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Tiller, D. K.; Rea, M. S.

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Summary The semantic differential has been used to characterise the psychclogical aspects of lighting. It is unclear whether results from semantic differential scaling can stand alone. Two analyses, one of already published data, the second of new data, suggest that a correlation procedure may form the missing link between semantic differential scaling and more rigorous traditional psychophysical procedures.

Semantic differential scaling: Prospects in lighting research

Dale K Tiller† DPhil and **Mark S Rea‡** PhD
† Institute for Research in Construction, National Research Council Canada, Ottawa, Ontario, K1A 0R6
‡ Lighting Research Center, Rensselaer Polytechnic Institute, Troy, New York, 12180-3590, USA

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1 Introduction

Psychophysics is the measurement of perceived physical characteristics of objects, using well defined behavioral responses from human observers. The aim is often to establish functional relationships between physical parameters and subjective reactions using written or verbal responses. Numerous techniques and procedures fall under the auspices of subjective reactions research. In lighting research, questionnaires (e.g. References 1–3), rating scales (e.g. Reference 4) and magnitude estimation techniques (e.g. Reference 5) have all been used in attempts to relate physical parameters to subjective responses. Of these various techniques, magnitude estimation has been exemplary in establishing predictive functional relationships between physical measures of light and quantitative perceptual effects.

Perhaps because of the success of magnitude estimation many believe that the more qualitative and etheral aspects of the visual environment can also be examined using subjective techniques. Unlike magnitude estimation procedures, however, many subjective reaction protocols do not have a well defined stimulus, nor do they utilise unambiguous responses.

Flynn[(4)] was one of the first to apply Osgood's[(6–10)] semantic differential in lighting research. It has since become the measurement tool of choice for most investigators interested in human responses to the qualitative aspects of the lighted environment (e.g. References 11–24).

The semantic differential consists of a set of bipolar, seven-category rating scales. The ends of each individual rating scale are defined by polar opposite adjectives (e.g. good–bad, large–small, spacious–cramped, hazy–clear etc.). People are asked to rate a variety of environmental attributes using each response scale. These ratings supposedly provide a characterisation of the quality and intensity of attributes along the dimensions rated.

Investigators using this technique have, at least implicitly, assumed that semantic differential scaling represents a typical instance of measurement, as might be exemplified in the measurement of objects using a metre stick. When several people measure the same object, or different objects using a metre stick, their individual measurements of each object will usually agree closely, despite any influence of random and/or systematic error in measurement. This is because each person uses the metre stick to measure the same quality of different objects, namely spatial extent, using the same units of measurement. It is helpful then to define measurement of *any* kind as the assignment of numbers to objects following some rule[(25–27)]. However, there is evidence to suggest that semantic differential scales are not always used consistently in measuring subjective reactions[(10, 28–30)].

One way to test whether different observers have used individual semantic differential scales in a consistent fashion is to examine the patterns of inter-scale correlations. If individual semantic differential scales have been applied consistently by independent groups of subjects rating the same stimulus, or by one group of subjects rating several different stimuli, then patterns of inter-scale correlation should remain relatively stable. In fact, Shaw[(30)] found stimulus-dependent variations in the patterns of inter-scale correlations for the word concepts that he studied. Osgood *et al.*[(10)] confirmed these findings, concluding such stimulus-dependent variations suggested that 'the meanings of scales and their relations to other scales vary considerably with the concept being judged' (Reference 10, p 187). More importantly, the changes in scale meaning identified by these two authors are *not* attributable to any random error or to systematic measurement biases. The scales are simply used in an inconsistent fashion. Therefore, collecting more data will *not*, through averaging, alleviate any problems due to random error. Further, no simple linear transforms will be able to account for systematic measurement biases. Thus, it is difficult to accept, *a priori*, that semantic differential scaling is always a case of orthodox measurement.

In this paper we examine and compare patterns of semantic differential scale inter-correlations in two different sets of data. One set of semantic differential ratings was originally collected by Rea[(31)], who had subjects rate six different task lighting schemes. The second set of semantic differential ratings reflected subjects' impressions of four office spaces that were illuminated with different types of lighting but were otherwise identical. This second set of ratings was collected in order that proper statistical analysis procedures could be applied, which was not possible with Rea's[(31)] data. To our knowledge, this is the first time that such techniques have been applied to semantic differential ratings collected in lighting experiments. The patterns of scale intercorrelations were found to vary across the different lighting schemes in both sets of data. The implications of these findings are discussed, and possible strategies to improve the use of semantic differential scaling for lighting are described.

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2 Study 1

2.1 Procedures

The subjective scaling data used in the analysis were collected by Rea[31] in conjunction with a visual performance experiment. These data were used because they were conveniently available, and were originally collected following procedures similar to those used in other studies on the psychological effects of lighting. The small number of semantic differential scales used by Rea[31] makes it easy to understand the implications of the observations.

Briefly, Rea[31] had subjects perform a numerical verification task, in which they compared two juxtaposed number lists for discrepancies. The list at the subject's left was the reference list, while the list on the right was the response list. The reference list acted as a standard against which the numbers on the response list were compared. The subject's task was to compare the two lists as quickly and accurately as possible, and note discrepancies by placing a mark on the response list.

Six different task lighting schemes produced changes in the contrast of the number lists, which affected task completion times and accuracy. Illumination on the task was provided

Table 1 Task evaluation scale intercorrelations across light settings

Light setting	Attribute scale	Correlation with							
		B–G	D–E	U–P	S–S	T–R	D–B	H–C	F–S
MP90	Bad–Good	1							
	Difficult–Easy	0.75711	1						
	Unpleasant–Pleasant	0.73236	0.78352	1					
	Subduing–Stimulating	0.5857	0.76763	0.92578	1				
	Tiring–Relaxing	0.7429	0.85372	0.94851	0.93714	1			
	Dim–Bright	0.70511	0.62959	0.33534	0.21604	0.37217	1		
	Hazy–Clear	0.6528	0.84444	0.88856	0.95527	0.94686	0.3121	1	
	Frustrating–Satisfying	0.8921	0.63955	0.66208	0.47439	0.62582	0.73493	0.4933	1
MP0	Bad–Good	1							
	Difficult–Easy	0.58298	1						
	Unpleasant–Pleasant	0.54653	0.49945	1					
	Subduing–Stimulating	0.48571	0.37784	0.91898	1				
	Tiring–Relaxing	0.54505	0.54901	0.90275	0.92118	1			
	Dim–Bright	0.74031	0.57625	0.41367	0.35746	0.43061	1		
	Hazy–Clear	0.00000	0.28894	0.24514	0.34929	0.4911	0.10198	1	
	Frustrating–Satisfying	0.58025	0.6469	0.64905	0.50197	0.50493	0.58326	−0.19973	1
PM90	Bad–Good	1							
	Difficult–Easy	0.77298	1						
	Unpleasant–Pleasant	0.81771	0.72644	1					
	Subduing–Stimulating	0.70796	0.58301	0.77983	1				
	Tiring–Relaxing	0.66763	0.5937	0.86732	0.69272	1			
	Dim–Bright	0.77373	0.74126	0.56149	0.3337	0.29422	1		
	Hazy–Clear	0.66203	0.58127	0.77531	0.46646	0.90282	0.40208	1	
	Frustrating–Satisfying	0.9175	0.77635	0.85454	0.68443	0.6535	0.75842	0.6566	1
PM0	Bad–Good	1							
	Difficult–Easy	0.57147	1						
	Unpleasant–Pleasant	0.61637	0.57673	1					
	Subduing–Stimulating	0.45785	0.46263	0.75724	1				
	Tiring–Relaxing	0.55321	0.53074	0.74278	0.87383	1			
	Dim–Bright	0.74474	0.50183	0.40276	0.55097	0.51556	1		
	Hazy–Clear	0.20371	0.42287	0.37361	0.76635	0.65775	0.48149	1	
	Frustrating–Satisfying	0.56305	0.54504	0.60208	0.52105	0.67082	0.63604	0.38067	1
LP90	Bad–Good	1							
	Difficult–Easy	0.80131	1						
	Unpleasant–Pleasant	0.84842	0.82795	1					
	Subduing–Stimulating	0.7156	0.7518	0.87704	1				
	Tiring–Relaxing	0.74385	0.77437	0.9027	0.97367	1			
	Dim–Bright	0.57471	0.44652	0.2891	0.10669	0.10303	1		
	Hazy–Clear	0.72875	0.75818	0.69947	0.75941	0.74159	0.52119	1	
	Frustrating–Satisfying	0.91809	0.76258	0.82929	0.62208	0.65776	0.63679	0.66936	1
LP0	Bad–Good	1							
	Difficult–Easy	0.78154	1						
	Unpleasant–Pleasant	0.83459	0.73577	1					
	Subduing–Stimulating	0.70305	0.57999	0.91697	1				
	Tiring–Relaxing	0.71818	0.65293	0.88741	0.95173	1			
	Dim–Bright	0.62828	0.53311	0.27603	0.1865	0.29938	1		
	Hazy–Clear	0.59433	0.51561	0.74466	0.83393	0.84702	0.16694	1	
	Frustrating–Satisfying	0.84369	0.73621	0.75414	0.6794	0.68819	0.40952	0.71884	1

by a single luminaire (aperture 95 × 95 cm), located above the subjects' task.

The six different lighting schemes were provided by changing the illumination angle or the degree of polarisation of illumination. Two illumination angles were provided by rotating the subject's desk about the centre of the task (0° veiling reflection angle and 90° illumination from the subject's left). Three degrees of vertically polarised illumination were produced by different luminaire diffuser panels (Plexiglass and mylar, PM, approximately 4%; multilayer polariser, MP, approximately 20%; linear dichroic polariser, LP, approximately 100%). The two illumination angles and three degrees of polarisation produced six different lighting schemes. Within each lighting scheme four randomly distributed examples of each type of reference sheet (having text printed with either black matte, black gloss, grey matte, or grey gloss ink) were presented.

Each of six subjects gave semantic differential ratings immediately after completing the number comparison tasks under a particular lighting configuration. Two sets of semantic differential scales were used in the experiment. One set of six 'feeling scales' dealt with how the subject felt during the preceding set of performance trials; the other set of eight 'task evaluation' scales dealt with the subject's overall evaluation of the task and environment during the preceding set of performance trials. All scales had negative valence terms on the left and positive valence terms on the right. Responses to the different scale categories were scored from one to seven; the better the perceived value of the attribute the higher the scale value.

Subjects did the task and scalings over the course of one morning and one afternoon session on two consecutive days. All experimental conditions were presented in a counterbalanced, randomised design. More complete details regarding apparatus, stimuli, observers and experimental protocol are available in Reference 31.

2.2 *Results*

Separate matrices of Pearson product-moment correlation coefficients, more commonly referred to as the sample correlation coefficient, or r[32], were calculated for the task evaluation and feeling scale ratings, at each of the six different lighting schemes, giving 12 correlation matrices in all (six task evaluation scale matrices, and six feeling matrices).

Table 2 Feeling scale intercorrelations across light settings

Light Setting	Attribute scale	Correlation with					
		B–G	T–R	S–A	T–R	U–C	D–S
MP90	Bad–Good	1					
	Tense–Relaxed	0.68501	1				
	Sleepy–Alert	0.85732	0.53694	1			
	Tired–Rested	0.89852	0.66909	0.7546	1		
	Uncomfortable–Comfortable	0.92853	0.62091	0.73648	0.94619	1	
	Discouraged–Satisfied	0.64869	0.64044	0.72638	0.61401	0.56545	1
MP0	Bad–Good	1					
	Tense–Relaxed	0.63813	1				
	Sleepy–Alert	0.90332	0.50124	1			
	Tired–Rested	0.88994	0.68343	0.90605	1		
	Uncomfortable–Comfortable	0.81197	0.67363	0.79724	0.91458	1	
	Discouraged–Satisfied	0.74146	0.54679	0.68695	0.70352	0.56195	1
PM90	Bad–Good	1					
	Tense–Relaxed	0.74234	1				
	Sleepy–Alert	0.83098	0.58433	1			
	Tired–Rested	0.84691	0.55202	0.78536	1		
	Uncomfortable–Comfortable	0.75199	0.6482	0.80693	0.76231	1	
	Discouraged–Satisfied	0.75129	0.82333	0.56177	0.41779	0.57943	1
PM0	Bad–Good	1					
	Tense–Relaxed	0.68897	1				
	Sleepy–Alert	0.82889	0.61386	1			
	Tired–Rested	0.60776	0.51282	0.83961	1		
	Uncomfortable–Comfortable	0.64921	0.55107	0.67407	0.74324	1	
	Discouraged–Satisfied	0.44565	0.64767	0.48453	0.60347	0.56625	1
LP90	Bad–Good	1					
	Tense–Relaxed	0.72681	1				
	Sleepy–Alert	0.90188	0.74227	1			
	Tired–Rested	0.84965	0.68388	0.96516	1		
	Uncomfortable–Comfortable	0.7786	0.72129	0.79401	0.79192	1	
	Discouraged–Satisfied	0.79808	0.77594	0.69568	0.7032	0.78017	1
LP0	Bad–Good	1					
	Tense–Relaxed	0.76838	1				
	Sleepy–Alert	0.79653	0.75692	1			
	Tired–Rested	0.83358	0.78505	0.96493	1		
	Uncomfortable–Comfortable	0.87557	0.70202	0.7989	0.80764	1	
	Discouraged–Satisfied	0.79147	0.76553	0.69381	0.74203	0.75427	1

Table 3 Range of variation in task evaluation scale intercorrelations across six lighting schemes

Attribute scale	Correlation with							
	B–G	D–E	U–P	S–S	T–R	D–B	H–C	F–S
Bad–Good	0.0000							
Difficult–Easy	0.2298	0.0000						
Unpleasant–Pleasant	0.3019	0.3285	0.0000					
Subduing–Stimulating	0.2578	0.3898	0.1685	0.0000				
Tiring–Relaxing	0.1988	0.3230	0.2057	0.2810	0.0000			
Dim–Bright	0.1990	0.2947	0.2855	0.4443	0.4125	0.0000		
Hazy–Clear	0.7287	0.5555	0.6434	0.6060	0.4558	0.4192	0.0000	
Frustrating–Satisfying	0.3550	0.2313	0.2525	0.2100	0.1833	0.3489	0.9186	0.0000

Table 4 Range of variation in feeling scale intercorrelations across six lighting schemes

Attribute scale	Correlation with					
	B–G	T–R	S–A	T–R	U–C	D–S
Bad–Good	0.0000					
Tense–Relaxed	0.1302	0.0000				
Sleepy–Alert	0.1068	0.2557	0.0000			
Tired–Rested	0.2908	0.2722	0.2106	0.0000		
Uncomfortable–Comfortable	0.2793	0.1702	0.1329	0.2030	0.0000	
Discouraged–Satisfied	0.3524	0.2765	0.2418	0.3242	0.2182	0.0000

Tables 1 and 2 show the different task evaluation and feeling scale correlation matrices. For each pair of scales in the different task evaluation and feeling scale matrices, there are six separate correlation coefficients, one at each of the different lighting schemes. Inspection of these tables suggests that the relations between the different scales varied depending on the particular lighting scheme rated. For example, the scores on the *hazy–clear* task evaluation scale correlated 0.84 with scores on the *difficult–easy* scale under the 90° multilayer polariser; rotating the desk to the 0° position under the same diffuser lowered the correlation between these two scales to 0.29. Similarly, scores on the *frustrating–satisfying* task evaluation correlated −0.20 with scores on the *hazy–clear* scale under the multilayer polariser at 0°; the correlation between the same two scales rose to 0.72 under the linear polariser at the same desk orientation. Thus, the strength of relationship between any two task evaluation scales, indicated by the value of r, could vary across the six light settings.

The feeling scale intercorrelations exhibited similar changes. Ratings on the *discouraged–satisfied* scale correlated 0.80 with scores on the *bad–good* scale under the linear polariser at 90°. The correlation between scores on these two scales fell to 0.45 under the plexiglass mylar diffuser at 0°.

The difference between the highest and lowest values of r for each pair of scales across the six different lighting schemes, or range, provides an estimate of the variation in the correlations across the different light settings used in the original experiment. Tables 3 and 4 show the range in correlations across the six lighting schemes, for the task evaluation and feeling scale ratings. Some of the scales showed wide variation, or instability, in their relationships with other scales across the six different lighting schemes.

Nevertheless, not all the scales were equally susceptible to instability, as indicated by fewer and smaller stimulus-

Table 5 Correlations for two different task evaluation scales with all other scales under the different light settings

Attribute scale		Correlation with			
		Dim–Bright		Hazy–Clear	
		90°	0°	90°	0°
Bad–Good	MP†	0.7051	0.7403	0.6528	0.0000
	PM‡	0.7737	0.7447	0.6620	0.2037
	LP§	0.5747	0.6283	0.7288	0.5943
Difficult–Easy	MP	0.6296	0.5763	0.8444	0.2890
	PM	0.7413	0.5018	0.5813	0.4229
	LP	0.4465	0.5331	0.7582	0.5156
Unpleasant–Pleasant	MP	0.3353	0.4137	0.8886	0.2451
	PM	0.5615	0.4028	0.7753	0.3736
	LP	0.2891	0.2760	0.6995	0.7447
Subduing–Stimulating	MP	0.2160	0.3575	0.9953	0.3493
	PM	0.3337	0.5510	0.4665	0.7664
	LP	0.1067	0.1865	0.7594	0.8339
Tiring–Relaxing	MP	0.3722	0.4306	0.9469	0.4911
	PM	0.2942	0.5156	0.9028	0.6578
	LP	0.1030	0.2994	0.7416	0.8470
Dim–Bright	MP	1.000	1.000	0.3121	0.1020
	PM	1.000	1.000	0.4021	0.4815
	LP	1.000	1.000	0.5212	0.1669
Hazy–Clear	MP	0.3121	0.1020	1.000	1.000
	PM	0.4021	0.4815	1.000	1.000
	LP	0.5212	0.1669	1.000	1.000
Frustrated–Satisfied	MP	0.7349	0.5833	0.4933	−0.1997
	PM	0.7584	0.6360	0.6566	0.3807
	LP	0.6368	0.4095	0.6694	0.7188

† MP = Multilayer polariser
‡ PM = Plexiglass mylar
§ LP = Linear polariser

dependent range variations in correlations with other scales. For example, intercorrelations of the *hazy–clear* task evaluation scale with the other seven scales showed larger stimulus-dependent range variations, than intercorrelations of the *dim–bright* task evaluation scale with the other seven scales. Table 5 presents the individual correlations for these two particular scales with all the other scales, under the different lighting schemes. Inspection of this table clarifies the nature of such scale instabilities. Correlations of the stable *dim–bright* scale with other scales are of similar magnitude across the different desk orientations and diffuser combinations. In contrast, correlations of the *hazy–clear* scale with other scales exhibit larger variations in magnitude at the two different desk orientation and diffusing filter combinations. Changes in the desk orientation had a particularly strong effect on correlations of the *hazy–clear* scale with all the other scales.

Although suggestive, these findings remain inconclusive because some scale instability would of course be expected due to simple chance variation alone. Proper statistical analysis procedures are required to establish whether the observed scale instabilities reflect chance variation or more systematic changes in scale intercorrelations. This issue was resolved in the second study.

3 Study 2

3.1 Procedures

Two independent groups of 24 subjects rated the lighting in four offices that were identical in all respects except for the type of lighting illuminating each space.

Each lighting scheme was selected to represent light settings used by John Flynn in his work on the psychological aspects of lighting. Rooms 1 and 3 were illuminated by overhead lighting. Room 2 was illuminated with a combination of overhead and peripheral wall lighting. Room 4 was illuminated with peripheral wall lighting. The luminances and illuminances at selected room surfaces under the respective lighting schemes are presented in Table 6. Details on the furniture and finishes installed in each of the four rooms are presented in Table 7.

Subjects rated their impressions of each room using a series of 30 semantic differential rating scales. The exact instructions and complete rating questionnaire are presented in the Appendix. At the second and subsequent rating sessions, the instructions were not repeated on the cover page of the questionnaire, as it was assumed that subjects could remember the task set for them.

Every subject rated each room once. The order in which rooms were rated was counterbalanced across subjects. At each of the four rating sessions, subjects entered the office, took the seat behind the standard desk facing the office door, and commenced the task.

3.2 Results

Separate matrices of Pearson product–moment correlation coefficients r were calculated from each group of ratings given in each room, giving eight matrices in all (i.e. two independent samples of scale ratings for each room). The

Table 6 Working plane horizontal illuminances and luminances of selected surfaces in four test offices†

Room	E (lux) at desk	Wall orientation	Maximum (cd m^{-2})	Minimum (cd m^{-2})	Mean (cd m^{-2})
1	1000	North	78.1	25.7	50.5
		South	58.4	24.1	41.8
		East	57.9	26.7	45.3
		West	74.1	27	49.6
2	300	North	36.7	20.2	27
		South	34.3	22.3	28.2
		East	46.4	18.8	27.6
		West	48.9	22.6	32.7
3	100	North	2.8	1.1	1.9
		South	6.5	1.6	3.8
		East	6.2	1	3.1
		West	7.1	1.3	3.4
4	100	North	25.8	7.4	11.5
		South	25.5	7	12.4
		East	50.1	7.6	20.8
		West	34.8	7.6	17.5

† Illuminances were measured from the same position on the desk top in each room using a Minolta T-1M Illuminance Meter. Luminances were measured with a Topcon BM-3 Luminance Meter. Fifteen luminance measurements were taken to characterise the North and South Walls, each of which was nominally 12 ft long, with an eight-foot ceiling. Twenty-one luminance measurements were taken to characterise the East and West walls, each of which was nominally 15 ft long with an eight-foot ceiling. The luminance photometer was mounted 49 in above the floor, on a tripod placed against the opposite wall. Each respective luminance measurement was taken by rotating the photometer to a different position in the vertical and azimuth planes.

Table 7 Furniture and interior surfaces finish specifications

Item	Manufacturer	Pattern	Colour	Colour value	Ref. No.	Reflectance
1 Carpet	Stratton Canada	Manchester	Laurel Griege	—	6300/72	0.11
2 Base board 4" high	Johnsonite	—	Silver Grey	—	—	0.36
3 Paint finish for door	Sico Paint	—	—	—	3209-21	0.75
4 Paint finish for door trim	Sico Paint	—	—	—	3209-41	0.442
5 Vinyl wall covering	B F Goodrich Coroseal	Espere	Pearl	—	0824-92	0.58
6 Worksurface laminate	Steelcase	—	Grey	1	2782	0.48
7 Workstation paint trim	Steelcase	—	Grey	2	4654	0.33
8 Desk chair fabric	Steelcase	—	Violet	3	B376	0.19
9 Desk chair outer shell and trim	Steelcase	—	Red	5	6250	0.02
10 Guest chair fabric	Steelcase	Coarsweave	Grey	3	5953	0.12
11 Guest chair outer shell and trim	Steelcase	—	Grey	2	6212	—

stability of response scale intercorrelations was tested by comparing respective intercorrelation pairs in the two independent matrices available for each room, using Edward's (Reference 33 pp 82–84) test for differences between two correlations. If the response scales were applied consistently, then each respective pair in the two independent matrices would be of similar direction and magnitude. On the other hand, if the response scales were applied in an inconsistent fashion by the two different groups of subjects, a large number of statistically significant differences between respective pairs of intercorrelations in the two matrices would be observed.

In fact, more statistically significant differences between respective pairs of intercorrelations in the two matrices for each room emerged than would be expected due to chance variation alone. At an alpha level of 0.05, one would expect 45 of the comparisons in a 30 × 30 matrix to achieve a statistically significant difference by chance alone. In room 1, 106 of the comparisons showed statistically significant differences; in room 2, 160 showed significant differences; 244 of the comparisons were significantly different in room 3; and finally, in room 4, 121 of the comparisons showed significant differences.

This analysis confirms that the scale instabilities observed in the first study reflect more than simple chance variation. Taken together, these results suggest either that semantic differential scaling is not an example of orthodox measurement, or that other factors (e.g. environmental, personal), affected the results. Without further evidence the former explanation is more parsimonious.

4 General discussion

As previously noted, psychophysics is the establishment of a functional relationship between a physically defined stimulus and a behavioral response. Semantic differential scales are a special and ambitious form of psychophysics in that the stimulus is often unknown and the bipolar, often emotive, adjective scales are not necessarily related in any way to the (unspecified) stimulus. Much of what we firmly believe about human phenomena is based upon experiments where specific hypotheses have been tested by careful manipulation of one or more independent variables (stimuli) and measurement and statistical analysis of the dependent variable (responses). Since semantic differential scaling experiments typically do not control the independent variable and do not necessarily isolate the best dependent variables, it is of little surprise then, that the more conservative psychophysicists have had little confidence in the technique or the results (e.g. Reference 29). Nevertheless, there are important questions about the perception of lighted spaces that probably cannot be answered with traditional psychophysical procedures whereby the stimulus and its associated responses have been clearly identified prior to the initiation of the experiment.

Often in a lighted environment the presumed stimulus and its associated evocative response are not well understood. The problem facing experimental psychologists interested in the more ethereal aspects of architectural lighting is resolving the dilemma between a desire to ask meaningful questions about the environment, and the constraints imposed by rigorous psychophysical procedures.

For this paper, the dilemma may be more narrowly defined by the question 'Can semantic differential scales be used to reduce our uncertainty about higher-order human perception of lighted environments?' The answer to this question *may* be 'yes', but the results of the previous analyses underscore the subtle and ambiguous nature of extracting information about human perception using semantic differential scales, as well as the importance of craftsmanship when conducting these experiments. Some of the important considerations for psychologists conducting experiments using semantic differential scales are discussed below.

4.1 Definition of the stimulus

Researchers interested in the qualitative effects of lighting assume that most of the variance in subjective responses is due to changes in the lighting of a space. Obviously, this is more likely if the instructions to the subject, or the experimental context itself, have defined lighting as the environmental aspect under study. The rigorous procedures used in traditional psychophysical methods are particularly effective in establishing an experimental context wherein the independent variable (e.g. light, sound, etc.) is defined as the stimulus to be evaluated. In contrast, investigators studying the qualitative effects of lighting have not always adequately specified the lighting, or some feature of the luminous environment, as the stimulus, likely because the experimenters themselves do not always know what aspect of the visual environment is important. Hence, the possibility that other environmental or psychological variables have influenced subjective ratings seems rather likely.

Many reports (e.g. References 11, 13, 20, 21, 22) do not describe verbatim the instructions given to subjects, so it is impossible to determine whether the semantic differential ratings collected in those studies were likely determined by attributes of the lighting alone, or by additional nonluminous aspects of the environment.

Even when verbatim instructions are provided, investigators have not always accurately specified the lighting as the stimulus (e.g. References 23, 24, 29). For instance, the instructions used by Rea[29] to collect the data analysed in study 1 of this paper, asked subjects to give an 'overall evaluation of the task and environment' (Reference 29 p 122). These instructions invite subjects to consider more than just the light in noting their subjective impressions of a space. Numerous other aspects of the experimental situation could have influenced ratings (e.g. luminaire appearance, colour and texture of interior finishes and furnishings, dress and appearance of experimenters). It is perhaps not surprising then, that Rea[29] found individual differences in response scale use. We do not know what stimuli his subjects were evaluating, whether different subjects were evaluating the same stimulus, or even whether the stimulus being evaluated remained constant for individual subjects. Since we do not know what constituted the stimulus, or stimuli, we cannot be certain that subjects' judgements would not have been more consistent had the stimulus been more accurately defined by the instructions.

The practical importance of adequate specification of the stimulus is highlighted by one other aspect of Rea's[29] findings. He originally believed responses to the *dim–bright* scale would reflect changes in the brightness of the task background and, since illuminance levels did not change, would remain constant throughout the experiment. However, two subjects used this scale to evaluate the experimentally manipulated target brightness (i.e. contrast). These two subjects were evaluating a different stimulus than had been assumed by the investigator. Clearly, it is not sufficient

Table 8 Semantic differential response dimensions as used in papers cited in text

Friendly–Hostile	Pleasant–Unpleasant	Large–Small
Harmony–Discord	Satisfying–Frustrating	Rounded–Angular
Sociable–Unsociable	Relaxed–Tense	Horizontal–Vertical
Clear–Hazy	Bright–Dim	Glare–Nonglare
Distinct–Vague	Focused–Unfocused	Confined–Spacious
Simple–Complex	Uncluttered–Cluttered	Functional–Nonfunctional
Long–Short	Spacious–Cramped	Overhead–Peripheral
Informal–Formal	Wide–Narrow	Real–Fantasy
Public–Private	Warm–Cool	Focused–Diffuse
Visually Warm–Visually Cool	Colorful–Colorless	Strong–Weak
Stimulating–Subduing	Cheerful–Somber	Mysterious–Obvious
Ordinary–Special	Nonspecular–Specular	Commonplace–Special
Uniform–Nonuniform	Frugal–Lavish	Comfortable–Uncomfortable
Stable–Unstable	Unattractive–Attractive	Unattentive–Attentive
Old Fashioned–Modern	Focused–Blurred	Discouraged–Satisfied
Poorly Arranged–Well Arranged	Bored–Alert	Unsatisfying–Satisfying
Uninteresting–Interesting	Sleepy–Alert	Stimulating–Depressing
Open–Closed	Tiring–Relaxing	
Fatigued–Rested	Natural–Unnatural	
Bad–Good	Like–Dislike	
Difficult–Easy	Beautiful–Ugly	
Frustrating–Satisfying	Interesting–Monotonous	
Very Little Effort–Very Great Effort	Faces Clear–Faces Obscure	
No Eye Discomfort–Great Eye Discomfort	Radiant–Dull	

for investigators to assume that subjects will evaluate the intended stimulus when the instructions and/or experimental context do not specifically and precisely define what is to be rated.

Reluctance on the part of the investigator to specify the stimulus in a semantic differential scaling experiment reflects uncertainty as to what in fact constitutes the stimulus under investigation. For traditional psychophysics this is a serious if not fatal problem with the procedure. Certainly the results of the present statistical analyses offer no support for the semantic differential approach since they clearly show that the scales were used inconsistently in the experiment (Tables 3 and 4), implying that the dependent variables (responses) were not unambiguously related to the independent variables (stimulus) under investigation (i.e. lighting geometry).

4.2 Definition of response dimensions

The second limitation with current semantic differential scaling practice involves the words that define the ends of the bipolar rating scales. In order for semantic differential scales to be used consistently by subjects, each response dimension should clearly refer to some salient and scalable aspect of the stimulus (e.g. the *dim–bright* scale refers to luminance, not to sound pressure). This will help ensure that every subject will always use a given scale in the same way to assess the same features of the different stimuli. If scales are used differently by different subjects or by the same subject at different times, the results will be difficult or impossible to interpret. In fact, Osgood showed that scales changed meaning as a result of inadequate definition of the dimension constituting each response scale.

In several studies Osgood deliberately failed to define the salient and scalable aspects of concepts that individual response dimensions referred to. For example, Osgood *et al.*[10] asked subjects to rate the concept BOULDER using a variety of semantic differential scales, including the following: long–short; healthy–sick; sacred–profane; and base–treble. Boulders are not normally considered to vary along any of these dimensions. Nevertheless, people rated boulders along all of them. Osgood argued that such ratings were possible through a metaphorical application of response dimensions to concepts. However, the concept-dependent changes in patterns of inter-scale correlations observed by Osgood suggest that individual subjects used different metaphors differently when evaluating the same concepts or stimulus. This is not orthodox measurement.

Not unexpectedly, similar difficulties exist when the semantic differential has been applied in lighting research. Table 8 shows the different semantic differential response dimensions used in previous studies. Inspection of this table suggests that only a few of the dimensions listed would potentially refer to scalable aspects of the luminous environment: clear–hazy; visually warm–visually cool; no eye discomfort–great eye discomfort; bright–dim; focused–unfocused; colourful–colourless; nonspecular–specular; focused–blurred; and glare–nonglare.

Some of the remaining dimensions do not refer to any obvious features of the luminous environment: friendly–hostile; harmony–discord; frugal–lavish; open–closed; mysterious–obvious; and real–fantasy. Many other dimensions might be metaphorically applied to the luminous environment, but could just as readily be applied to numerous other aspects of any space: informal–formal; public–private; old fashioned–modern; uninteresting–interesting; cheerful–somber; pleasant–unpleasant; bad–good; natural–unnatural; commonplace–special; and functional–nonfunctional. Faced with response dimensions that do not refer to any salient aspects of the luminous environment, subjects in a typical lighting experiment must select some feature of the lighting, themselves, the room, or past experience, that each dimension might apply to and then give a rating. When response scales are applied metaphorically, we cannot expect different judges to apply the same metaphor in evaluating particular light settings, or single response dimensions to evoke similar metaphorical extensions across several different light settings. Nevertheless, metaphorical application of scales to stimuli may not always be problematic. The cross modality matching procedures of psychophysics (e.g. Reference 5 pp 99–133) suggest that metaphorical extensions are legitimate, as long as different subjects use the same metaphor consistently to evaluate stimulus attributes. Here again, however, reduced ambiguity, both in terms of the stimulus and the response is very important.

Traditional psychophysical techniques present subjects with a standard stimulus (referred to as a modulus), that serves as a baseline against which all the stimuli to be judged in the actual experiment are compared[5]. Subjects might be presented with a series of pre-experimental standards, one for each response dimension studied, that would limit the range of stimulus conditions presented during the actual experiment. So, for example, to define the salient and scalable aspect of the visual environment referred to by the response dimension 'visually warm–visually cool', subjects could be placed into a room having fluorescent lamps with a high correlated colour temperature, where it would be explained that the lighting in the room would be rated as 'visually cool'. They would then be escorted into another room, where lamps with a lower correlated colour temperature had been installed, and told that the conditions in this second room would be rated as 'visually warm'. Any intermediate conditions observed during the experiment itself would be rated accordingly, using the range of categories on the response scale. This procedure would be repeated for each of the response dimensions included in any experiment. In this way, an attempt to ensure that different subjects use individual response dimensions consistently to scale the same aspects of different stimuli would have been made. This procedure might also limit range biases, as discussed by Poulton[28].

4.3 *Intercorrelations*

The discussion up to this point has been argued from the position of traditional psychophysics, namely, that the stimulus must be well defined and the response clearly related to that stimulus. As suggested in the first part of this section, however, semantic differential scales may offer some hope for psychologists wanting to extract information about higher-order perceptual events by relaxing the adherence to these traditional psychophysical tenets. If experimental psychologists are hampered in their efforts to understand perception by restricting enquiry to those experiments where the stimulus and response are clearly defined, it seems unlikely that progress can be made in understanding higher-order perceptual events where the stimulus and the response are not precisely known. On the other hand, deliberate or inadvertent ignorance of rigorous experimental control and protocol, which require an understanding of the independent (stimulus) and dependent (response) variables, will only serve to confuse or mislead architects and lighting designers about perceptual phenomena. To break out of this dilemma, intercorrelation analyses like the one conducted in this paper may serve as the missing link between traditional psychophysics and studies of higher-order subjective reactions. To appreciate this point better it is worth discussing the results of this analysis in more detail.

From the intercorrelations in Tables 1 and 2 and the subsequent analyses presented in Tables 3 and 4, it is clear that some scales are used inconsistently. Some of these inconsistencies are apparently reliable. For example, the *hazy–clear* scale is used in a particularly inconsistent fashion. It is not always associated in the same way with, say, the *good–bad* scale. This means, in effect, that a 'clear' stimulus is 'good' sometimes, but not always. There are at least two possible interpretations of these results. The first is that the *hazy–clear* scale was a meaningless and unreliable tool for measuring human subjective reactions because it was used inconsistently. A more interesting alternate interpretation is that the *hazy–clear* scale was, in fact, getting at something different than the other scales when the experimental conditions were assessed by subjects. However, one does not know from this analysis which interpretation is more likely.

Therefore, at least two experiments must be performed in this line of research. The semantic differential scale should serve as a formal 'fishing expedition' for generating hypotheses that can be tested in a more rigorous psychophysical context. In other words, the results of semantic differential scaling experiments are, by themselves, meaningless, but coupled with a series of strategically planned experiments, they can serve as an invaluable first step in developing an understanding of higher-order human reactions to lighted environments. Thus, the intercorrelation analysis may serve as the vital missing link in identifying those scales which subjects have used (consistently) in a peculiar fashion. It also serves to identify those scales which have been used in the same way and thus may help make the experimental procedures more efficient through identification of scale redundancies.

This leads us then, to return to the results of Rea's paper[29] and speculate about the nature of the *hazy–clear* scale with the purpose of developing a hypothesis and proposing a new experiment. In effect, the following is an example of how one might proceed from the results of a semantic differential scaling experiment.

Examination of Table 5 shows that at the 90° desk orientation there was a high correlation between the 'clear' response and the 'good', 'easy', 'pleasant', 'stimulating', 'relaxing', and 'satisfied' responses. At the 0° orientation, however, these correlations were reduced or disappeared. Hence, some important factor other than lighting geometry could have been influencing the subjective responses, because the *hazy–clear* response was not always clearly associated with the other subjective evaluations under this condition. Further detailed examination of the results in Table 5 shows that the correlations between 'clear' responses and 'good', 'easy', 'stimulating', 'relaxing', 'pleasant', and 'satisfied' responses were high when the linear polariser was used at 0°. Since the linear polariser was designed to reduce veiling reflections, as did rotation of the desk to 90°, it may be inferred that the *hazy–clear* response, unlike the other identified responses, did not covary with changes in the amount of veiling reflections. Rather, a different factor influenced responses on this scale. To speculate, then, the targets may remain 'clear' at the 0° desk orientation, irrespective of contrast-reducing veiling reflections. When veiling reflections reduced the contrast of the print under the two other diffusers, the relationships between 'clear' ratings and the other more global responses breaks down. Hence, *hazy–clear* may relate to image quality (which always remains high), while the other, more global responses relate to contrast, or to a combination of many visual factors including contrast and image quality, that were modulated by veiling reflections. To test this hypothesis, a subsequent study should be conducted whereby both contrast and image quality are used as independent variables.

Although an hypothesis can be formulated about the meaning of the *hazy–clear* scale it should be carefully noted that development of this hypothesis hinged upon an assumption about visual responses from other lines of enquiry (i.e., refraction and entoptic scatter). It is still unclear whether there is an answer to our earlier question: 'Can semantic differential scales be used to reduce our uncertainty about higher-order human perception of lighted environments?' Is there really a stimulus for the scale *spacious–confined* as Flynn proposed, or, as Osgood has suggested, are responses of this type simply metaphors for something simpler, like overall brightness? Without an understanding of psychological responses from other lines of enquiry it may be impossible to move beyond semantic differential scales. It is certainly true that without ingenious experiments which may follow from the results of semantic differential scaling experiments, it will be impossible ever to resolve these alternative explanations.

In summary, without serious attempts by future experimental psychologists to perform a series of strategic experiments, little progress will be made in developing an understanding of higher-order, subjective responses. Semantic differential scaling experiments are meaningless by themselves, but *can* serve as the critical first step in developing reasonable hypotheses about proposed higher-order phenomena. Such studies must be followed by rigorous psychophysical experiments where the stimulus and response have been clearly defined.

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Appendix: Semantic differential scaling questionnaire used in Study 2

Lighting Impressions Questionnaire

Name:___________________________

This questionnaire is part of a larger project studying the effect of environmental factors on several kinds of human behavior. Your task today is to rate the moods, feelings and impressions that the lighting in this room creates for you using a series of rating scales.

The ratings are to be done in the following manner. If you would describe the lighting in this room as very good, you would place a check mark on the scale as shown below:

Bad ___:___:___:___:___:___:✓ Good

On the other hand, if you would describe the lighting in this room as very bad, your check mark should be placed as follows:

Bad ✓:___:___:___:___:___:___ Good

Use the intermediate categories of the scale to indicate intermediate judgements. Be sure to read both words at each end of a scale before you decide where to place your check mark. There are no right or wrong answers: we are interested only in your subjective judgement concerning the room's appearance under its present lighting system.

After completing this set of ratings, we will arrange three other times for you to return to rate other styles of room lighting. Three other return appointments will be made before you leave today.

Now please turn the page, and rate your subjective impressions of the lighting in this room using the rating scales provided. Thank you.

Please do not write in this space:

Room No.:_____ Session:_____

Time:_____ Level:_____

Temp:_____

Beautiful	___:___:___:___:___:___:___	Ugly
Hazy	___:___:___:___:___:___:___	Clear
Large	___:___:___:___:___:___:___	Small
Visually Warm	___:___:___:___:___:___:___	Visually Cool
Dislike	___:___:___:___:___:___:___	Like
Simple	___:___:___:___:___:___:___	Complex
Pleasant	___:___:___:___:___:___:___	Unpleasant
Glare	___:___:___:___:___:___:___	Non-glare
Public	___:___:___:___:___:___:___	Private
Confined	___:___:___:___:___:___:___	Spacious
Relaxing	___:___:___:___:___:___:___	Tense
Bright	___:___:___:___:___:___:___	Dim
Stimulating	___:___:___:___:___:___:___	Subduing
Distinct	___:___:___:___:___:___:___	Vague
Satisfying	___:___:___:___:___:___:___	Frustrating
Colorful	___:___:___:___:___:___:___	Colorless
Functional	___:___:___:___:___:___:___	Non-functional
Lively	___:___:___:___:___:___:___	Subdued
Ordinary	___:___:___:___:___:___:___	Special
Cluttered	___:___:___:___:___:___:___	Uncluttered
Stable	___:___:___:___:___:___:___	Unstable
Friendly	___:___:___:___:___:___:___	Hostile
Harmony	___:___:___:___:___:___:___	Discord
Sociable	___:___:___:___:___:___:___	Unsociable
Interesting	___:___:___:___:___:___:___	Monotonous
Focused	___:___:___:___:___:___:___	Unfocused
Radiant	___:___:___:___:___:___:___	Dull
Long	___:___:___:___:___:___:___	Short
Rounded	___:___:___:___:___:___:___	Angular
Informal	___:___:___:___:___:___:___	Formal

Figure A1