EFFECT OF FIVE DIFFERENT LIGHT SOURCES ON MATCHING 25-PAIR TELEPHONE CABLE

by

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ABSTRACT

Background: Analog telephone service is commonly transmitted using 25-pair telephone cable. The fifty copper wires inside the cable are twisted into twenty-five pairs and organized with a color coding system where each pair has its own two-color combination. Although there are twenty-five different two-color combinations, only ten total colors are used, and it may be difficult to distinguish among many of the pairs. The objective of this study is to determine the effects of five different light sources (illuminant C, an incandescent lamp, a fluorescent lamp, a metal halide lamp, and a sodium vapor lamp) on the ability to accurately distinguish among each of the twenty-five pairs of wires. *Methods:* Thirty-three optometry students with normal color vision were tested. Sections of each of the twenty-five pairs of cable were aligned in random order on one side of a poster board and labeled 1-25. On the other side, sections of each pair were aligned in random order and labeled A-Y. Subjects were asked to match each numbered pair of wires with the pair on the other side with the same two-color combination. The test was repeated and timed under each of the five different light sources. *Results:* Subjects made more errors with sodium vapor which was shown to be a statistically significant difference when compared to the other four illuminants. There were also statistically significant differences in the completion times between many of the illuminants. *Conclusions:* The source of illumination affects the ability to accurately and efficiently match pairs of 25-pair telephone cable.

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LIST OF TALBES

Background

Telephone service is commonly transmitted using copper wiring. These wires are twisted into pairs and organized using a color-coding system. With 25-pair telephone cable, there are ten colors that are arranged into twenty-five different two-color combinations. The ten colors used are white, red, black, yellow, violet, blue, orange, green, brown, and slate. Each pair of wires has its own two-color combination. Each individual wire has a main color and a wrap color, and it is twisted with another wire which has the exact opposite main and wrap colors. For example, one wire will have a main color of blue and a wrap color of white. It is twisted with a wire that has a main color of white and a wrap color of blue. This is the only one of the twenty-five pairs that has the blue-white combination. Appendix A shows the color combinations used with 25-pair telephone cable. With twenty-five different two-color combinations, it may be difficult to distinguish among many of the pairs. For example, the blue and white pair may be difficult to distinguish from the blue and yellow pair. When linemen and servicemen are required to distinguish among these twenty-five different color combinations, they will not necessarily have optimal lighting conditions to do so, potentially making the matching process even more difficult.

Two common methods of describing illuminants are color temperature and color rendering index. The color temperature of an illuminant refers to the temperature in Kelvins at which a blackbody radiator would appear the same color. In general, an illuminant with a lower color temperature will appear reddish, while an illuminant with a higher color temperature will appear bluish. The color rendering index refers to how the illuminant affects the appearance of colored objects. The color rendering index is between 1 and 100, with a higher index indicating that the illuminant renders colors more accurately relative to a blackbody radiator or daylight. Two illuminants may have the same color temperature and different color rendering indices. For example, if one light source does not produce as much red light as another, red objects will not appear the same with the two illuminants even if their color temperatures are the same.[1]

The importance of the source of illumination has been demonstrated in color vision. Humans display color constancy, the ability to perceive color as being unchanged in different illuminations.[2] However, studies have shown the importance of the illumination type in color vision testing. Children were more likely to fail the AO-HRR when using an illuminant other than the recommended standard illuminant.[3] Normal and color deficient patients performed differently on various color vision tests when using different sources of illumination.[4,5] Dental students were more accurate at matching shades with a light-correcting device than under natural light.[6]

The objective of this study is to determine the effect of five different light sources (illuminant C, an incandescent lamp, a fluorescent lamp, a metal halide lamp, and a sodium vapor lamp) on the ability to accurately match one section of each of the twenty-five twisted pairs of wires to another section with the same two-color combination. It was predicted that there would be no statistically significant difference between the speed at which matches could be made and no statistically significant difference in the mean number of errors per subject with the five different light sources.

Methods

Five testing stations were arranged. At each testing station, there was a white poster board illuminated with one of the following five light sources: 1) Illuminant C with a color temperature of 6740 and a color rendering index of 100 using the MacBeth Easel Lamp, 2) Incandescent Philips 60-Watt Duramax soft white bulb with a color temperature of 2700 and a color rendering index of 100, 3) Fluorescent Sylvania 13-Watt CFT13WDS/EC/841 with a color temperature of 4100 and a color rendering index of 82, 4) Metal halide GE Mercury 100-Watt HR100DX38/Med with a color temperature of 3900 and a color rendering index of 50, 5) Sodium vapor Philips 50-Watt C50S68/M with a color temperature of 2100 and a color rendering index of 21. These light sources were each calibrated to provide the same illuminance of approximately 28 foot-candles for each poster board. Along the left side of each poster board, five-inch sections of each of the twenty-five twisted pairs of wire from a 25-pair telephone cable were placed approximately one inch apart in random order and labeled "1" through "25". Along the right side of each poster board, five-inch sections of each of the twenty-five twisted pairs of wire were aligned in random order and labeled "A" through "Y". The column of wires on the left and that on the right were separated by a two-inch strip of black construction paper. Appendix B shows a diagram of the layout of the boards.

Thirty-three optometry students with normal color vision and normal ocular health volunteered as test subjects. Each subject was given a numbered recording form (shown in Appendix C) and assigned a random number. Before starting any testing, the subjects recorded their age and gender. They were shown samples of the wiring that would be used in the testing. It was explained that at each station there would be two columns of wires and they were to match the wires on the left to the wires on the right with the same two-color combination by recording the appropriate letter next to the corresponding number. The subjects were informed that they would be timed at each testing station. The subject was then brought to their first testing station and told to begin recording their matches. At this time, the stop-watch was started, and it was stopped when the subject recorded the last letter on their recording form. The time to complete the test was recorded, and the subject was taken to their next testing station.

Results

Appendix D shows the complete data collected regarding the number of correct and incorrect responses and the time to complete each test for each participant and for each light source. Table 1 shows the average number of errors per subject for each light source as well as the average number of seconds per subject to complete each testing session.

Table 1. Average Number of Errors and Average Time per Light Source

Illumination Source	Average Number of Errors	Average Time (sec)
Illuminant C	0.55	153.15
Incandescent	0.36	163.67
Fluorescent	0.27	149.91
Metal Halide	0.52	170.76
Sodium Vapor	2.85	172.67

Using SPSS, a repeated measures within-subjects ANOVA test was performed on both the number of errors per subject and the completion time per subject. In addition to the ANOVA, a pairwise planned contrast was performed. Mauchly's Test of Sphericity, which compares the variance within the light sources, was also calculated. Mauchly's Test of Sphericity was found to be significant ($p<0.001$) with a value of 0.147 for the number of errors per subject and was found to be significant (p=0.002) with a value of 0.417 for the completion time per subject. This means that equal variances between the light sources cannot be assumed. Since equal variances could not be assumed, a Huynh-Feldt correction was employed.

When using the Huynh-Feldt correction to evaluate the repeated measures analysis, a statistically significant difference between the means was observed for the number of errors per subject and for the completion time per subject. Analyzing the number of errors per subject, Table 2 reveals that the Huynh-Feldt test found a statistically significant difference at the alpha = 0.05 level between the light sources (F = 32.662, p < .001) and the number of errors per subject using those light sources.

Table 2. Tests of Within-Subjects Effects -- Errors

Source		df	F	Sig.
Match	Sphericity Assumed	4	32.662	.000
	Greenhouse-Geisser	2.209	32.662	.000
	Huynh-Feldt	2.380	32.662	.000
	Lower-bound	1.000	32.662	.000

Analyzing the completion time per subject (Table 3) reveals that the Huynh-Feldt test did find a statistically significant difference at the alpha = 0.05 level between the light sources (F = 4.604, p < .005) and the completion time per subject when using those different light sources.

Table 3. Tests of Within-Subjects Effects -- Time

Source		df	F	Sig.
TIME	Sphericity Assumed	4	4.604	.002
	Greenhouse-Geisser	2.619	4.604	.007
	Huynh-Feldt	2.874	4.604	.005
	Lower-bound	1.000	4.604	.040

Table 4 reveals there was a statistically significant difference between the mean number of errors per subject when comparing sodium vapor to all other light sources.

Table 4. Comparisons between Light Sources

Pairwise Comparisons				
(I) MATCH	(J) MATCH	Mean Difference (I-J)	Std. Error	Sig.
Illuminant C	Incandescent	.182	.127	.160
	Fluorescent	.273	.205	.194
	Metal Halide	3.030E-02	.220	.891
	Sodium Vapor	-2.303	.355	.000
Incandescent	Illuminant C	-.182	.127	.160
	Fluorescent	9.091E-02	.147	.540
	Metal Halide	-.152	.222	.501
	Sodium Vapor	-2.485	.337	.000
Fluorescent	Illuminant C	-.273	.205	.194
	Incandescent	-9.091E-02	.147	.540
	Metal Halide	-.242	.209	.254
	Sodium Vapor	-2.576	.346	.000
Metal Halide	Illuminant C	-3.030E-02	.220	.891
	Incandescent	.152	.222	.501
	Fluorescent	.242	.209	.254
	Sodium Vapor	-2.333	.384	.000
Sodium Vapor	Illuminant C	2.303	.355	.000
	Incandescent	2.485	.337	.000
	Fluorescent	2.576	.346	.000
	Metal Halide	2.333	.384	.000

Table 5 reveals there was a statistically significant difference between the mean completion time per subject for the combination of illuminant C and metal halide; illuminant C and sodium vapor; incandescent and fluorescent; fluorescent and metal halide; and fluorescent and sodium vapor lights.

Table 5. Comparison of Completion Time

Pairwise Comparisons				
(I) TIME	(J) TIME	Mean Difference (I-J)	Std. Error	Sig.
Illuminant C	Incandescent	-10.515	6.252	.102
	Fluorescent	3.242	5.342	.548
	Metal Halide	-17.606	8.171	.039
	Sodium Vapor	-19.515	6.742	.007
Incandescent	Illuminant C	10.515	6.252	.102
	Fluorescent	13.758	5.828	.025
	Metal Halide	-7.091	6.711	.299
	Sodium Vapor	-9.000	5.794	.130
Fluorescent	Illuminant C	-3.242	5.342	.548
	Incandescent	-13.758	5.828	.025
	Metal Halide	-20.848	8.990	.027
	Sodium Vapor	-22.758	7.385	.004
Metal Halide	Illuminant C	17.606	8.171	.039
	Incandescent	7.091	6.711	.299
	Fluorescent	20.848	8.990	.027
	Sodium Vapor	-1.909	5.083	.710
Sodium Vapor	Illuminant C	19.515	6.742	.007
	Incandescent	9.000	5.794	.130
	Fluorescent	22.758	7.385	.004
	Metal Halide	1.909	5.083	.710

Conclusions

The ability of the volunteers to accurately match 25-pair telephone cable was shown to be affected by the source of illumination used. The number of errors made was significantly increased when using the sodium vapor illuminant when compared to each of the other illuminants that were tested. Furthermore, there were significant differences with many of the illuminants when comparing the amount of time the subjects took to complete each test. The results indicate that the source of illumination is an important factor in the ability of linemen and servicemen to work with 25-pair telephone cable. It has been demonstrated, as previously described, that the source of illumination affects the perception of colors and that certain illuminants must be used in order to accurately test color vision. In the same sense, it may be beneficial for those working with 25-pair cable to use certain illuminants in order to perform their job more efficiently. It is also reasonable to consider that the type of illumination is likely an important factor in the ability to perform many other jobs that require the ability to distinguish among colors. Further studies might investigate whether the type of illuminant does indeed affect the accuracy or speed of other jobs involving color vision.

One limitation of this study was due to the testing method. It was recognized that since subjects were told to match one letter for each number, they would not be likely to record the same letter for more than one number. Although the wires were arranged randomly on each side of each poster board, there may have been two or more pairs in a row that could be easily confused. In this case, a subject would be more likely to continue to search for a different match rather than list the same letter two or three times in a row. On the other hand, if the easily confused pairs were not placed very close to each other, the subject may not have realized that they did indeed record the same letter for two different numbers. Also, we did not record or study the specific color combinations that were more likely to be incorrectly matched. This information may give more insight into how and why the type of illuminant affects the perception of color.

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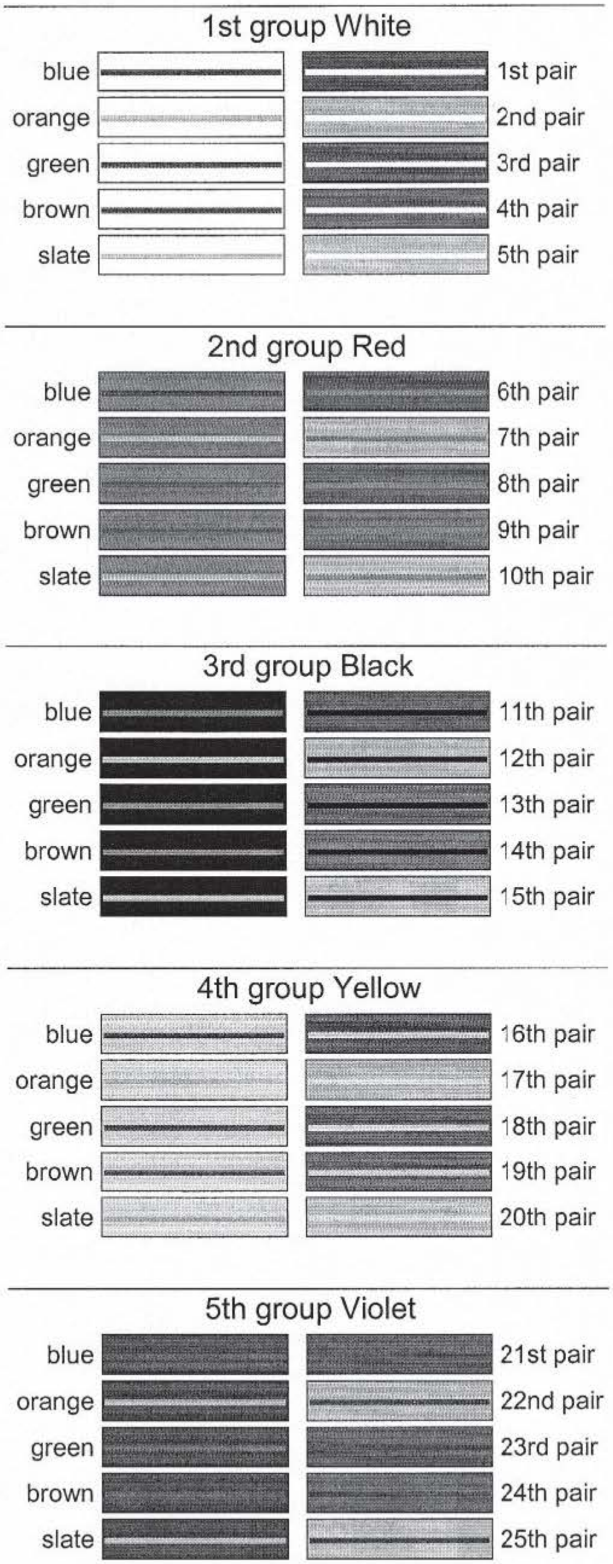
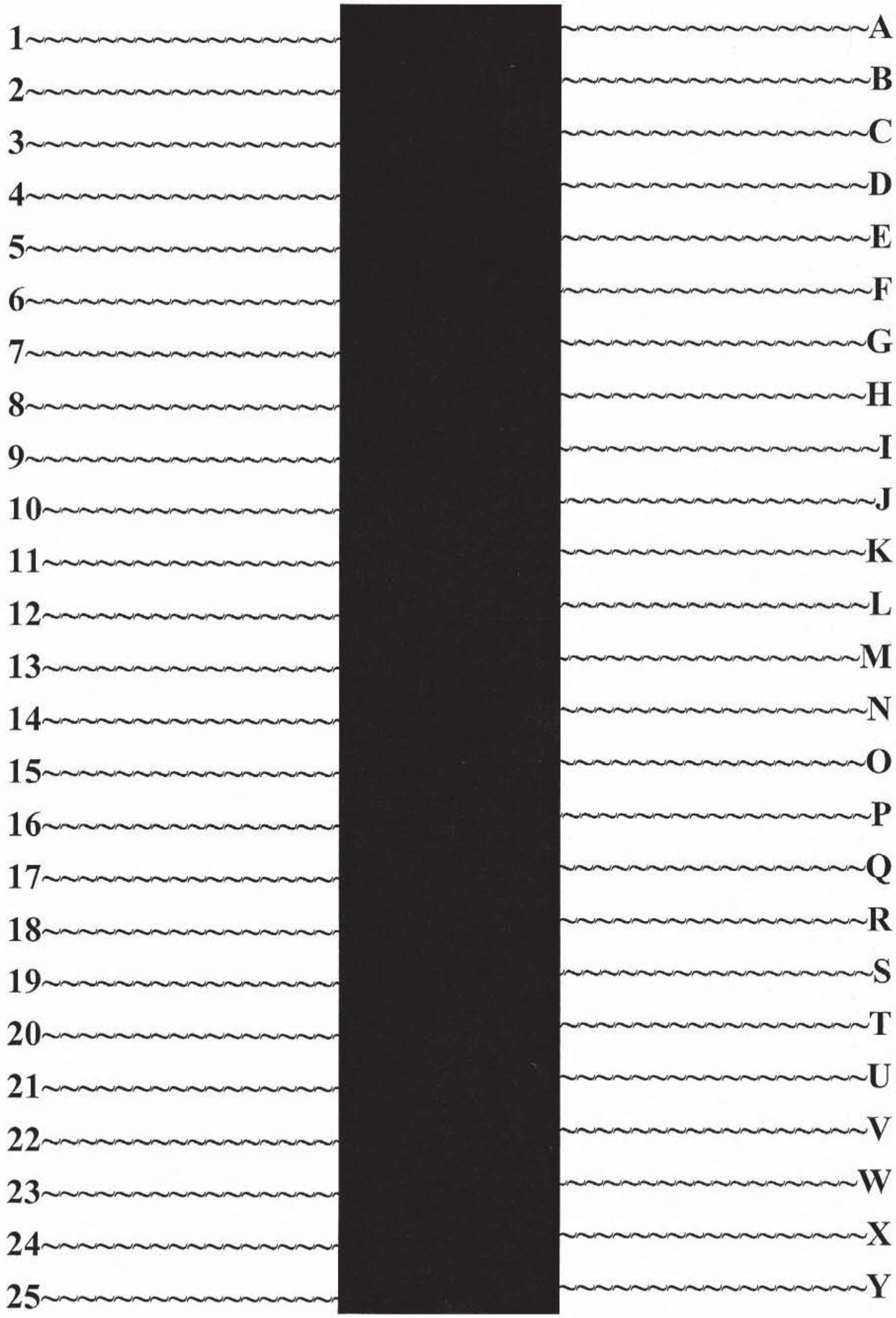
APPENDIX A

COLOR COMBINATIONS IN 25-PAIR TELEPHONE CABLE


1st group White
blue
orange
green
brown
slate
1st pair
2nd pair
3rd pair
4th pair
5th pair
2nd group Red
blue
orange
green
brown
slate
6th pair
7th pair
8th pair
9th pair
10th pair
3rd group Black
blue
orange
green
brown
slate
11th pair
12th pair
13th pair
14th pair
15th pair
4th group Yellow
blue
orange
green
brown
slate
16th pair
17th pair
18th pair
19th pair
20th pair
5th group Violet
blue
orange
green
brown
slate
21st pair
22nd pair
23rd pair
24th pair
25th pair

APPENDIX B

DIAGRAM OF TEST LAYOUT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APPENDIX C

PARTICIPANT RECORDING FORM

AGE:______
GENDER:______

Part One	Part Two	Part Three	Part Four	Part Five
1.______	1.______	1.______	1.______	1.______
2.______	2.______	2.______	2.______	2.______
3.______	3.______	3.______	3.______	3.______
4.______	4.______	4.______	4.______	4.______
5.______	5.______	5.______	5.______	5.______
6.______	6.______	6.______	6.______	6.______
7.______	7.______	7.______	7.______	7.______
8.______	8.______	8.______	8.______	8.______
9.______	9.______	9.______	9.______	9.______
10.______	10.______	10.______	10.______	10.______
11.______	11.______	11.______	11.______	11.______
12.______	12.______	12.______	12.______	12.______
13.______	13.______	13.______	13.______	13.______
14.______	14.______	14.______	14.______	14.______
15.______	15.______	15.______	15.______	15.______
16.______	16.______	16.______	16.______	16.______
17.______	17.______	17.______	17.______	17.______
18.______	18.______	18.______	18.______	18.______
19.______	19.______	19.______	19.______	19.______
20.______	20.______	20.______	20.______	20.______
21.______	21.______	21.______	21.______	21.______
22.______	22.______	22.______	22.______	22.______
23.______	23.______	23.______	23.______	23.______
24.______	24.______	24.______	24.______	24.______
25.______	25.______	25.______	25.______	25.______
TIME____	TIME____	TIME____	TIME____	TIME____

APPENDIX D

NUMBER CORRECT, NUMBER INCORRECT, AND TIMES RECORDED

Sex	Age	Illuminant C			Incandescent			Fluorescent			Metal Halide			Sodium Vapor			Total			Average		
		Correct	Incorr.	Time	Correct	Incorr.	Time	Correct	Incorr.	Time	Correct	Incorr.	Time	Correct	Incorr.	Time	Correct	Incorr.	Time	Correct	Incorr.	Time
M	28	25	0	170	25	0	210	24	1	185	24	1	295	20	5	275	118	7	1135	23.6	1.4	227
F	23	25	0	146	24	1	195	24	1	130	23	2	185	22	3	170	118	7	826	23.6	1.4	165.2
M	26	24	1	150	25	0	180	25	0	151	21	4	167	22	3	175	117	8	823	23.4	1.6	164.6
F	22	25	0	155	24	1	153	25	0	104	25	0	167	23	2	175	122	3	754	24.4	0.6	150.8
M	30	25	0	178	25	0	160	25	0	150	25	0	210	22	3	220	122	3	918	24.4	0.6	183.6
F	23	25	0	131	25	0	153	25	0	160	25	0	145	21	4	160	121	4	749	24.2	0.8	149.8
M	29	25	0	178	25	0	238	25	0	117	25	0	246	21	4	217	121	4	996	24.2	0.8	199.2
F	24	25	0	151	25	0	159	25	0	138	25	0	280	25	0	255	125	0	983	25	0	196.6
F	24	25	0	143	25	0	186	25	0	177	25	0	167	18	7	150	118	7	823	23.6	1.4	164.6
M	26	25	0	140	25	0	170	25	0	160	25	0	140	24	1	190	124	1	800	24.8	0.2	160
F	24	24	1	130	25	0	165	25	0	135	23	2	140	22	3	185	119	6	755	23.8	1.2	151
F	22	25	0	98	25	0	96	25	0	111	24	1	147	24	1	135	123	2	587	24.6	0.4	117.4
F	25	25	0	153	25	0	156	25	0	149	25	0	137	24	1	122	124	1	717	24.8	0.2	143.4
F	23	25	0	98	25	0	140	25	0	116	24	1	120	19	6	126	118	7	600	23.6	1.4	120
F	26	24	1	126	24	1	135	25	0	138	25	0	122	25	0	135	123	2	656	24.6	0.4	131.2
F	26	25	0	130	25	0	163	24	1	144	25	0	210	19	6	137	118	7	784	23.6	1.4	156.8
F	37	21	4	137	23	2	125	24	1	178	23	2	146	20	5	126	111	14	712	22.2	2.8	142.4
M	25	25	0	105	25	0	110	25	0	130	25	0	145	24	1	165	124	1	655	24.8	0.2	131
M	24	24	1	130	25	0	146	24	1	141	25	0	166	23	2	163	121	4	746	24.2	0.8	149.2
F	23	24	1	181	25	0	121	25	0	146	25	0	146	22	3	154	121	4	748	24.2	0.8	149.6
M	39	20	5	161	21	4	163	24	1	142	25	0	123	18	7	160	108	17	749	21.6	3.4	149.8
M	25	25	0	186	25	0	129	25	0	138	25	0	160	24	1	150	124	1	763	24.8	0.2	152.6
M	26	22	3	226	24	1	260	25	0	205	21	4	285	22	3	291	114	11	1267	22.8	2.2	253.4
F	22	24	1	159	25	0	139	25	0	120	25	0	128	24	1	152	123	2	698	24.6	0.4	139.6
F	22	25	0	145	24	1	167	25	0	136	25	0	157	20	5	138	119	6	743	23.8	1.2	148.6
F	21	25	0	120	25	0	170	25	0	179	25	0	136	23	2	141	123	2	746	24.6	0.4	149.2
M	27	25	0	229	25	0	237	25	0	185	25	0	297	24	1	228	124	1	1176	24.8	0.2	235.2
F	22	25	0	235	25	0	140	24	1	190	25	0	120	24	1	164	123	2	849	24.6	0.4	169.8
F	29	25	0	168	24	1	144	25	0	155	25	0	153	23	2	150	122	3	770	24.4	0.6	154
M	25	25	0	149	25	0	132	25	0	138	25	0	124	25	0	115	125	0	658	25	0	131.6
M	28	25	0	179	25	0	237	25	0	234	25	0	175	19	6	203	119	6	1028	23.8	1.2	205.6
F	22	25	0	119	25	0	115	23	2	105	25	0	125	22	3	177	120	5	641	24	1	128.2
F	24	25	0	148	25	0	207	25	0	160	25	0	171	23	2	194	123	2	880	24.6	0.4	176
Total		807	18	5054	813	12	5401	816	9	4947	808	17	5635	731	94	5698	3975	150	26735			
Ave		24.45	0.55	153.15	24.64	0.36	163.67	24.73	0.27	149.91	24.48	0.52	170.76	22.15	2.85	172.67	120.45	4.55	810.15			
Rng	21-39	20-25	0-5	98-235	21-24	0-4	96-260	23-25	0-2	104-234	21-25	0-4	120-297	18-25	0-7	115-291	108-125	0-17	600-1267			