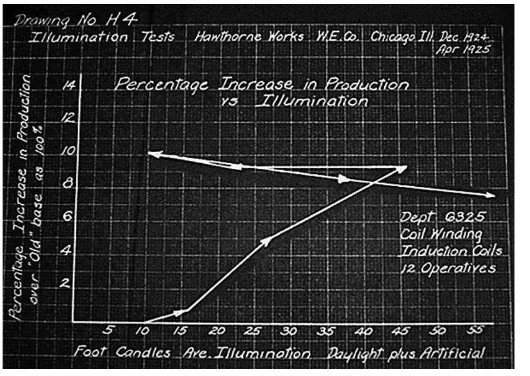

Figure 1. Vector Analysis Graph. Created and used by Snow to interpret effects of illumination on production increases. In this example Snow plots the percentage changes in productivity with light level. Photograph taken in 2011. Photograph by Michael D. French. Credit: Charles D. Wrege Collection, History of Management Photographs, Kheel Center, Cornell University.

Present Study

The records in Collection No. 5167 at Cornell University's Kheel Center for Labor-Management Documentation and Archives were accessed. These records contained the unpublished reports of the three illumination experiments, and the appendices presented summaries of the original data in tables and graphs. The appendices revealed that Snow drew his conclusions from an eyeball analysis of vector graphs that plotted the percentage changes in production against lighting treatments and light levels. Figure 1 shows an example of one of Snow's vector graphs from his analysis of the illumination experiments. Statistical tests were in their infancy and were not reported in any of the data analysis. Using the unpublished manuscripts of Snow's reports, we determined the experimental design of the three illumination experiments and conducted a secondary data analysis using modern statistical methods.

Figure 2. The Hawthorne Works of the Western Electric Company. Note the abundance of windows in the façade and the absence of shading buildings. Photograph taken in 1977. Photographer unknown. Credit: Charles D. Wrege Collection, History of Management Photographs, Kheel Center, Cornell University.

GENERAL METHOD

Overview of Test Site

The Hawthorne Works (Figure 2) employed some 31,000 employees and specialized in the manufacturing of telephone components, producing some 60 billion piece parts each year. Three departments, Relay Assembly, Coil Winding, and Jack Shell and Spring Inspection (hereafter, Inspection), were selected for the experiments. The departments were located in separate large rooms with dissimilar features. Snow (1925) disclosed in the first illumination test report the reasons for the selection of these three departments: (a) They were typical of

Figure 3. Relay Assembly Task. Photograph taken in 1925. Photographer unknown. Credit: Charles D. Wrege Collection, History of Management Photographs, Kheel Center, Cornell University.

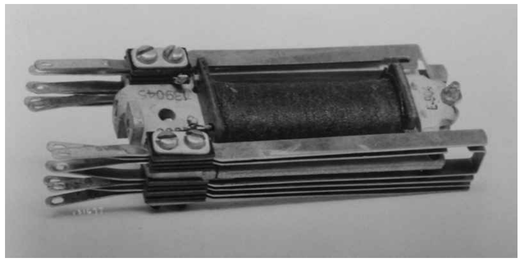

Figure 4. E Type Relay. Photograph taken in 1925. Photographer unknown. Credit: Charles D. Wrege Collection, History of Management Photographs, Kheel Center, Cornell University.

factory operations at the time, (b) lighting and considerable use of the eyes were supposedly required, (c) they performed repetitive tasks, (d) outputs were easy to compare, and (e) the three different types of incentive payments were represented.

Hawthorne had its own power plant to generate electricity; however, the stability of the voltage generated varied. When the load in the factory was high, the voltage available for the artificial lighting was reduced, and consequently, the artificial light levels were dimmer at some times than at others (C. D. Wrege, personal communication, July 2, 2010).

Overview of Work

Workers (termed "operatives" by Snow) from the three departments worked 6 days a week and began their workday promptly at 7:30 a.m. and worked until 4:15 p.m. or 5:00 p.m. On Mondays, the orders for the relays were distributed, and often there was a delay in the start time because these orders had to be written by production clerks, who started work at 6:00 a.m. but were not always finished by 7:30 a.m. Saturday was only a 4-hr work day.

Relay Assembly. The Relay Assembly department was responsible for piecing together telephone switchboard relays. Figure 3 shows an example of the relay assembly task. Individual piece parts were used to assemble a wide variety of relay designs. Approximately 3,500 different designs and 7 million relays were manufactured annually. An example of a relay is shown in Figure 4. Each relay design comprised a series of piece parts and a single base component. Different workers could make different relays throughout the day, and the work was considered unskilled. Snow was unfamiliar with telephone relay components. Therefore, it was difficult for him to distinguish completed parts from incomplete parts. "For example in the E relays, workers could be assembling E901 that could become E904, but by visual inspection they would be identical" (C. D. Wrege, personal communication, March 13, 2010). Consequently, the daily average incentive earnings per hour was used to measure productivity output in Relay Assembly instead of the number and type of relays assembled.

Coil Winding. Work in the Coil Winding department involved a worker using a foot-operated treadle in the hand winding of induction coils and receiver coils used in desk telephones (Figure 5). This task was considered the most skilled work of the three departments. The primary task in Coil Winding was to loop wire coils onto winding arbors (Figure 6). Coil winding was performed only by women because they were believed to be the best coil winders, and also it was believed that good coil winders were "born" rather than trained, even though workers received intensive training on this task

Figure 5. Coil Winding Department. Photograph taken in 1925. Photographer unknown. Credit: Charles D. Wrege Collection, History of Management Photographs, Kheel Center, Cornell University.

Figure 6. Coil Winding Task. Photograph taken in 1925. Photographer unknown. Credit: Charles D. Wrege Collection, History of Management Photographs, Kheel Center, Cornell University.

(C. D. Wrege, personal communication, April 10, 2010). To wind the coils, a worker used a foot pedal to power the coil winder machine, and some of the machines operated more easily than others. Workers tended to know how best to work their machines to avoid fracturing the delicate wire winding. The productivity measure in Coil Winding was the daily average number of coils wound per hour.

Inspection. Workers in the Inspection department performed the visual inspection of jack shells and springs to detect any defects (Figure 7). Approximately 30 pieces were placed in one hand and inspected from various angles. Only a portion of the 30 pieces was inspected at one time. Productivity was measured by the daily average count of the number of parts inspected per hour.

Figure 7. Visual Inspection of Jack Springs. Photograph taken in 1925. Photographer unknown. Credit: Charles D. Wrege Collection, History of Management Photographs, Kheel Center, Cornell University.

Existing Test Room Conditions

Relay Assembly. The department had a solid roof with monitors that opened to provide better ventilation, but these monitors did not let sunlight enter the space. Snow located his test groups deep in the building floor away from the windows to minimize any effect of variations in daylight. The baseline artificial lighting consisted of XE Holophane reflectors containing frosted 50-watt lamps. These reflectors were popular in the period between 1915 and 1924 because they were supposedly engineered to provide controlled light so that the light was more concentrated to illuminate interiors. A night survey photograph of the room is shown in Figure 8.

Coil Winding. A saw-toothed glass roof provided good natural light in the daytime for the Coil Winding department. The baseline artificial lighting was the XE Holophane reflectors containing 150-watt bowl enameled lamps. Figure 9 shows the Coil Winding room at night.

Figure 8. Relay Assembly Room at Night with 200 Watt Glassteel Diffusers. These light fixtures created considerable glare. Photograph taken in 1925. Photograph by Marty Labnos. Credit: Charles D. Wrege Collection, History of Management Photographs, Kheel Center, Cornell University.

Figure 9. Coil Winding Room at Night with 150 Watt Holophane Reflectors. Photograph taken in 1925. Photograph by Marty Labnos. Credit: Charles D. Wrege Collection, History of Management Photographs, Kheel Center, Cornell University.

Inspection. The Inspection department had a lower roof than the other two departments. Because the inspected pieces were lustrous metal parts, glare from the fixtures was especially problematic. The baseline lighting was the XE Holophane reflectors containing 150-watt bowl frosted lamps. Figure 10 shows the Inspection room at night.

Figure 10. Jack Shell and Spring Inspection Room at Night with 150 Watt Holophane Reflectors. Photograph taken in 1925. Photograph by Marty Labnos. Credit: Charles D. Wrege Collection, History of Management Photographs, Kheel Center, Cornell University.

Overview of Materials and Original Procedure

For the illumination experiments, glassteel diffusers patented by Ward Harrison, manufactured by the Ivanhoe Division of GE, and designed to diffuse light over large interior spaces were tested. The glassteel diffusers contained 100-, 200-, or 300-watt Type C lamps. A Macbeth illuminometer was used to measure light levels in units of footcandles. During the experiments, lighting measurements were taken hourly at six points in each room. Snow had surveyors take the lighting measurements, and the obtained values were averaged. Lighting treatments were changed on Sunday, and light levels were measured at night to account for the artificial light intensity and during the day to obtain daylight plus artificial light intensity.

Present Procedure

All Hawthorne illumination experiment data were obtained from Cornell University's Kheel Center for Labor-Management Documentation and Archives. After analyzing extensive archival records, the original data were extracted from the tables and graphs found in the appendices of the illumination reports and were entered into electronic spreadsheets.

Present Data Analysis

Data were organized, coded, and transformed and then imported to IBM SPSS Statistics (Version 19) software for statistical analysis. Data analysis methods are described separately for each experiment.

FIRST ILLUMINATION EXPERIMENT

Method

Participants. A total of 64 female workers of Polish ancestry from the three departments participated in the experiment. These women were chosen by the foreman, Frank Platenka, who preferred Polish women, as he was able to communicate with them in their language (C. D. Wrege, personal communication, December 4, 2010). The mean age of the workers was 19.8 years. In each department, the workers were further differentiated by specific tasks. In Relay Assembly, 23 workers were separated according to whether they were assembling an E-type relay ($n = 16$) or an A-type relay ($n = 7$). In Coil Winding, 27 workers were in three groups: a control, nonlighted group ($n = 10$); an induction coil group ($n = 12$); and a receiver coil group ($n = 5$). Inspection included 14 workers who were inspecting either jack shells ($n = 7$) or jack springs ($n = 7$). In all, seven testing groups participated.

Procedure. From November 26, 1924, to April 11, 1925, six of the seven groups of workers worked with four different lighting treatments in three separate rooms in a repeated-measures design. The control, nonlighted Coil Winding group did not receive any lighting treatments besides the baseline, but no control groups were used in the other departments. There were eight lighting periods; the four lighting treatments were repeated twice with all six groups exposed to the same lighting treatment during each period; however, the sequence of treatments was changed when this was repeated. Table 2 includes the lighting period dates, the various lighting treatments, and Snow's reported means for light levels. Snow's reports do not state whether workers knew the details of the experimental design (e.g., the order of the lighting treatments and the duration of the periods). Snow (1925) stated that the standard deviation for the reported mean light levels at midday was 3 fc (32.3 lux). Supervision prior to the experimen was one instructor for every 10 or 12 workers, but during this experiment, supervision increased to one instructor for every 8 workers.

Worker productivity was recorded five times daily in the Relay Assembly and Coil Winding departments, at 8:30 a.m., 9:30 a.m., 2:00 p.m., 3:00 p.m., and 4:15 p.m. or 5:00 p.m. Productivity was recorded on an hourly basis in the Inspection department. However, Snow presented only daily productivity averages in some of his graphs. Other variables, such as attendance, worker satisfaction, temperature, humidity, ventilation, and line voltage, were recorded, but these data were not summarized for analysis. In addition to the experimental procedures, Snow chronicled his research and time spent at Hawthorne in a personal log.

The glassteel diffusers proved to be a source of considerable glare. To decrease glare, just before halfway through the experiment, two physical interventions, lighting baffles and hoppers, were introduced to all three departments during the fourth period. The baffle consisted of "a metal band which fastened some white cardboard to the edge of the reflector" and "black boxes were constructed to use as hoppers" (Snow's log notes, February 3–5, 1925).

Data analysis. Productivity data for each group were summarized in Snow's illumination report; however, only Saturday productivity (only a 4-hr workday) was presented for the control, nonlighted coil winding group, and consequently this group was omitted from the statistical analysis.

Group productivity was averaged each day, so individual worker productivity data were unavailable and nowhere to be found in Snow's records. To enable comparisons between groups, the mean daily average production data for each group were standardized as Z scores. These standardized productivity data were analyzed with a mixed-model analysis of variance that included the independent variables of month, repetition (first or second time the lighting treatment was applied), and light level (average total illumination, or the combination of artificial light and daylight experienced by workers) with standardized productivity as the dependent variable.

TABLE 2: Lighting Conditions and Productivity for the First Illumination Experiment

			Relay Assembly				Coil Winding				Jack Inspection			
			Mean Light Level in Footcandles (Lux)		Productivity		Mean Light Level in Footcandles (Lux)		Productivity		Mean Light Level in Footcandles (Lux)		Productivity	
Period	Date	Lighting Treatment	Illum	Total Illum	E Relay	A Relay	Illum	Total Illum	I. Coil	R. Coil	Illum	Total Illum	Shell Inspect	Spring Inspect
Time 1														
1	Nov. 24, 1924–Dec. 26, 1924	Existing lighting treatment[a]	2.6 (28)	5.0 (54)	51.3	67.9	4.0 (43)	10.0 (108)	11.7	80.9	2.8 (30)	6.5 (70)	665.3	1210.9
2	Dec. 29, 1924–Jan. 10, 1925	100 watts	11.6 (125)	12.0[b] (129)	54.6	68.8	8.6 (93)	16.0 (172)	11.8	81.3	6.0 (65)	10.0 (108)	658.7	1137.5
3	Jan. 12, 1925–Jan. 31, 1925	200 watts	25.7 (277)	25.5[b] (274)	55.5	69.0	21 (226)	29.0 (312)	12.4	83.8	14.5 (156)	17.5 (188)	691.8	1229.5
4	Feb. 2, 1925–Feb. 14, 1925	300 watts	42 (452)	44.0[b] (473)	54.9	72.8	36 (388)	46.0 (495)	12.8	83.0	23 (248)	30.0 (323)	695.2	1192.4
Time 2														
5	Feb. 16, 1925–Feb. 28, 1925	100 watts	11.6 (125)	14.5 (156)	55.0	71.6	8.6 (93)	21.0 (226)	12.7	83.9	6.0 (65)	11.5 (124)	704.9	1235.6
6	Mar. 2, 1925–Mar. 7, 1925	Existing lighting treatment[a]	2.6 (28)	6.5 (70)	56.3	74.5	4.0 (43)	10.0 (108)	12.9	80.9	2.8 (30)	6.5 (70)	697.7	1271.7
7	Mar. 9, 1925–Mar. 28, 1925	200 watts	25.7 (277)	33.0 (355)	56.5	74.8	21 (226)	38.0 (409)	12.8	84.3	14.5 (156)	27.0 (291)	699.8	1306.7
8	Mar. 30, 1925–Apr. 11, 1925	300 watts	42 (452)	56.0 (893)	55.7	72.5	36 (388)	58.0 (624)	12.7	85.0	23 (248)	40.0 (430)	745.0	1269.1

Note. Illum = artificial light; Total Illum = artificial light + daylight; I. Coil = Induction Coil; R. Coil = Receiver Coil; Inspect = inspection.

a. Existing lighting treatment for departments as follows: Relay Assembly = 50-watt Holophane reflector frosted lamps; Coil Winding = 150-watt Holophane reflector enameled lamps; Jack Inspection = 150-watt Holophane reflector frosted lamps.

b. In Periods 2, 3, and 4 for Relay Assembly, the total illuminance values were either close to or less than the illuminance values. Reductions in supply voltage to the lamps during the daytime most likely account for this phenomenon.

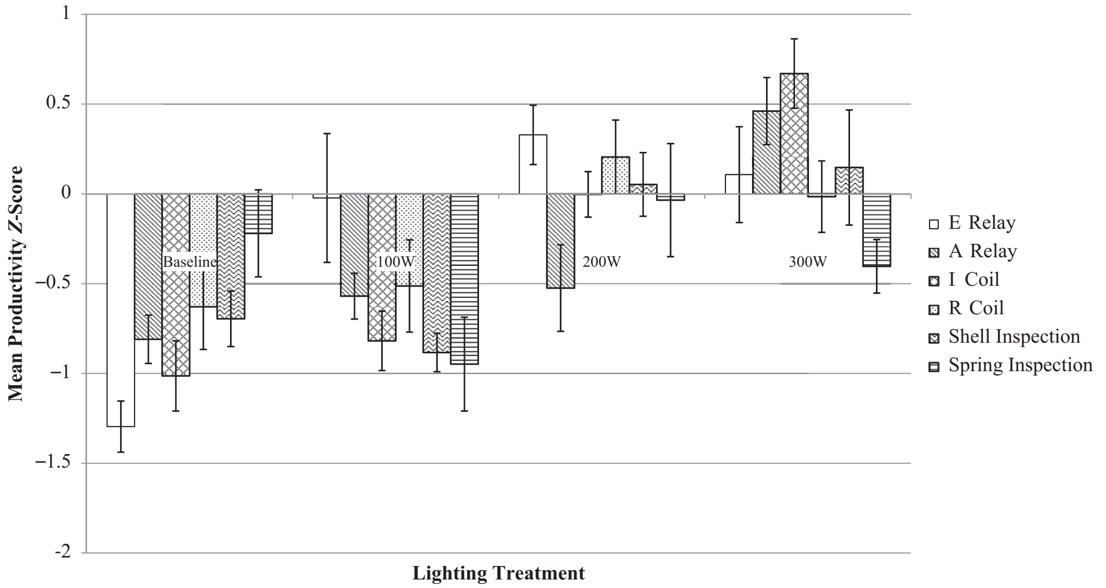

Figure 11. Group Productivity and Lighting Treatments (Time 1).

Results

The analysis showed main effects of repetition ($p < .001$) and month nested within repetition ($p = .010$), and light level ($p < .001$) and an interaction of repetition and light level ($p = .002$). The effects of light level on standardized productivity across all six groups for the first and second treatment sequences are shown in Figures 11 and 12, respectively. To investigate the interaction, the data file was split by repetition, and a mixed-model analysis was repeated for each treatment sequence. For the first series of lighting treatments, there was a significant main effect of light level ($p < .001$) and a significant effect of month ($p = .023$). For every footcandle increase in light level, there was a 0.039 ± 0.009 increase in the productivity Z score. For the second series of lighting treatments, there was no significant effect of month ($p = .062$) or light level ($p = .318$).

Discussion

Snow (1925) originally concluded that there was no effect of light level on productivity for this experiment. Our analysis shows that there was an effect of light level on standardized productivity for the first treatment sequence whereby productivity was higher at the higher light levels. This first treatment sequence ran from November through January when daylight levels would have been at their lowest and day length at its shortest. However, there was also an effect of treatment repetition on productivity, and overall, there was greater productivity during the second treatment sequence, which ran from February through April, when days become longer and daylight levels increase, and in this treatment, light level did not have an effect on productivity. Unfortunately, it is not possible to further disentangle these effects because of the limited data collected and summarized by Snow.

SECOND ILLUMINATION EXPERIMENT

Method

Participants. Female workers from the three departments were the participants. It is not known whether these were the same Polish women from the first experiment, but if they were, the experiment was conducted 1 year later, so carryover effects might be minimal. A total of 64 workers were in one of four groups: induction coil control ($n = 16$), induction coil test ($n = 16$), receiver coil ($n = 11$), and E-type relay assembly ($n = 21$). Three of these groups remained in their same testing room location from the first experiment, but

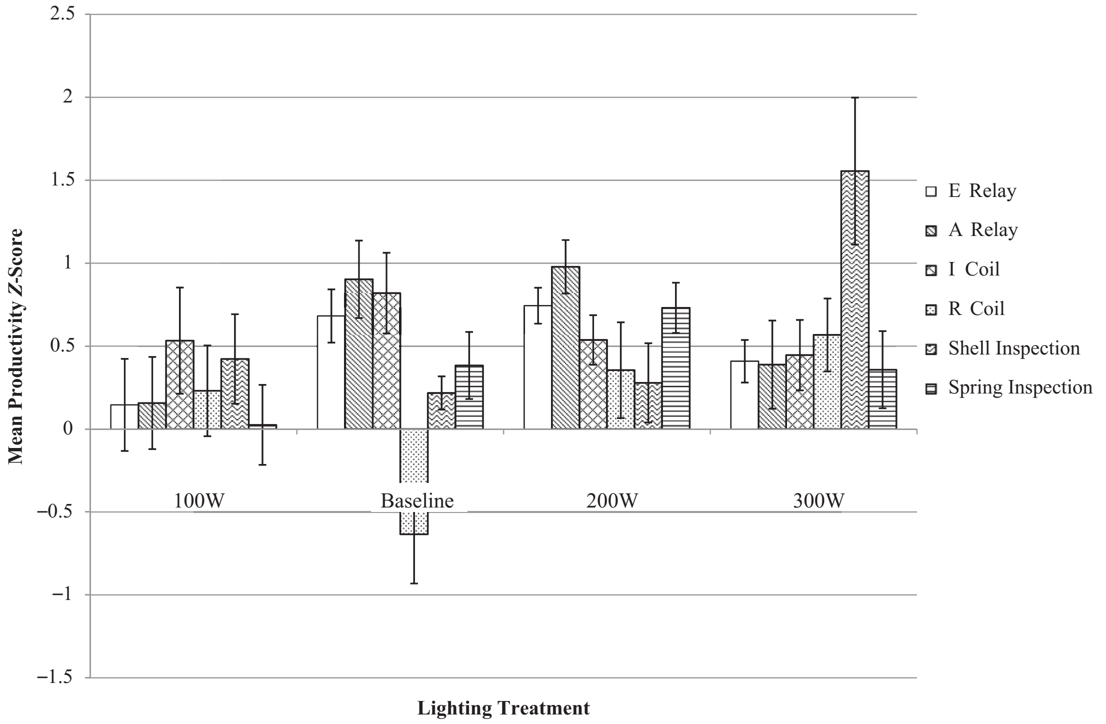

Figure 12. Group Productivity and Lighting Treatments (Time 2).

the induction coil control group was moved to another building because of some concern that intergroup competition with the induction coil test group could influence the productivity results.

Procedure. This experiment lasted from February 15, 1926, to April 24, 1926, and consisted of three different tests, which we denote as 2A, 2B, and 2C. There were three lighting periods for all three tests, but only 2A was a true lighting experiment (2B was a psychological experiment and 2C was a supervisory experiment). Production was recorded five times daily, at 8:30 a.m., 9:30 a.m., 2:00 p.m., 3:00 p.m., and 5:00 p.m., but only the daily group averages were available for analysis.

In Test 2A, which was the main illumination experiment, the induction coil control group continuously worked with the baseline lighting treatment of 150-watt lamps for all three lighting periods, whereas the induction coil test group worked with increasing amounts of light from 150-watt to 200-watt to 300-watt lamps. A summary of the experimental details is presented in Table 3. Workers received the same degree of supervision and demand for output; nevertheless, the two groups were located in different buildings and had different supervisors. Clues as to the ratio of instructors to workers were not found in the records; consequently, the level of supervision is not known.

Data analysis. Three lighting treatments were compared for Test 2A. Only a daily productivity total was available for each group. The data file was split for the three different treatments. An independent-samples *t* test was performed to compare productivity differences between the control and test groups for each period.

Results

No significant differences were found between the productivity levels of the test and control groups for any of the treatment periods: Period 1 ($p = .932$), Period 2 ($p = .772$), and Period 3 ($p = .514$). The productivity data for each group and each period are shown in Figure 13. The absence of individual worker data or actual illuminance measurements at workstations negates

TABLE 3: Lighting Conditions for the Second Experiment

			Total Illuminance in Footcandles (lux)		Productivity (Mean Hourly Coils Wound)	
Period	Date	Lighting Treatment[a]	Control	Test	Control	Test
1	Feb. 15, 1926–Feb. 27, 1926	Existing lighting treatment (150 watts)	15.8 (170)	23.7 (255)	12.1	12.1
2	Mar. 1, 1926–Mar. 27, 1926	200 watts	20.5 (221)	46.3 (498)	13.7	13.8
3	Mar. 29, 1926–Apr. 24, 1926	300 watts	28.1 (302)	67.2 (723)	14.0	14.3

a. The Induction Coil (I. Coil) control group received a constant lighting treatment of the existing 150-watt lamps for all three periods.

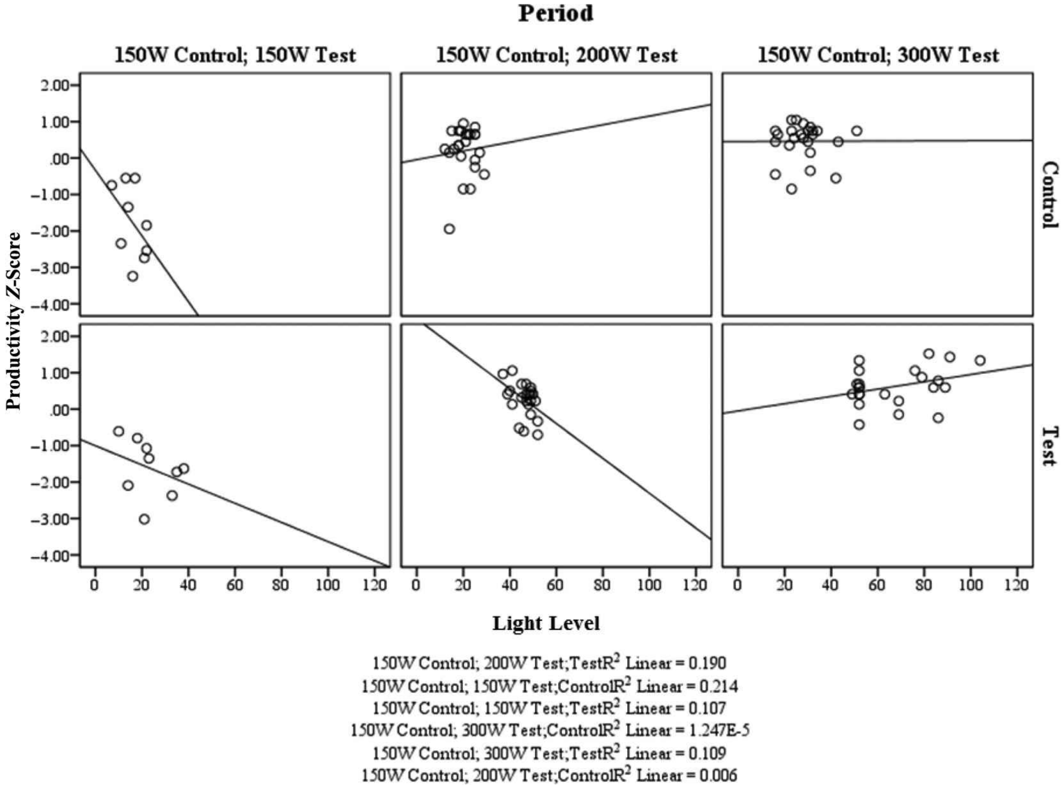

Figure 13. Paneled Scatterplots of Productivity for Control and Test Groups for the Second Experiment.

the application of a more sophisticated multivariate statistical analysis.

Discussion

Snow (1926) stated that overall, the second experiment yielded higher productivity than the first experiment. Yet, he credited this increase in productivity not to changes in lighting but instead to supervision. He explains "that the effect of increased supervision and the psychological factors incident to test conditions are of such magnitude as to completely mask any effect of illumination on production" (Snow, 1926, p. 8). Our analysis confirmed that there was no significant effect of lighting on productivity, but how supervision levels were changed is unknown.

THIRD ILLUMINATION EXPERIMENT

Method

Participants. This experiment was conducted with 32 female workers in the induction coil section of the Coil Winding department, who were split into a test group (n = 16) and a control group (n = 16). It is not known if any of these workers participated in the previous experiments. Workers were matched so as to have an even level of productivity for both groups at the outset.

Procedure. A new experimental design was implemented "to discover the critical point in the illumination intensity" (Snow, 1927a, p. 1). Two identical enclosures were built within a large room, one for the test group and one for the control group. The test group was assigned the east section of the room, and the control group was assigned the west section of the room. Both enclosures featured windows and a saw-toothed glass roof that was covered up pane by pane with paper that was painted either green or white. The enclosures were sealed off with partitions, and any remaining gaps above and below the partitions were covered with burlap. One of these enclosures is depicted in Figure 14. These modifications were made because it was vital for this experiment to test the effect of artificial lighting without the adulteration of daylight.

Workers from the two induction coil groups began working in the built enclosures 5 days prior to the start of the experiment to adjust to their new environment. From September 13, 1926, to April 30, 1927, there were 11 lighting periods in which the control group worked with a constant light level of 11 fc (118.4 lux), whereas the test group worked with decreasing light levels starting from 11 fc. The lighting treatments for the third experiment are shown in Table 4. Productivity again was recorded five times daily, at 8:30 a.m., 9:30 a.m., 2:00 p.m., 3:00 p.m., and 5:00 p.m., but only period averages were available for analysis. During the ninth period, the two groups swapped enclosures. Supervision was increased in the ninth period; however, the instructor-to-worker ratio is not known.

Figure 14. Built Enclosure in the Coil Winding Room. Photograph taken in 1926-27. Photographer unknown. Credit: Charles D. Wrege Collection, History of Management Photographs, Kheel Center, Cornell University.

Data analysis. The average coils wound per hour was the productivity measure. Only the period productivity means for the two groups were available from the records, not the daily means. Differences between the test and control groups for the illuminance levels and productivity were calculated and analyzed with a Pearson correlation and a segmented regression model.

Results

There was a significant negative correlation between the differences of productivity and light level (p = .031), shown in Figure 15.

Discussion

Snow had concluded that there was no apparent effect of light level on coil winding productivity in the third experiment.

> This test in a attempt to find the critical point of illumination . . . has demonstrated that the operatives will maintain their productive output at that level or in the neighborhood of that level which is customary, even in the face of insufficient illumination and the attending discomfort. (Snow, 1927a, pp. 10-11)

However, statistical analysis revealed an unexpected effect, namely, that test group

TABLE 4: Lighting Conditions and Productivity for the Third Experiment

Period	Date	Lighting Treatment		Total Illuminance in Footcandles (Lux)		Productivity in Average Coils per Hour	
		Test	Control	Test	Control	Test	Control
1	Sept. 13, 1926–Oct. 2, 1926	100 watts	100 watts	11 (118)	11 (118)	13.2	12.6
2	Oct. 4, 1926–Oct. 23, 1926	100 watts	100 watts	9 (96.8)	11 (118)	13.4	13
3	Oct. 25, 1926–Nov. 13, 1926	75 watts	100 watts	7 (75.3)	11 (118)	13.3	12.7
4	Nov. 15, 1926–Dec. 4, 1926	75 watts	100 watts	6 (64.5)	11 (118)	13.6	13
5	Dec. 6, 1926–Dec. 24, 1926	60 watts	100 watts	5 (53.8)	11 (118)	13.6	13.1
6	Dec. 27, 1926–Jan. 15, 1927	50 watts	100 watts	4 (43)	11 (118)	13.7	13.1
7A	Jan. 17, 1927–Feb. 7, 1927	40 watts	100 watts	2.7 (29)	11 (118)	14	13.2
7B	Feb. 8, 1927–Feb. 26, 1927	40 watts	100 watts	2.7 (29)	11 (118)	13.8	13.1
8	Feb. 28, 1927	25 watts	100 watts	1.4 (15)	11 (118)	13.4	12.3
9	Mar. 1, 1927–Mar. 19, 1927	100 watts	100 watts	11 (118)	11 (118)	13.7	13.5
10	Mar. 21, 1927–Apr. 9, 1927	100 watts	100 watts	11 (118)	11 (118)	14.1	13.6
11	Apr. 11, 1927–Apr. 30, 1927	50 watts	100 watts	4 (43)	11 (118)	14.1	13.8

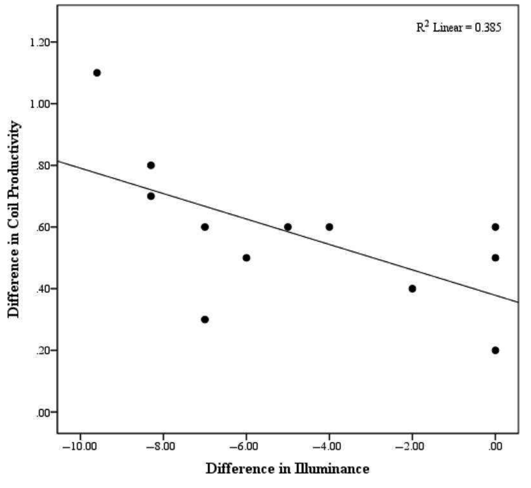

Figure 15. Scatterplot of the Differences in Productivity and Lighting between the Test and Control Groups for the Third Experiment.

productivity was higher as the difference between test and control group light levels was greater (i.e., test group light levels were lower). This experiment investigated only the effects of lowering light levels for the test group on productivity, and there was no repetition of the lighting treatments, so treatment and time were confounded in this design. Perhaps the range of light levels for the test group was not great enough to produce any consistent effect of their productivity, or maybe the manual task could be adequately performed even in low light levels.

GENERAL DISCUSSION

Three illumination experiments were conducted at the Hawthorne Works between 1924 and 1927. The experiments were designed to test whether supplemental artificial lighting would increase the productivity of workers. Contrary to firsthand and secondhand reports of the research, the results of the first experiment initially revealed a statistically significant relationship between the light level and the normalized productivity of workers in the six test groups, such that output increased at the higher light levels after first administration of the treatment. However, this relationship was not confirmed in the second administration of the lighting treatment. An association between lighting and productivity was not found in the second experiment. A negative association between light level and productivity was found in the third experiment. There are several confounding factors and plausible explanations for these inconsistent findings, including the light levels that were administered, the experimental design, data factors, and uncontrolled work-related factors.

Light Level Range

In the first experiment, some evidence of a possible association between lighting and productivity was found for the highest light level in the first treatment sequence although not in the second sequence. In the second and third experiments, the light levels that were tested mostly were lower than in the first experiment. This difference is especially true for the third experiment, in which even the highest light level was quite low and only one fifth of that tested in the first experiment. The first experiment had greater ranges of average light levels, from 2.6 fc (28.0 lux) to 58 fc (624 lux); in the second experiment, the light levels ranged from 15.8 fc (170 lux) to 67.2 fc (723 lux); and the test group in the third experiment experienced light levels ranging from 1.4 fc (15.1 lux) to 11 fc (118.4 lux). By modern standards, many of these light levels are quite low (Illuminating Engineering Society of North America, 2011), and perhaps this is why consistent associations with productivity were not found.

Design of the Experiments

Unfortunately, the design of each of the illumination experiments had several problems. The duration of the lighting treatments was not consistent across the three experiments. Lighting periods lasted anywhere between 1 and 24 days. The lower boundary of the range (1 day) was because of Western Electric Company's influence on the experimental design, and the upper boundary of the range (24 days) was because of the length of time it took to install the different lighting treatments (C. D. Wrege, personal communication, July 28, 2010). Western Electric Company was afraid that a low-light-level condition, such as the 1.4 fc (15 lux) period in the third experiment, would damage employee relations. Therefore, the company allowed this low-light-level condition to last for only a day. Installation of the lighting treatments was time-consuming, which prolonged the duration of the lighting period in some sessions while the lighting treatment for the ensuing lighting period was being prepared. To compare productivity results across experiments, lighting treatment duration ideally should have remained comparable for all three experiments, but this aspect was beyond Snow's control.

Building layout may have also affected the results of the illumination experiments, especially for the first and second experiments. The three departments selected for study were located in different rooms and on different floors. Each of the rooms had varying fenestrations that would have altered the light levels. Also, in the course of the first experiment, modifications were made to the lighting fixtures to reduce glare, which may have altered the light levels between baseline and test conditions.

Although the illumination experiments were concerned with the effect of supplemental artificial lighting on productivity, the first two experiments mixed artificial light with daylight. Additionally, there were anomalous light levels recorded for Periods 2, 3, and 4 in the first experiment whereby the artificial light levels were either very close to the total artificial-plus-daylight levels or, according to some recorded data, they even exceeded these levels (clearly an impossible situation and probably a data entry error). Some anomalies in the light levels can be attributed to the vacillating line voltage, as Hawthorne used its own generator (Snow's log notes, March 9, 1925). Furthermore, it was discovered after careful examination of the photographs that task lighting was available to some of the workers. In Figure 16, desk lamps (Snow referred to them as bench lights) can be seen mounted on the edge of the workstations in the Inspection department. Whether the workers used these desk lamps during any experiment is unknown.

The photographs of the rooms show that there appears to have been a substantial amount of daylight available to perform manual tasks, and even though Snow focused on those workers sitting farthest away from the windows, there could still have been an effect of either daylight or the presence of the window and the ability to see changing outdoor light patterns. It was discovered that from time to time, Snow attempted to control the amount of daylight entering the room during the first experiment. Several entries in his log notes reveal that he "went around to all the departments and fixed the shades to prevent abnormal

Figure 16. Task Lighting Available for Inspection Workers. Photograph taken in 1925. Photographer unknown. Credit: Charles D. Wrege Collection, History of Management Photographs, Kheel Center, Cornell University.

readings" (Snow's log notes, March 3-4, 1925). In the third experiment, he was able to control for daylight by constructing enclosures that blocked any daylight.

Another questionable design element is the abrupt introduction of interventions, including physical interventions and a social intervention. In addition to changes in the light sources, two physical interventions—lighting baffles and hoppers—were introduced during the fourth period in the first experiment. A social intervention, increased supervision, was introduced to the test group during the ninth period in the third experiment. The impact of these abrupt interventions is confounded with the lighting changes. The first experiment occurred across a long period, and an intermittent effect of month was found, but because Snow did not have an adequate control group for the first experiment, month was confounded with lighting treatment.

Data Factors

Although Snow's notes indicate that productivity data was gathered at several times during the day and presumably for individual employees, these original data entries are not contained in the archive. Snow appears to have averaged the productivity data across time and workers. Likewise, original surveyed lighting data were unavailable, and although Snow described that lighting measures were taken at six locations, it is unknown where these measures were within the room and how frequently they were taken for each day. Consequently, the analyses we conducted had to involve daily group averages and a general lighting treatment level, and this limitation substantially reduces the power and possibilities for statistical analysis.

Work-Related Factors

As mentioned in the reasons for the selection of department for the experiments, Snow included the three types of incentive payments operating at the Hawthorne Works. Hourly wages were determined by the difficulty grade of labor, meaning that operations requiring more skill were rated as more difficult and thus, a higher wage was paid (Roethlisberger & Dickson, 1939). Coil Winding was paid on a straight piecework basis. "This method of payment involves a maximum of direct responsibility and individual initiative" (Snow, 1925, p. 3). A gang piece rate basis in which "the efforts of each individual are reflected in the earning of all" was operated in Relay Assembly (Snow, 1925, p. 3). Last, for the Inspection department, the day rate basis was used. From the description that Snow gives for day rate basis, it is unclear as to how workers in this department were actually paid: "The inspection department operatives were paid by a day rate wage, which does not afford a direct incentive for work, although wage increases were based on amount of work output" (Snow, 1925, p. 3).

Using these different incentive payments could have triggered varying worker motivation levels and could have enhanced or detracted from any effects directly related to lighting. The fact that Coil Winding was paid as piecework also may have influenced results if workers continued to produce coils even if they experienced uncomfortable lighting conditions.

Snow stated that all three departments shared in the repetitiveness of work and the considerable use of lighting and the eyes for the work, but the incentive payments indicate that the work between departments was not in fact equal. Certain types of work require different amounts of light to complete the task efficiently. For instance, detailed work, such as visual inspection, requires good lighting for the eyes to discriminate and prevent visual discomfort (Boyce, 2003). It is possible that relay assembly may not have been a visually demanding task but rather was a manual task that relied more on motor memory, just as one can write one's name in the dark, but one cannot read a book in the dark. Interview responses from Hibarger's (1927) special illumination test suggest that Relay Assembly required little use of the eyes and light:

> Q: Do you think you could assemble if you were blindfolded?
> A: Yes, but it wouldn't be nice to have your eyes covered up all the time and you do need to see a little, you can work faster.
> Q: Suppose the lights were turned out altogether, could you do the work then?
> A: Yes, for a little while, but it would get tiresome.

Each of the departments probably required a different amount of lighting to be able to complete their respected task, yet the departments were given the same lighting treatments during the experiments.

The Original Hawthorne Effect

Just as the accounts of the Hawthorne illumination experiments have fluctuated through the years, so has the definition of the "Hawthorne effect." A workplace motivation definition of the Hawthorne effect suggests that worker productivity increases are attributable to the social effects of management's showing an interest in the workers (Murrell, 1976). In psychology, the Hawthorne effect has been defined as the unavoidable consequence that results when participants know that their behavior is being examined (Brannigan, 2004). In our study, we uncovered an excerpt from the first illumination report that describes what we believe to be the original conception of the Hawthorne effect. Snow (1925) writes,

> Another reason for a production increase during the test was the increased supervision incidental to the test. The operatives were very conscious of the fact that they were taking part in a test because the whole matter had been explained to them in a personal talk with the foremen. In addition, they were interviewed once during each lighting period by the foreman or "gang" chief to obtain their comments on the new lighting as has been previously explained. . . . The mere taking of the records more frequently than usual was in itself effectively increased supervision. (p. 66)

In the research literature, the first usage of the term *Hawthorne effect* is unclear. Some attribute the term to Landsberger in his 1958 work, *Hawthorne Revisited*; however, the term does not appear in this publication. Other sources point to Paul Lazarsfeld and his 1941 article, yet again, after a review of Lazarsfeld's article, we found that the term was not used. After some investigation, we believe that the Hawthorne effect was first used by John R. P. French Jr. in 1950 and again in 1953. When talking about the illumination experiments and their findings, French (1950) writes, "The experiments did demonstrate in a dramatic way, however, the importance of social factors in group productivity. From a methodological point of view the most interesting of these findings was what we might call the 'Hawthorne effect'" (p. 82).

From the current discussion, it is clear that although Snow may have never used the term *Hawthorne effect*, he should certainly be credited as being the first to conclude that supervision and the various social interventions that occurred during the first experiment may have played a significant role. Snow's conception embraces both the workplace motivation definition and psychology definition of the Hawthorne effect. Furthermore, the Hawthorne effect should not be interpreted as "proof" that lighting does not affect productivity because of the numerous limitations of the three experiments that have been described.

Contributions, Limitations, and Implications of the Illumination Experiments

One of the main contributions as a result of the Hawthorne illumination experiments was the emphasis that was placed on the relationship between management and workers. Although worker satisfaction was not the focus of the illumination experiments, it was inadvertently introduced by the interviewing of workers, who were asked questions about their working conditions, which in turn revealed the importance of the relationship between management and workers. From this accidental start, the importance of considering the psychological and social aspects within the workplace began to be realized (Adair, 1984).

Another major contribution of the Hawthorne illumination experiments was the insight they provided into the reactivity of human participants in experiments. This insight has had profound implications in the fields of psychology and education, in which the majority of studies are performed in the field rather than in a laboratory setting (Adair, 1984). The series of illumination experiments was an early example in social science research that highlighted the need to consider threats to validity and the role of extraneous variables.

Less often noted is that the illumination experiments were an example of an early cost-benefit study, a pressing contemporary issue concerning the fields of ergonomics and environmental design, because the illumination experiments were set up to determine the costs and benefits of lighting by measuring productivity via workers' incentive earnings. These fields still struggle with converting performance data into monetary figures, and as a result, data on the costs and benefits of ergonomic and environmental design improvements are scarce (Beevis & Slade, 2003).

Although complete details of the illumination experiments have not been published until now, the brief descriptions that were released have been influential in shaping the fields of labor management, experimental design, and workplace research. Emergence of new details of the illumination experiments and our statistical findings reveal numerous experimental design inadequacies, many of which were beyond the researcher's control. The design of the first experiment was compromised by unequal lighting treatment intervals, the use of two different treatment sequences, the introduction of interventions midway in the experiment, and the lack of appropriate control groups. Data on individual performance and lighting conditions at each workstation also were unavailable. Lighting conditions were compromised by technical issues, such as variations in the supply voltage and variations in daylight, and these issues meant that illuminance varied throughout the day and from day to day. Productivity measures varied because different products were being produced at different times on different days. There were also unmeasured variations in levels of supervision between the departments tested.

In the second experiment, a control group was used, and although daily production averages were recorded for each group, there was no record of individual performance levels, and consequently, statistical analysis was restricted. In the third experiment, a control group again was used, and this time extensive measures were taken to build identical enclosures to control for potential physical confounding variables, such as daylight and room size. The number of lighting treatments was extended. The control group received a constant light level of 11 fc (118 lux), but all lighting treatments for the test group were at or below this relatively low level. Again, individual and daily productivity measures have not survived, and only data on average group productivity per treatment were available, which seriously limits the statistical analysis. Strangely, there seems to have been some effect of lighting. This effect is the reverse of that expected; that is, productivity was slightly higher at lower light levels, possibly because of less glare, but the reason is unclear.

Overall, the illumination experiments illustrate the difficulties of trying to conduct field experiments in a factory where the focus was on high-capacity production. When the results for the first experiment did not meet expectations, enthusiasm for subsequent studies began to wane. Ultimately, attempts were made to conceal findings and then to destroy records because they did not provide favorable publicity for the lighting industry. A final report on the illumination experiments was originally set to be submitted to the CIL. The final report was started by Snow and was 80% completed, but it was never finished because of the disappointing findings. Nonetheless, Snow prepared an outline of the final report in which he included recommendations for test procedures for any future work. The recommendations featured methods of payment, supervision, glare, the use of control and test groups, and securing identical work conditions (Snow, 1927b). The outline suggests that Snow was well aware of the experimental design shortcomings previously mentioned.

Eventually, the term *Hawthorne effect* emerged, entered academic folklore, and subsequently, has been used as "proof" that lighting and physical workplace conditions are unimportant when compared with supervision and worker-management relations. For many years after Snow's work, no further studies of lighting and performance were undertaken. However, this simplistic interpretation is unfair, given the serious design limitations of the illumination experiments.

Unfortunately, in Snow's records, the data set is incomplete. In addition to sporadic missing cases, all of the productivity data retrieved were group daily productivity means or group period productivity means. Individual participant data were nowhere to be found within the collection. These problems with the data, together with the experimental designinadequacies discussed, drastically limited our statistical analyses.

CONCLUSION

Statistical analyses of the productivity data from the three illumination experiments conducted at the Hawthorne Works show inconsistent associations between lighting and productivity, but these analyses are limited by data inadequacies and flaws in the experimental designs not previously described. Historical analysis also revealed that accounts of the illumination experiments commonly presented in textbooks and other sources tell an incomplete and sometimes erroneous story. Our findings should serve as a caution against the uncritical use of secondary sources on the illumination experiments and the unquestioning interpretation of what has entered into academic folklore as the Hawthorne effect's proving that lighting has no effect on work performance.

Our analyses of the Hawthorne illumination experiments have shown the value of understanding the historical, organizational, and business context in which this work was undertaken, but a complete discussion of such considerations is beyond our scope, and we refer the interested reader to Wrege's (1986) dissertation.

Finally, we agree with Wrege (personal communication, May 7, 2010) that we have barely scratched the surface of understanding the complexity of the Hawthorne studies, and there remains a treasure trove for future research to be conducted with Collection No. 5167.

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KEY POINTS

- Without any statistical analyses, Snow concluded from visual analysis of vector graphs that there was no effect of lighting on productivity for the three illumination experiments.
- Manuscript draft reports of the illumination experiments were saved by the original researcher Snow, acquired by historian-archivist Wrege, and donated to Cornell University, where they are archived.
- Statistical analyses of the archived data have revealed inconsistent significant effects of lighting on productivity in two of the three illumination experiments.
- A detailed account of the three illumination experiments is presented, which also highlights numerous experimental design inadequacies.
- The historical context for the studies and the origins of the Hawthorne effect are described.

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