LIGHT,
MOOD AND PERFORMANCE
AT SCHOOL:-

TRIPHOSPHOR PHASE #3

For:

The Educational Facility Research Group

DET/DPWS (NSW)

by

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Executive Summary

This report follows the Final Report on 'Light, Mood and Performance at School' of Sept 1999. It is an account of a Triphosphor Phase (#3), and represents an extension to the original work concluded earlier at Seven Hills West Primary School, Sydney.

Results confirm previous Phase #2 findings that students exposed to Full Spectrum Lighting perform significantly better than those in the Control or Standard lighting situations - as measured by the PsychoBiological Assessment Scale (PBAS), developed during the previous phases of the research program. Results also indicate that Triphosphor lamps appear to have similar positive influences to Full Spectrum lighting on mood and performance. This would suggest that the proposed policy of replacing Standard lighting with Triphosphor lighting in schools in NSW could be beneficial in both energy-emission and mood-performance dimensions.

1 Introduction

The Purpose of undertaking a further phase of testing was to evaluate whether the relationship between Full Spectrum Light (FSL) and mood/performance[1] that had emerged in earlier phases of the research program would be verified; and to evaluate the influence, if any, of a third light spectrum (source), *viz:* Triphosphor lamps.

Theoretically, the Triphosphor lamps, with light quality spectrums measured at about **85** CRI[2] as compared to the FSLs @**95** CRI and the Standard lamps @**65** CRI, should be expected to fall between the two in terms of impact on psycho-biological functioning. This is on the assumption that the photo-neuron relationship is linear *ie* the higher the spectrum quality, the better the mood and performance ratings (see Final Report).

The Rationale behind the department's deliberations concerning the installation of Triphosphor lamps in schools, to replace the Standard Department-issue lamps, is due to their relative energy efficiency, in accordance with the State Government's directive to cut back on greenhouse gas emissions. This energy efficiency label would appear to not refer to the lamps drawing less energy, *per se*, but to their higher luminous output per watt of energy consumed.

The fact that the Triphosphors also have a higher quality spectrum than the Standard lamps seems to have been largely incidental to these deliberations (prior to the current research proposal). Nonetheless, being able to demonstrate that Triphosphors are both efficient and of sufficiently high spectral quality to have a beneficial impact on mood and performance, would be a win-win outcome.

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[1] as assessed on the PBAS scale: see Final Report for robustness and reliability measures and Factor Analyses of the scale.

[2] CRI = Colour Rendering Index (100 = perfect daylight-simulation)

Lamp Characteristics

Siemens/Osram lamps were deployed in the experimental classrooms:-

Full Spectrums: (Lumilux de Luxe–Daylight L36W/12–950) CRI 95, CCT 5400K[3]

Triphosphors: (Cool White L36W/21–840) CRI 84, CCT 5000K

Standard Whites used in the Control rooms average CRI 65, CCT 4000K.

Luminous Efficacy

26mm, 36watt Triphosphors produce about 95.8 lumens per watt; 36watt FSLs about 65 lumens per watt, and Standard *40watt* Cool Whites about 70 lumens per watt. Technically, the Triphosphors have a luminous flux of 3450, and FSL of 2350. In reality, *ie* in the exact classroom situations at Seven Hills West, this translates into the following average illumination levels, *at desk height*[4]:-

- Triphosphors = 425 lux; FSLs = 285 lux; and Standards = 258 lux[5]

The Triphosphors thus emit about 40% more than the Standards and about 33% more than the FSLs. Theoretically, if 4 of every 10 Triphosphors in each classroom were removed they should provide about the same illumination/lux

[3]CCT = Correlated Colour Temperature (>5000=cool)

[4] The luminaires are about +/- 2 metres above the desks, and all lamps are turned on

[5] Note: *less* than FSLs (unexpected).

levels as 10 Standards. If 3 of 10 were removed they should be equivalent of the light emitted by 10 FSLs. Possibly this might help resolve the question of how many lamps to remove to effectuate the energy savings required and still provide much the same light levels as at present, under normal circumstances.

Again, the issue of whether Triphosphor light at these lower illumination levels will have the same effect as evidenced in Table 2 is unknown. Some research suggests that light level itself is important to the photon-neuron interrelationship, while other research, including the current work, would suggests that it is the *duration of exposure* and not the level of light that is critical (see Final Report). If the latter is the case, both energy efficiency and relatively high quality spectral light could be provided by the deployment of Triphosphors in schools, albeit that the substantial benefits accruing from the 95 CRI Full Spectrum light cannot be attained.

It is self-evident that if both the Triphosphors and the FSLs consume 36Watts to function, the efficiency potential lies in taking advantage of the higher luminous output of the Triphosphors *ie* unless *less* lamps are deployed in classrooms the energy consumption would remain the same. Neither would technological advances, such as slim-line lamps which are even more energy efficient, necessarily reduce power take-out, unless they are of a lower wattage variety.

Spectrum Peaks

Triphosphor lamps have mercury peaks which are very similar to cool white lamps, at 406 nm, 436 nm and 578 nm; while the Full Spectrum lamps have noticeably lower mercury lines, particularly in the red range. The Triphosphors also blend three narrow band rare phosphors that reproduce the three primary colours of the spectrum, each with a very narrow bandwidth, which causes additional high peaks but which in turn allow a high output of light (Cook, 1998).

In general, according to theory, the closer the temperature of the artificial light to that of daylight (CCT 6500K), the better.

Methodology

Running another testing period presented no difficulty; the same strategy employed during Phase #2 was followed here again (see Final Report). Only the headmaster was aware that the lights had been changed, and that teachers would be asked to complete one assessment for each child in their class on the PBAS scale, at the end of the five-to-six month period. The test period was from January 2000 when school started through to the winter vacation at the end of June. This was again inclusive of the shorter day period, a critical time when diminished daylight increases the likelihood of negative mood and performance symptoms becoming apparent (see Final Report). As in Phase #2, teachers were unaware that the research program was continuing, following the strategy shown previously (and empirically) to be successful. The same twelve experimental classrooms as previously made up the test sample (some 330 students being assessed on this occasion). During the Christmas vacation period, 4 of the 8 classrooms previously lamped with FSL tubes were re-lamped with Triphosphors, 4 remained as FSL, and the 4 control classrooms were retained.

Thus, 3 groups of 4 classrooms were generated. Classroom numbers were as follows:-

Controls	**Triphosphor**	**FSL**
3	11	12
4	19	20
9	23	24
21	37	38

2 Brief Summary: Prior Research using Triphosphor Lamps

Bernecker et al (1991) found differences between the colour characteristics of lamps despite their generic classification as Triphosphors, and subsequent differences in subjective responses to them. CRI varied from 77 to 82, for instance, with the higher rating lamp being more blue in colour, and also appearing to be ‘cooler’ to respondents. Other research has claimed an advantage for Triphosphor lamps in terms of visual clarity. Thornton (cited in Worthey, 1985) found large improvements in visual clarity in experiments at Westinghouse using Triphosphor (prime-colour) lamps; and Worthey focused on 'opponent-colour theory' as an explanation of the

visual clarity: 'lamps which give greater visual clarity are those which better reveal the *red-green* contrasts of objects in a scene'. This increased perceived brightness is due to 'chromatic brightness' and perceived distinctness of the borders formed by the colours of the object (:239). Triphosphors are said to reveal *red-green* contrasts and give colourful scenes greater visual clarity, while cool white colour lamps provide low red-green contrast. This is due to the physiology of the eye. Blue receptors, essential for perception of blue-yellow contrasts, are the least numerous receptors in the retina.

Previous research of the consultant in a commercial building in Sydney, using the same experimental lamps as in this school research, showed that FSL lamps were most beneficial over a range of performance and satisfaction factors. Only in one marginally significant case did the Triphosphors function in a beneficial way - related to having 'experienced less headaches at work' (based on a self-report evaluation). The standard lamps were the least beneficial in all categories tested (Samuels and Ballinger, 1992).

3 Results and Discussion

Multivariate and Univariate Analyses of Variance have been undertaken, as in Phase #2. The critical findings of Phase #3 have been extracted and summarised in Table 2. The aim is to present the conclusive results in one easy to grasp format, and present other *statistically* necessary information (such as standard deviations) elsewhere. Gender differences are also considered (Tables 4 and 5).

Table 1: Multivariate Analysis of Variance: **All PBAS Variables**

Multivariate Tests

	Value	**F**	**Sig.** [6]
Pillai's Trace	.370	4.692	**.000****
Wilks' Lambda	.630	4.692	**.000****
Hotelling's Trace	.586	4.692	**.000****
Roy's Largest Root	.586	4.692	**.000****

[6] Sig. = Analysis of Variance/Statistically Significant Differences
***** = .05 to .01 range ****** = .000 range (**§** = marginally significant *ie* . 05 to .06)

Table 2: LIGHT INDEX:- Performance…by Light Quality & Lamp Type [7, 8, 9]

Variable	**Inattention**	*Sig*	*Means* [10] **Controls**	**Triphosphor**	**FSL**
1	Pre-occupied	.440	2. 52	2.34	2.50
2	Off-task	.030*	2. 55	**2.16**	2.22
3	Restless	.458	2.35	2.13	2.30
4	Distracted	.046*	2.58	**2.14**	2.36
5	Forgetful	.012*	2.40	**1.96**	2.06
6	Short attention span	.027*	2.38	**1.99**	**1.99**
7	Not work independently	.000**	2. 40	1.89	**1.77**
8	Uninterested	.002**	1.99	1.60	**1.54**
	Behaviour Problems				
9	Impatient	.306	1.63	1.58	1.42
10	Impulsive	.339	1.88	1.75	1.61
11	Excitable	.397	1.80	1.63	1.53
12	Disruptive	.087	2.13	1.92	1.74
13	Temper	.000**	1.62	**1.19**	1.23
14	Aggressive, Bossy	.002**	1.65	1.28	**1.26**
15	Mood changes	.009**	1.59	**1.30**	**1.30**
16	Irritable	.008**	1.54	**1.25**	1.26
17	Frustrated	.001**	1.73	1.36	**1.31**
18	Hyperactive	.120	1.73	1.45	1.54
	Anxiety				
19	Fearful	.000**	1.70	1.40	**1.29**
20	Upset easily	.001**	1.66	1.54	**1.37**
21	Routine wanted	.000**	1.67	1.60	**1.25**
22	Distressed	.035*	1.55	1.53	**1.37**
23	Dominated	.001**	1.51	**1.24**	1.31
24	Dependent	.141	1.44	1.30	1.32
	Depression				
25	Low participation	.025*	1.95	1.68	**1.54**
26	Discouraged/negative	.013*	1.74	1.52	**1.44**
27	Low self-esteem	.000**	1.87	1.53	**1.49**
28	Not glad/cheerful	.005**	1.78	1.54	**1.48**
29	Unemotional	.006**	1.70	1.46	**1.38**
30	Low sociability	.001**	1.65	1.41	**1.30**
	S.A.D.				
31	Sleepy/yawns	.028*	1.52	1.41	**1.24**
32	Sleepy after 2pm/lunch	.012*	1.49	1.52	**1.23**
33	Lethargic	.033*	1.51	1.38	**1.25**
34	Fatigued	.068	1.48	1.34	1.25
n=	***av.***		***104***	***113***	***110***

[7] Univariate ANOVA: Significant Differences/All Variables/Means
[8] =All 34 PBAS Variables (35th = Headaches, removed from Table - *see* Discussion & Final Report)
[9] Light Quality = CRI and CCT values, previously defined (*see* Final Report)
Lamp Type = experimental FSL, Tris, and Std fluorescent lighting (*see* 3 x 4 classroom settings)
[10] The lower the Mean, the better the Performance (*see Appendix 1* for Means & Standard Deviations).

Discussion

The MANOVA tests indicate a very highly significant difference when all three groups are considered together on the PBAS variables. Univariate Analysis indicates that the differences are not between the Triphosphors and FSLs, but between them and the Controls.

Univariate Findings

The item 'Headache' was removed from the Tables since it is uncertain that this aspect can be reasonably assessed by outsiders: teachers are unlikely to ask each child when doing their assessments. All other items can be scored without any interaction with the student respondents. Further, it is unlikely that students themselves would accurately recall headache episodes over a 4 to 6 week period prior to the testing, even if asked. This was mooted in the Final report, and has been acted on here.

Means[11]

The Results are derived from teacher assessments of students on the PBAS scale, where 1 = never and 5 = very frequently. Thus, the lower the Mean or average result for each classroom setting the better the mood and performance, as measured on this scale.

In a general sense, whether statistically significant or not, in every case but one, the Control Means are higher than the Triphosphors; while the FSL Means indicate a better performance (*ie* are lower) on every measure when compared with the Controls. This exactly duplicates the previous research (Phase #2) for the FSLs, and is here indicative of a poorer performance of students in low spectral quality conditions, in comparison to those exposed to *both* superior lamp types.

This finding is vital to both theoretical and empirical understandings - *viz*: the beneficial influence of daylight and daylight-simulating fluorescent light.

[11] All Standard Deviations are well within acceptable ranges

Again, in this general and non-statistical sense, the trend evident in the findings also shows that the FSLs Means are lower than those in the Trisphosphor condition on most PBAS mood/performance items, as might be expected. But, certainly, the more relevant finding is that they are not significantly different from each other (see below), hence the 85CRI spectrum can be considered to mimic the 95CRI range (and natural daylight) significantly more than it does the 65CRI range. Thus, the Triphosphors are very similar to the FSLs in impact on mood and performance.

Significant Findings

Of the 21 significant findings, 15 or 60% are at the very highly significant level (.000 range), giving the results an added legitimacy.

The FSL and Triphosphors are not significantly different from each other *ie* their Means are very similar, sometimes even the same; but they *are* significantly different to the Control groups. This means the Triphosphors and FSLs are similar in their effects, both benefiting performance

Where the FSLs and Triphosphors are significantly different from the Controls, 72% of the time it is the FSL groups which have the lower Means; sometimes these indicate important differences, other times there is little between the two experimental lighting conditions. The rationale for why the Triphosphors and FSLs are likely to be similar has been previously elaborated in the Final Report, viz: *light deficiency and the photon-neuron response*.

The most positive impacts of the FSLs appear to be in the Internalised Dimensions (Anxiety, Depression and S.A.D.); while there is equal impact with the Triphosphors in the Externalised Dimensions (Inattention and Behaviour).[12]

The Triphosphors perform *least well* in comparison to the FSLs in Anxiety items such as ‘upset easily’ and ‘distressed’. Here they seem more similar to the Controls, while the FSLs continue to be significantly better than both. Indeed, on all four occasions

[12] although not on the same items

where the *Control and Triphosphor* Means do not differ significantly from each other, but are very similar, the FSL Means continue to be significantly different from both groups (see also Table 3, over). Where this implicates the vital S.A.D. item 'sleepy/after lunch/2pm' it conforms to theoretical expectations, since this is a prominent S.A.D. symptom readily manifested in light deprivation situations (see Final Report).

In conclusion, the general relationships between the Means confirm the hypothesis that the impact of light on mood and performance is linear *ie* any increase in spectral quality towards the daylight spectrum is beneficial. Moreover, from our understanding of the significance of these differences in the Means, it is clear that the Triphosphors are functioning at a similar level to FSL. In other words, as lighting quality increases performance increases on PBAS mood/performance items.

Table 3: Performance…by…Triphosphor and FSL Conditions +

Variable	Inattention	Sig.
1	Pre-occupied	.257
2	Off-task	.973
3	Restless	.417
4	Distracted	.393
5	Forgetful	.724
6	Short attention span	.902
7	Not work independently	.567
8	Uninterested	.789
	Behaviour Problems	
9	Impatient	.277
10	Impulsive	.410
11	Excitable	.707
12	Disruptive	.265
13	Temper	.616
14	Aggressive, Bossy	.958
15	Mood changes	.984
16	Irritable	.991
17	Frustrated	.692
18	Hyperactive	.285
	Anxiety	
19	Fearful	.106
20	Upset easily	.009**
21	Routine wanted	.000**
22	Distressed	.028*
23	Dominated	.913
24	Dependent	.812
	Depression	
25	Low participation	.352
26	Discouraged/negative	.371
27	Low self-esteem	.401
28	Not glad/cheerful	.296
29	Unemotional	.403
30	Low sociability	.155
	S.A.D.	
31	Sleepy/yawns	.091
32	Sleepy after 2pm/lunch	.007**
33	Lethargic	.191
34	Fatigued	.349

+ Univariate ANOVA: Significant Differences - All Variables/Means

Table 3 indicates that there is *little* significant difference between the Triphosphors and FSLs.. The items in which the Triphosphors fail to be differentiated from the Controls and are significantly different from the FSLs are items: 20, 21, 22 and 32.

Gender Differences

Table 4: Gender Differences in FSL Groups +

Variable	Inattention	Sig.	Means: FSL		Std. Dev.	
			M	F	M	F
1	Pre-occupied	.011*	2.76	2.20	1.22	1.22
2	Off-task	.032*	2.47	1.92	1.11	1.23
3	Restless	.028*	2.53	2.02	1.13	1.24
4	Distracted	.085	2.59	2.10		
5	Forgetful	.376	2.19	1.92		
6	Short attention span	.518	1.83	1.88		
7	Not work independently	.390	1.83	1.71		
8	Uninterested	.540	1.57	1.49		
	Behaviour Problems					
9	Impatient	.016*	1.59	1.25	1.03	0.59
10	Impulsive	.136	1.72	1.47		
11	Excitable	.014*	1.71	1.35	1.09	0.77
12	Disruptive	.228	1.83	1.63		
13	Temper	.395	1.17	1.29		
14	Aggressive, Bossy	.646	1.28	1.25		
15	Mood changes	.840	1.31	1.28		
16	Irritable	.964	1.28	1.25		
17	Frustrated	.865	1.29	1.33		
18	Hyperactive	.276	1.60	1.45		
	Anxiety					
19	Fearful	.567	1.29	1.29		
20	Upset easily	.778	1.45	1.29		
21	Routine wanted	.982	1.29	1.22		
22	Distressed	.457	1.40	1.35		
23	Dominated	.541	1.40	1.22		
24	Dependent	.946	1.38	1.27		
	Depression					
25	Low participation	.798	1.59	1.49		
26	Discouraged/negative	.699	1.50	1.49		
27	Low self-esteem	.644	1.59	1.37		
28	Not glad/cheerful	.440	1.59	1.37		
29	Unemotional	.096	1.59	1.35		
30	Low sociability	.056§	1.45	1.14	0.96	0.40
	S.A.D.					
31	Sleepy/yawns	.089	1.33	1.16		
32	Sleepy after 2pm/lunch	.061	1.33	1.14		
33	Lethargic	.106	1.34	1.16		
34	Fatigued	.047*	1.36	1.14	0.77	0.49

+ Univariate ANOVA: Significant Differences - All Variables/Means

Table 5: Gender Differences in Triphosphor Groups [+]

Variable	Inattention	Sig.	Means: Tris		Std. Dev.	
			M	F	M	F
1	Pre-occupied	.052§	2.53	2.14	1.10	1.00
2	Off-task	.026*	2.40	1.91	1.26	1.02
3	Restless	.014*	2.40	1.86	1.24	1.03
4	Distracted	.020*	2.41	1.86	1.32	1.09
5	Forgetful	.045*	2.17	1.73	1.26	0.94
6	Short attention span	.010*	2.28	1.70	1.25	1.01
7	Not work independently	.112	2.07	1.71		
8	Uninterested	.060	1.76	1.43		
	Behaviour Problems					
9	Impatient	.266	1.67	1.48		
10	Impulsive	.016*	2.00	1.50	1.15	0.95
11	Excitable	.057§	1.79	1.46	1.09	0.77
12	Disruptive	.045*	2.12	1.71	1.06	1.09
13	Temper	.325	1.24	1.14		
14	Aggressive, Bossy	.053§	1.41	1.14	0.88	0.52
15	Mood changes	.870	1.31	1.29		
16	Irritable	.972	1.26	1.25		
17	Frustrated	.634	1.40	1.32		
18	Hyperactive	.066	1.59	1.30		
	Anxiety					
19	Fearful	.701	1.43	1.38		
20	Upset easily	.833	1.53	1.55		
21	Routine wanted	.538	1.55	1.64		
22	Distressed	.461	1.59	1.46		
23	Dominated	.090	1.33	1.14		
24	Dependent	.253	1.22	1.38		
	Depression					
25	Low participation	.078	1.90	1.46		
26	Discouraged/negative	.337	1.59	1.45		
27	Low self-esteem	.121	1.64	1.41		
28	Not glad/cheerful	.189	1.64	1.45		
29	Unemotional	.026*	1.62	1.30	0.91	0.60
30	Low sociability	.155	1.52	1.30		
	S.A.D.					
31	Sleepy/yawns	.201	1.50	1.32		
32	Sleepy after 2pm/lunch	.043*	1.67	1.36	0.91	0.67
33	Lethargic	.015*	1.53	1.21	0.82	0.49
34	Fatigued	.032*	1.48	1.20	0.80	0.56

+ Univariate ANOVA: All Variables/Means

Discussion of Tables 4 and 5

It was considered of interest to evaluate any gender difference patterns which might emerge within the FSL and Triphosphor experimental classroom settings. Hypothetically, if light and mood/performance relationships are based on a photon-neuron relationship, a better quality of light should act more or less equally on males or females, young or old, and in any racial/ethnic groups – all things being equal.

Some significant differences have emerged from this research. It appears that they lie mostly in the Externalised dimensions (Inattention and Behaviour) in both the Triphosphor and FSL conditions, and less so in the Internalised dimensions. Possibly this might indicate that light is more generically beneficial in counteracting anxiety, depression and Seasonal Affective Disorder symptoms. Items in which girls did significantly better than boys in *both* lighting conditions are the following:-
1, 2, and 3, 11, and 34 (see Tables above).

Overall, girls performed better than boys on the PBAS items - their Means are lower for virtually every item in both lighting conditions. Generally, however, the gender impact seems more pronounced in the Triphosphor conditions (14 instances of significant differences) compared to the FSLs (with 7 significantly different scores). In no cases are differences very highly significantly different.

In a general sense, this conforms to expectations: where the light spectrum is closest to daylight least differences in performance between genders should be evident. In other words, the best lighting conditions are better for both boys and girls.

4 Conclusion

From the findings from Phase #3, and in the general context of this research, it seems permissible to assume that the installation of high luminosity Triphosphor lighting in schools will be of significant benefit to student mood and performance. Thus, the proposed DET/DPWS light/energy/greenhouse gas emission policy is strongly supported here with pedagogical reasoning: standard lighting is associated with poorer performance, higher quality light with better performance.

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6 Appendix 1: Means and Standard Deviations: Three Groups