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Clinical User Experience Testing of Ambient Lighting for Neonatal Intensive Care

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Abstract: Believed to the first application of its kind in the UK, Philips has installed dynamic and ambient LED lighting in the recently extended Neonatal Intensive Care Unit, (NICU), at St Michael's Hospital, Bristol. The neonatal facility was redeveloped in late 2011 with a new ICU built next to an existing ICU. This provides the opportunity to make comparisons between old and new ICU. In work conducted directly for UK Lighting, Philips Research has conducted a clinical user experience trial to assess nurse's reactions to the two ICUs.

Conclusions: A 3 week user trial of the nurse's experiences, showed significant benefits. Complaints of irritability reduced by 70%, headaches by 63%, eye distress by 56% and sleepiness by 51%. A startling finding is also that the nurses report these complaints getting significantly worse throughout the day in the old ICU, but report almost no change to their condition the new ambient ICU. A further unexpected benefit is the staff relax and talk in quieter voices causing a reduction of noise in the new unit, which can otherwise have a detrimental effect on the baby's development. Staff at the unit are so pleased with the new ambient lighting that they written to tender for it the whole neonatal unit.

Management Summary

This report describes a clinical trial to evaluate the effectiveness of a new neonatal intensive care unit at St Michael's Hospital Bristol, equipped with state-of-the-art ambient lighting system from Philips. Neonatal ICU's are stressful environments where staff perform complex tasks. The trial attempted to evaluate whether some of the symptoms of stress were relieved, leading to fewer medication errors and a positive user experience.

The neonatal facility was redeveloped in late 2011 with a new ICU built next to an existing ICU. The nurses drug preparation areas, which sits between the two rooms was also re-developed with new ambient lighting. It should be noted that are some important differences between the old and new intensive care units. Although they have a similar basic size, the old unit has 8 cots, but the new room has 4 cots. The old room has a standard background lighting system, where the new unit is equipped with a dynamic ambient lighting system with cove lighting that is configurable by the nurses.

Philips research, Cambridge was invited to conduct a clinical trial to investigate the effects of the lighting on the clinical care. Research evaluated the primary objective of the trial was to see if the Philips lighting system was improving the care delivered to premature infants in neonatal intensive care by reducing medication errors over a period of 6 months. This is ongoing work and will be the subject of a follow-up report.

The secondary objective was to conduct a 3 week user trial of the nurse's experiences of using the two rooms on a daily basis. Nurses entered their responses into a questionnaire hosted on a tablet computer with the results relayed in real-time back to our server. 281 responses from 40 different nurses from both rooms show a clear preference towards the new room. Complaints of irritability reduced by 70%, headaches by 63%, eye distress by 56% and sleepiness by 51%. A startling finding is also that the nurses report these complaints getting significantly worse throughout the day in the old ICU, but report almost no change to their condition in the new ambient room. Confidence in the data is supported in the analysis, which shows a strong statistical significance in the results ($p<0.001$). A further unexpected benefit is the staff relax and talk in quieter voices causing a reduction of noise in the new unit, which can otherwise have a detrimental effect on the baby's development. Staff at the unit are so pleased with the new ambient lighting that they written to tender for it the whole neonatal unit.

Thirdly a set of parents were questioned on their reaction to the lighting of the just the new ICU to see if they thought the lighting was a benefit. Their results were broadly positive.

Contents

1. Introduction

This report describes the clinical trial that was created to evaluate the effectiveness of a dynamic lighting system installed in a new neonatal intensive care ward.

Neonatal intensive care units are stressful working environments in which complex tasks are performed. Inadequate lighting conditions can compound the burden of stress, potentially leading to medical errors. Adequate lighting conditions, on the other hand, can be beneficial to both patients and staff, for example, by improving sleep and satisfaction, respectively[1].

Believed to the first application of its kind in the UK, Philips has installed dynamic and ambient LED lighting in the recently extended Neonatal Intensive Care Unit, (NICU), at St Michael's Hospital, Bristol.

An extension to the existing facilities of the neonatal intensive care unit (intensive care room including four cots and new utility area) at St Michael's Hospital in Bristol has been built. The newly built intensive care room is equipped with ambient lighting ('LuxSpace' LED fittings controlled by a 'Dynalite' system and 'Cove QLX') and the utility area with dynamic lighting ('Savio'). The new room sits alongside the existing ICU, where nurses from the unit work in both areas. This provides the opportunity to create a study to make objective comparisons between the two working area.

The overall objective of this work was to:

1. Provide a proof point that lighting can enhance the environment in critical care areas, adult or paediatric (Neonatal intensive care units, Intensive care units, paediatric intensive care units)
2. Provide research based evidence of environmental improvements achieved for staff, relatives and possibly also patients
3. Look at trying to achieve a cost neutral proposal/ small cost against commonly used lighting solutions in new builds.
4. Demonstrate the power and effect of cross business working in this example Healthcare and Lighting.

In terms of the this research study, the overall objective of the proposed study will be to evaluate a Philips lighting system in improving the care delivered to premature infants in neonatal intensive care by reducing medication errors (primary objective) and the burden of stress on staff (secondary objective). Medication errors have been reported to be the most common type of medical error in neonatal intensive care; two common sources of medication errors are incorrect programming of infusion pumps and incorrect dosage of drugs[2].

Clinical data will be ascertained by means of medical records and incident reporting forms provided by St Michaels Hospital. The clinical staff was asked to find an equivalent period in 2011 in terms of pressure on staff and stress to that 6 months after the lighting was installed, this is ongoing work to be reported later.

User experience data was also collected from the nurses using an especially adapted question-

[1] Joseph A. The impact of light on outcomes in healthcare settings. Concord, CA: The Center for Health Design; 2006.

[2] Lerner RB, de Carvalho M, Vieira AA, Lopes JM, Moreira ME. Medication errors in a neonatal intensive care unit. J Pediatr (Rio J) 2008; 84: 166-170.

naire that is hosted on Philips **e-tool** platform (Dell Streak computer tablet). The platform software is a user experience test platform previously developed with the University of Southampton. This software enables a questionnaire to be developed quickly using a web application and hosted to the tablet. Nurses at the hospital use the tablet computer touchscreen to answer specific questions, relating to headache, eye strain and sleepiness during their normal work. The answers were automatically relayed in real-time over the cellular network to Philips host server for collection and analysis. This enabled the Philips support team to check on the progress of the trial as it happened to ensure the data was recorded.

Finally, parents were also asked for their views about the lighting in the new ICU. A separate questionnaire was compiled for the tablet computer that asked if they thought the lighting was comforting and for their views on whether they thought the lighting was beneficial for their baby.

2. Building Modifications to Intensive Care Unit

The Neonatal ICU was extended in 2 ways, firstly the addition of a new ICU and secondly to redevelop the nurses drug preparation area. Both new areas were to be equipped with state-of-the-art Philips ambient lighting system.

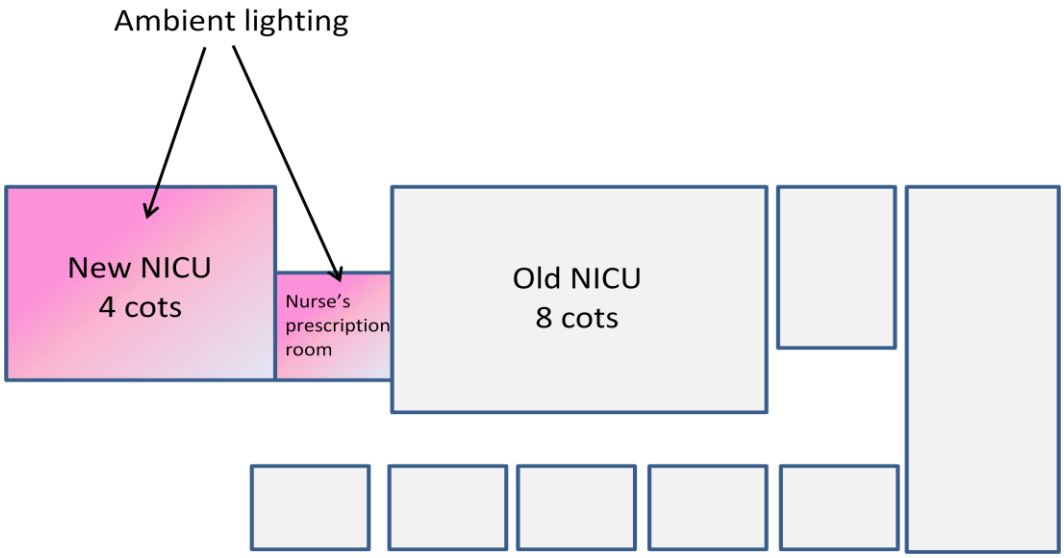

Figure 1 Plan of St Michael's Neonatal unit

2.1. Existing ICU

The existing ICU comprised 8 cots in an area of around 30m^2. It is lit using standard white fluorescent lights mounted on the ceiling.

Figure 2 The old neonatal ICU

2.2. New ICU Unit

The new ICU unit is slightly smaller than the existing ICU as depicted in Figure 1. However, it should be noted that it hosts 4 cots rather than the 8 of the old ICU. The LED lighting in the main unit can be dimmed in a range of colours. When required, the lighting can also be made brighter over each cot when hospital staff are caring for the babies or analyzing data on the patient monitor screens. In the additional clinical areas dynamic lighting can mimics the changing nature of natural daylight.

The design consists of ambient lighting in the patient area and dynamic lighting in the clinical area for drug preparation etc.

The lighting for the new ICU unit was designed by John Pool[3] (*Figure 4*) uses:

- General light: 19 Philips BBS498 1xDLED-4000 Luxspace 3000k down lighters with Dynalite controller.
- Ambient Light: 57 COLOR KINETICS INCOR i-Color Cove MX Powercore Cove QLX with ToBeTouched controller

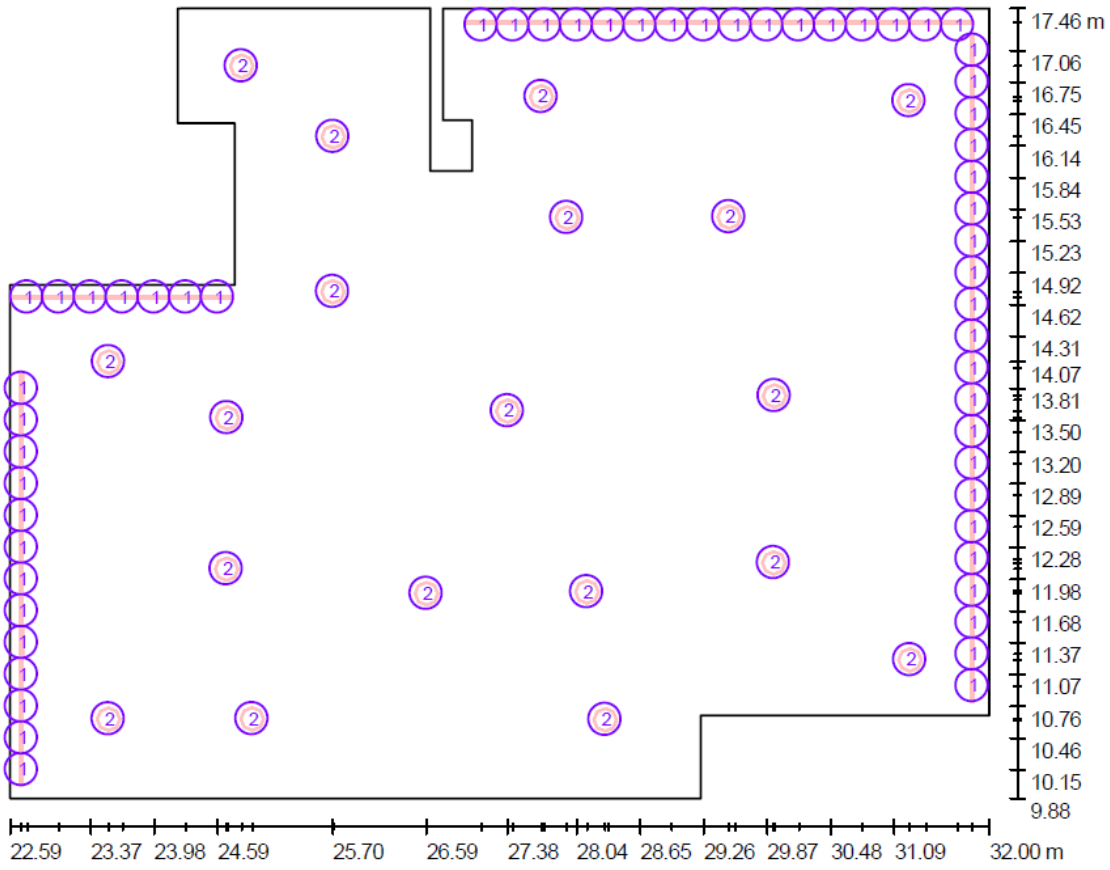

Figure 3 Lighting design for the new neonatal ICU

[3] Pool, J. St Michaels Hospital – Bristol, 8.08.2011

Figure 4 Philips BBS498 downlighter and iColor Cove QLX lights

Figure 5 *the new ICU in operation*

Figure 6 A range of different ambient lighting effects

Figure 7 Nurses drug preparation area

3. Cinical User Trial

The team work 12 hour shifts, days and nights 0730 – 20.00. The staff in the group of 20 work in both the old and new unit on both days and nights. The staff was allocated an anonymous number and be asked to complete the questionnaire 3 times per shift, start, coffee break and before leaving.

It was agreed to also try and look to see if there was a reduction in clinical errors by comparing two time period from 2011 and 2012. The neonatal ICU records the numbers of prescription drug errors and infusion pump errors for each month. This will provide evidence of nurse attentiveness before and after the lighting installation.

3.1. Medication Errors

The frequency and type of medication errors will be analysed for six consecutive months from January 2012 onwards. This will be compared to the frequency and type of medication errors in the six months preceding the completion of the construction work. Premature infants suffering from complex medical problems are more exposed to medical errors during hospital stay[2]. Other potential confounders include gestational age, body weight, nursing personnel on duty, occupancy rate and time of day (day versus night shift).

Two types of medical errors are recorded for analysis:

- Prescription errors
- Infusion pump errors

3.2. User Experience Trial

3.2.1. Data Gathering Mechanism

User experience data was gathered electronically via a Dell Streak Tablet computer that was supplied to St Michaels Hospital prior to the trial. The trial was conducted on a platform developed at Cambridge research for monitoring patients in clinical trials, which was previously developed in collaboration with Southampton University. This platform provided web tools to prepare the questionnaire for upload onto the e-tool and also a host server to collect live data.

The tablet provided two questionnaires: one for the nurses and the other for parents in a simple multiple choice format. On completion of each questionnaire, the tablet sent the data via the cellular network back to the Philips server. This enabled live data collection, enabling the progress of the trial to be monitored. Importantly it also provided feedback to the nurses the data important and being recorded as part of the trial.

Figure 8 the Philips user experience e-tool

3.2.2. Nurse Questionaire

The questionnaire is designed to compare nurse's comfort and attention levels for the new room compared with the old room over the same time period. Nurses from both rooms contributed their answers during the study period. At the start of the trial each nurse was given a unique ID, which they could enter into the questionnaire. This was anonymous to the data gathering process, but ensured that a number of different nurses provided reports to remove individual inconsistencies.

The questions related to:

- Irritability and / or difficulty concentrating
- Headache
- Eye discomfort
- Sleepiness

Questionnaires will be formatted based to meet the requirements of the Karolinska Sleepiness Scale[4] and the Headache and Eye Strain Scale. The scales serve to evaluate whether the ambient lighting (new intensive care room) reduces the burden of stress on staff compared to the standard lighting (old intensive care room).

3.2.3. Parent Questionaire

We also considered it interesting to understand how the baby's parents appreciated the dynamic lighting available within the new ICU. The survey was conducted by asking 12 parents 3 statements about the lighting:

- I feel that the lighting in this room is comforting?
- I appreciate the lighting for my baby's cot?
- Do you appreciate the variable coloured lighting for the cots?

Each parent was asked choose for each statement whether they:

- Strongly agree
- Agree
- Neither agree or disagree
- Disagree
- Strongly disagree

[4] Akerstedt T, Gillberg M. Subjective and objective sleepiness in the active individual. Int J Neurosci 1990; 52: 29-37.

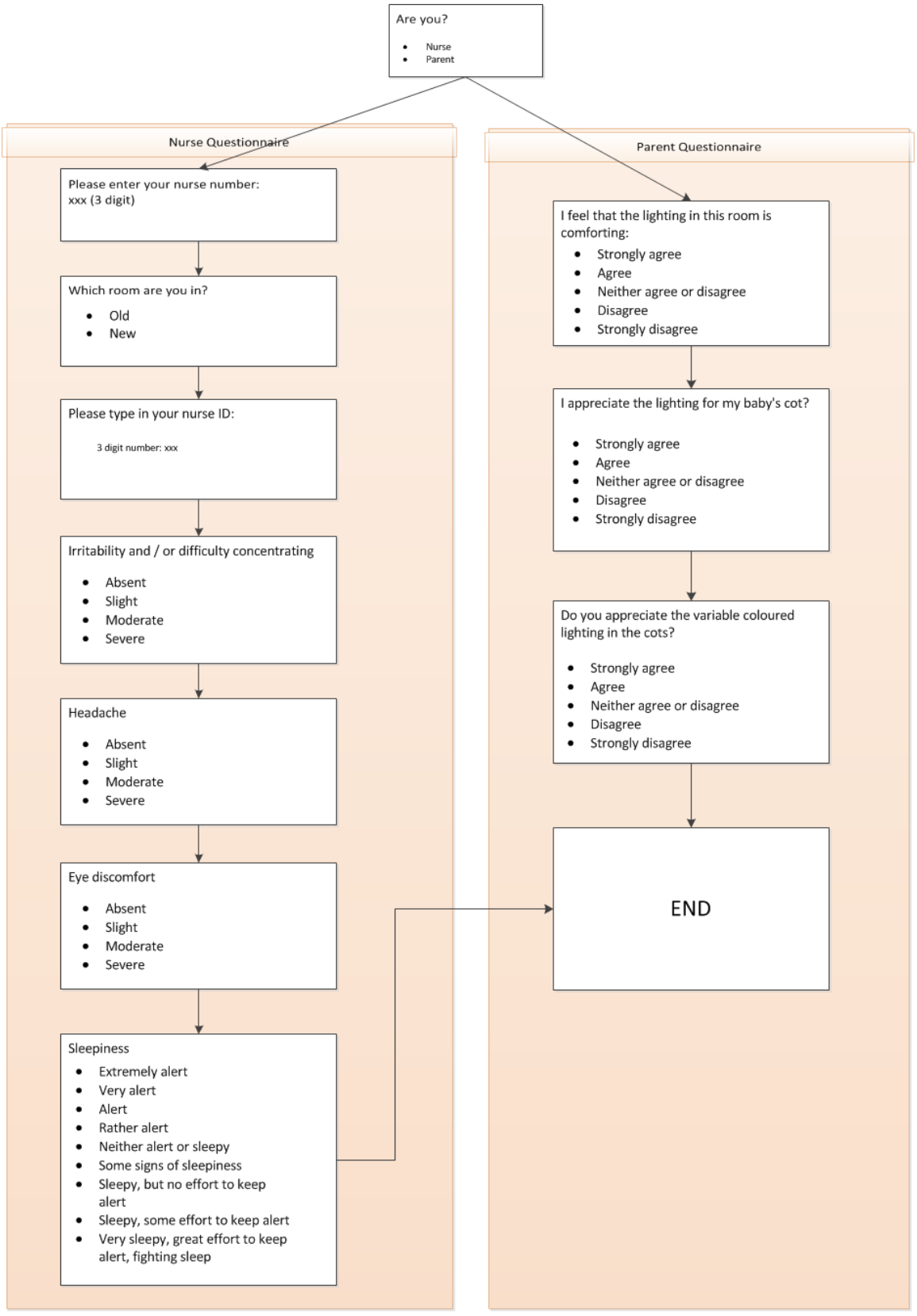

Figure 9 Nurse and parent questionnaire design

4. Trial Results

4.1. Medication Errors

At the time of publication, the medication error data is the subject of on-going work as part of this project. St Michael's is investigating if the trust safety team can set-up a small project to sift through the medical reports to extract the required data. An updated version of this report will be published if suitable data becomes available.

4.2. User Experience Trial

We received 281 responses from 40 different nurses, who had used the e-tool to self-report on sleepiness, headache, eye strain and irritability. The timing information of when the nurse's made their responses is shown in Figure 10.The nurses had been working in either the 'old room' (shown in black) or the 'new room' (red). The first set of questions was answered at 2012-05-24 at 07:54 AM and the last on 2012-06-15 at 11:28 AM. All results were obtained between 7AM and 8PM (hence not during night shifts). Analysis shows clear clustering and periodicity in the data, suggesting the nurses from both rooms have passed the device around during breaks.

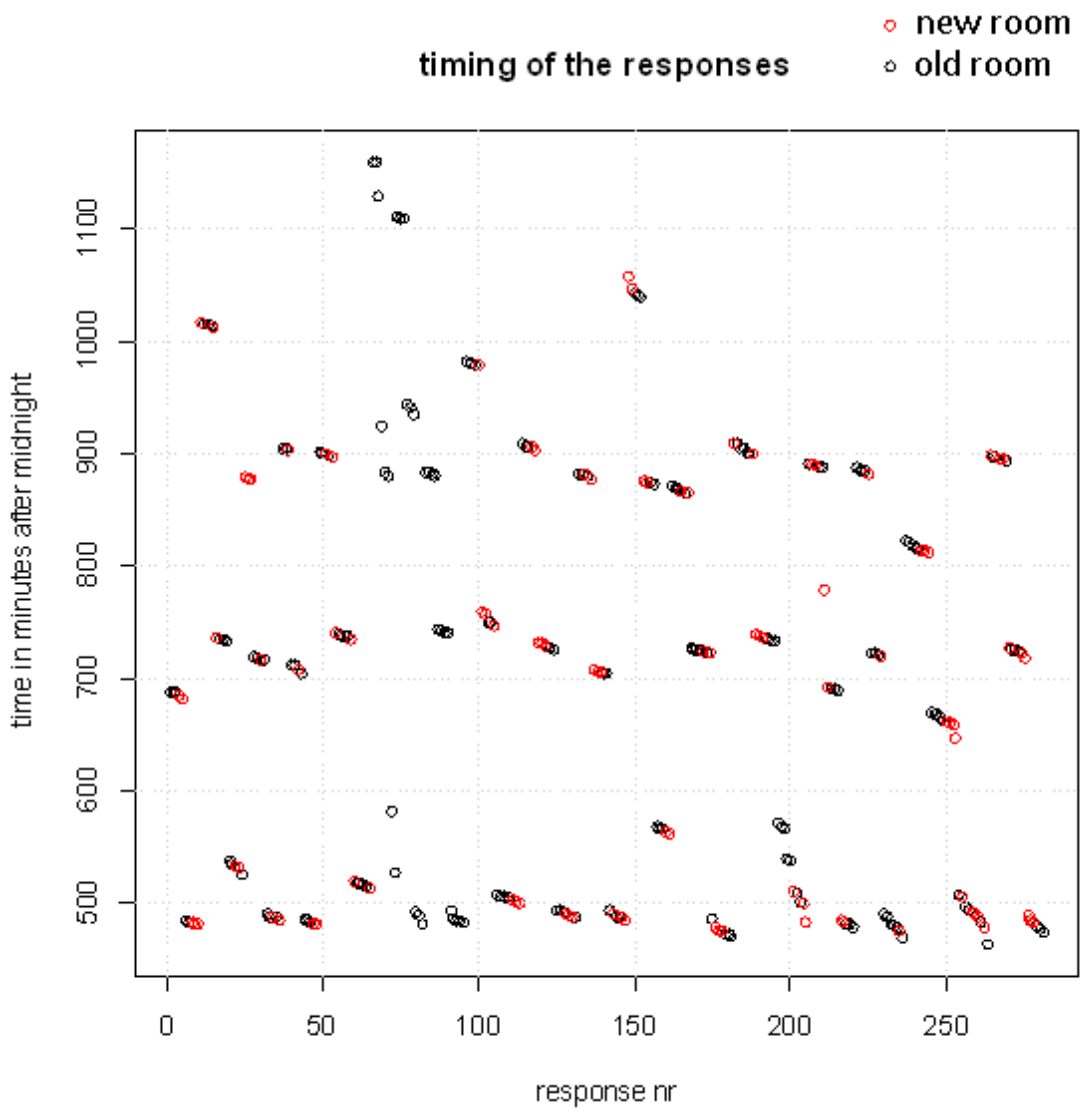

Figure 10 Timing of the nurse's responses

The results for each of the four questions from all nurses together are given in Figure 11. Data in green indicate nurses feeling well. Clearly, nurses feel better working in the new room. Sleepiness was found to be significantly reduced in the new room: 77% reported to feel alert, very alert or extremely alert; this was 54% in the old room. Some degree of headache was reported by 35% of the respondents in the old room, this reduced to 13% in the new room. Some degree of irritability was reported by 40% of the respondents in the old room, this reduced to 12% in the new room.

Some degree of eye distress was reported by 41% of the respondents in the old room, this reduced to 18% in the new room. All effects are statistically significant ($p<0.001$). Results for each of the 40 nurses are shown in the additional material. Many nurses (21) reported about one room only; there are 19 nurses that reported on both rooms.

It is illuminating to focus on the relative reduction in complaints, From the results table below, we see irritability reduced by 70 %, headaches by 63%, eye distress by 56% and sleepiness by 51%.

	IRRITABILITY		reduction complaints
	old.room	new.room	in %
Absent	0.6	0.88	
Slight	0.34	0.12	
Moderate	0.061	0	
sum complaints	0.401	0.12	70
	HEADACHE		
	old.room	new.room	
Absent	0.65	0.87	
Slight	0.29	0.13	
Moderate	0.061	0	
sum complaints	0.351	0.13	63
	EYE DISTRESS		
	old.room	new.room	
Absent	0.59	0.82	
Slight	0.39	0.17	
Moderate	0.022	0.01	
sum complaints	0.412	0.18	56
	SLEEPYNESS		
	old.room	new.room	
Extremely alert	0.0055	0.19	
Very alert	0.18	0.31	
Alert	0.35	0.27	
Rather alert	0.16	0.08	
nor sleepy	0.12	0.09	
Some signs of sleepiness	0.17	0.04	
no effort to keep alert	0.028	0.02	
sum complaints	0.478	0.23	52

Figure 11 Summary of the nurse's responses

We also plotted this data, and calculated the p-value that there would be no difference between the rooms in the nurse's experience. All differences are found highly significant and in favour of the new room, see Figure 12.

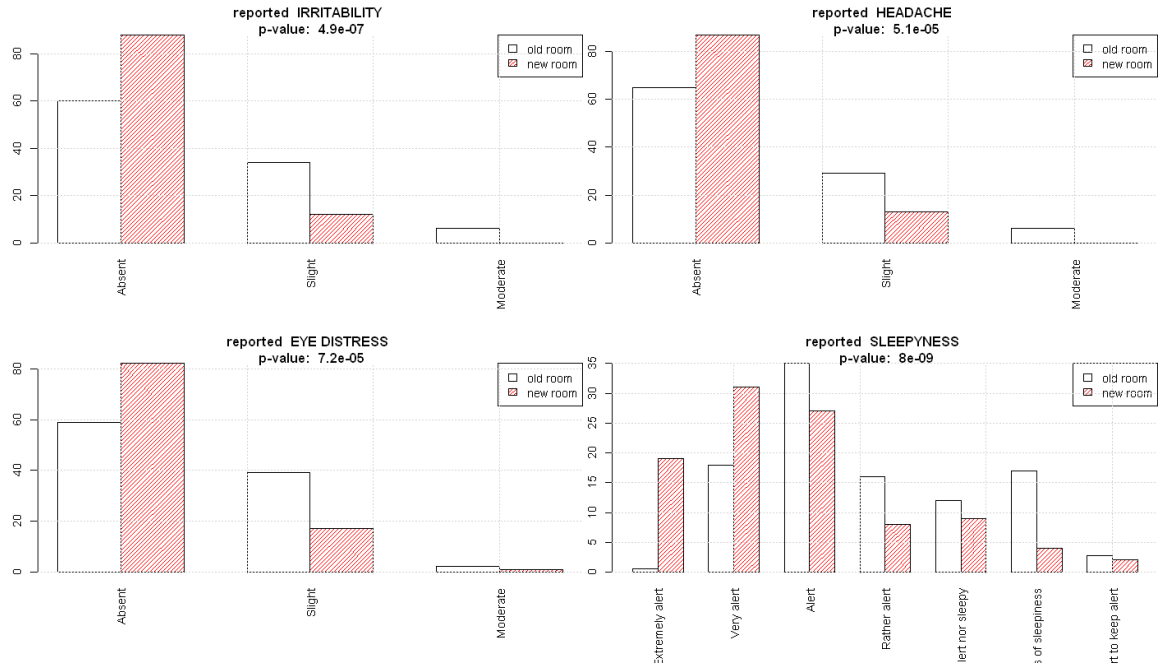

Figure 12 Graphical representation of the nurse's responses

Another somewhat more global way of looking at the data is to introduce a scoring mechanism for the answers. We will use here the QLQ-C30 system, which maps the answers on a linear scale from 0 to 100%. Such scaling is commonly done to process e.g. quality of life questionnaires. Applying this system, the average symptom scores for the old and the new room compare as shown in Figure 13.

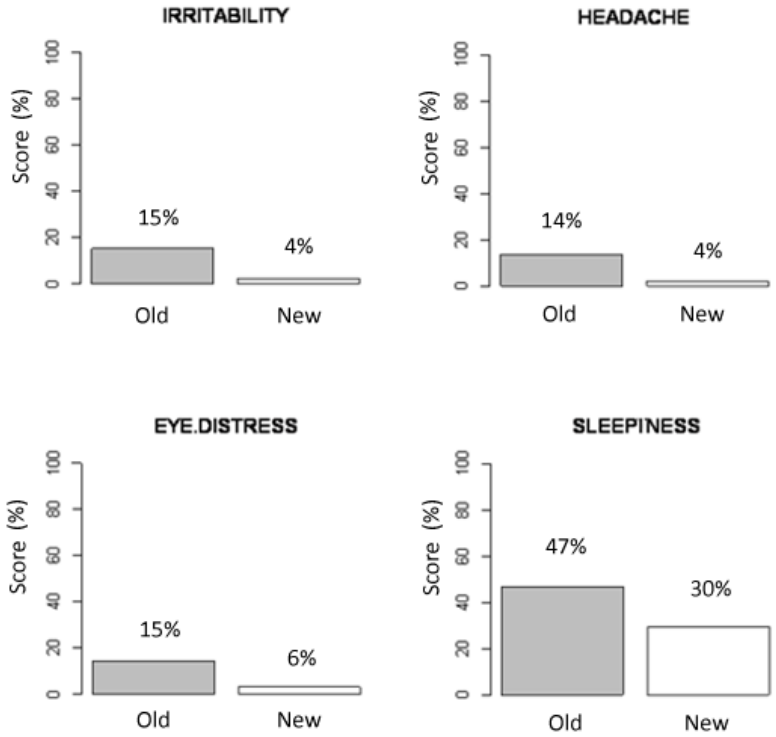

Figure 13 Nurse's results scored using QLQ-C30 system

So using these scores, sleepiness decreases from 47 to 30%, a relative reduction of (17/47)*100% = 36%, headache is reduced by (10/14)*100% = 71%, eye distress by 60% and irritability by 73%.

The various symptoms reported are not independent, but show correlations from 0.30 up to 0.48 for the correlation between headache and irritability, see the correlation matrix in Figure 14.

	room	IRRITABILITY	HEADACHE	EYE.DISTRESS	SLEEPINESS	hours
room	1.00	-0.30	-0.25	-0.23	-0.32	-0.07
IRRITABILITY	-0.30	1.00	0.48	0.41	0.34	0.15
HEADACHE	-0.25	0.48	1.00	0.41	0.30	0.27
EYE.DISTRESS	-0.23	0.41	0.41	1.00	0.32	0.20
SLEEPYNESS	-0.32	0.34	0.30	0.32	1.00	0.05
hours	-0.07	0.15	0.27	0.20	0.05	1.00

Figure 14 Correlation matrix

The negative correlation between room and all 4 symptoms reflects the influence of the new room on the symptoms as discussed. There is also a relation between the time of the day (in hours) and some of the symptoms, but as we have seen, no relation between the recording time and workplace (old or new room). We also see that the several symptoms are partially correlated, especially headache, irritability and eye distress.

We investigated the time dependence of the 4 symptoms for the two rooms separately and found a startling behaviour, see Figure 15. In the old room, the reported symptom scores increase with time. The red lines are the best linear fit, but may underestimate the nurses' complaints at the end of the shift, especially for sleepiness and headache.

By contrast, in the new room, the scores are not only lower, but also stay constant over time, with the exception of eye distress, which increases slightly towards the end of the shift. This is an important finding of the study. The nurse's report a steady worsening of irritability, headache, eye distress and sleepiness throughout the day in the old room. However, not only does the new room provide fewer complaints, their conditions do not get worse throughout the day.

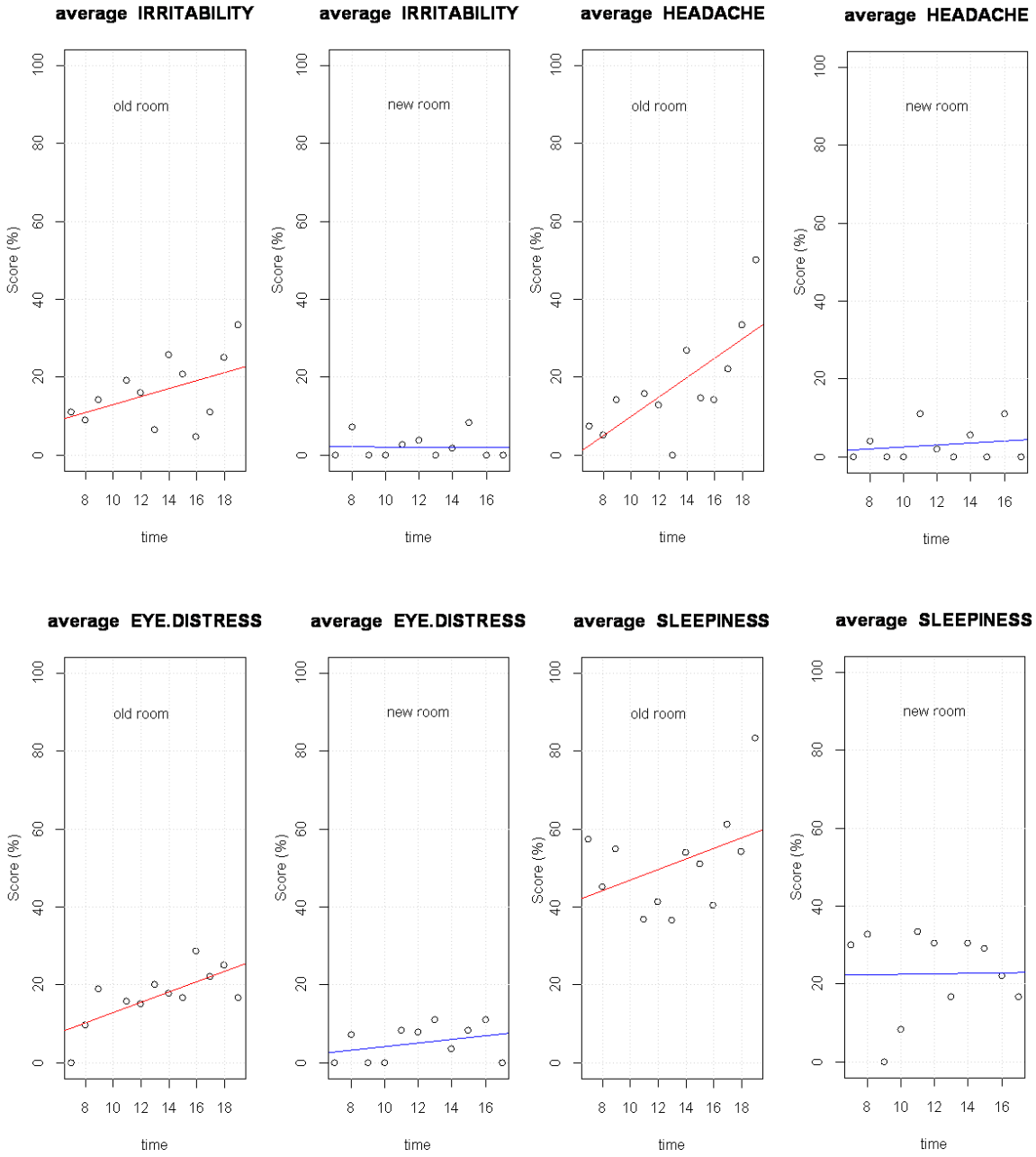

Figure 15 Complaints shown against time

In the Additional material (in the APPENDIX) we show the results for the 40 individual nurses. Some nurses have been much more active reporting than others, and most more than half of the nurses reported only on one room, which makes it difficult to get to the preference of the nurses individually. However, as we have seen, taking the data all together, nurses feel clearly better in the new room in all 4 aspects addressed.

As mentioned, the new room differs from the old neonatal intensive care unit in several aspects. We can therefore not directly link the reported improved wellness to the new lighting system, but the effect of light especially on sleepiness and eye-strain has been well-documented.

What matters in the end of course is the health of the neonatal patients. To demonstrate improvements there however will be too complex and costly. As an intermediate step we will inves-

tigate the number of medication errors from the same unit, in the next few months.

4.2.1. Parent's Appreciation Of The Ambient Lighting

The nurses also questioned parents using the e-tool application. We received feedback by 12 parents, as shown in Figure 16. The responses are broadly positive, with a few negative responses. In retrospect, it would have been better to understand why they made their selections, especially the negative answers. Perhaps a future version of the e-tool might be able to record short audio clips, where users are happy to volunteer additional information to record why the parents made their selections and what they actually thought of the lighting.

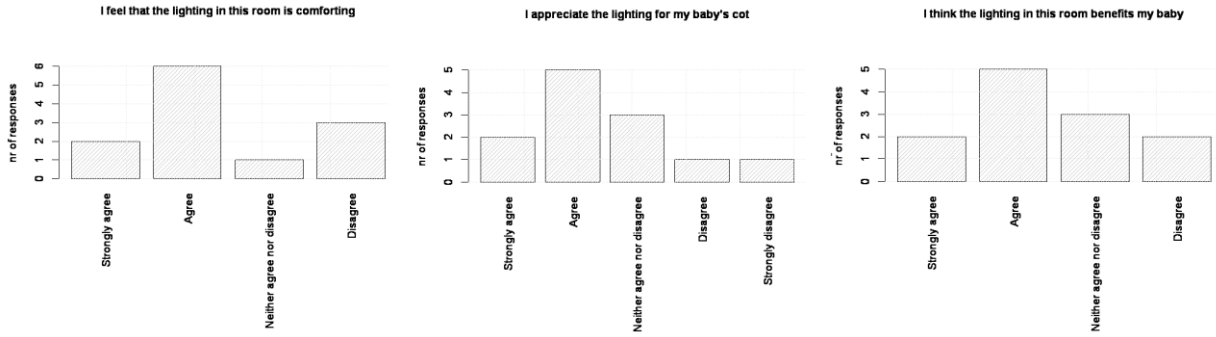

Figure 16 Parent responses

5. Discussion

At the time of publishing we are unable to report on the medication error data. Appropriate data needs to be extracted from St Michael's records system to reduce the likelihood of confounding factors of affecting the data. We will extend this report when this data becomes available.

The user experience trial was run by the nurses providing real-time feedback on a day to day basis. The time data shows a pattern of behaviour, with regular changeover times from both old and new ICUs, where the nurses were free to provide their feedback within just a few minutes of each other. The data on nurses reported symptoms of irritability, headache, eye distress and sleepiness is compelling and shows that the nurses clearly preferred the new room.

A startling finding beyond this clear preference is that these complaints get consistently worse throughout the day in the old room; however, this time dependency disappears in the new room. Nurses report that they leave the new ICU in the same state of irritability, headache, eye distress and sleepiness as they started their shift, hours before. This is an important finding that opens up new questions as to exactly why and whether this same ambient lighting can keep people fresh in other environments and workplaces.

There are of course confounding factors such as more space per cot, however, the staff clearly indicated that the lighting played an important part. As Kay Pullen, unit matron, sums up, "The lighting is a great improvement. Without doubt, the facility now is second to none in terms of state-of-the-art medical equipment but it is perhaps the visual impression, which makes it even more exceptional. The lighting has changed the whole ambience of the room."

An unexpected benefit that was reported is that the nurses speak in gentle hushed voices in the new room, reducing noise levels in the unit with the special lighting. Noise is known to have a really detrimental effect on the neonatal baby's development.

The consultant neonatologist, Pam Cairns and the Matron, Kay Pullen and the staff are so thrilled with the lighting they have written it in to the tender for the whole unit.

5.1. Suggestions For Future Work

In a future study the nurse's absence (sick days) data can be collected over the period of the trial for those nurses that worked in only one ICU to identify if there was any statistical difference in sickness between the two rooms. This would provide be a direct economic argument.

An additional question can also be provided for nurses to ask if they considered the improvement in the experience of the new room was due to:

- The equipment in the room
- More space
- The lighting

Further trials clearly need to examine the time dependency of complaints reported in ambient lighting. Such lighting can be extended to completely different environments, which if proven could significantly widen the appeal of ambient lighting to keep people fresh in the workplace.

6. Acknowledgements

A large team of people were involved in bringing about a successful clinical trial. We are extremely grateful to the staff at St Michael's Hospital, particularly Bridget Robbins, Pam Cairns and Kay Pullen.

Trust:
Pam Cairns
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Kristy Hodgson
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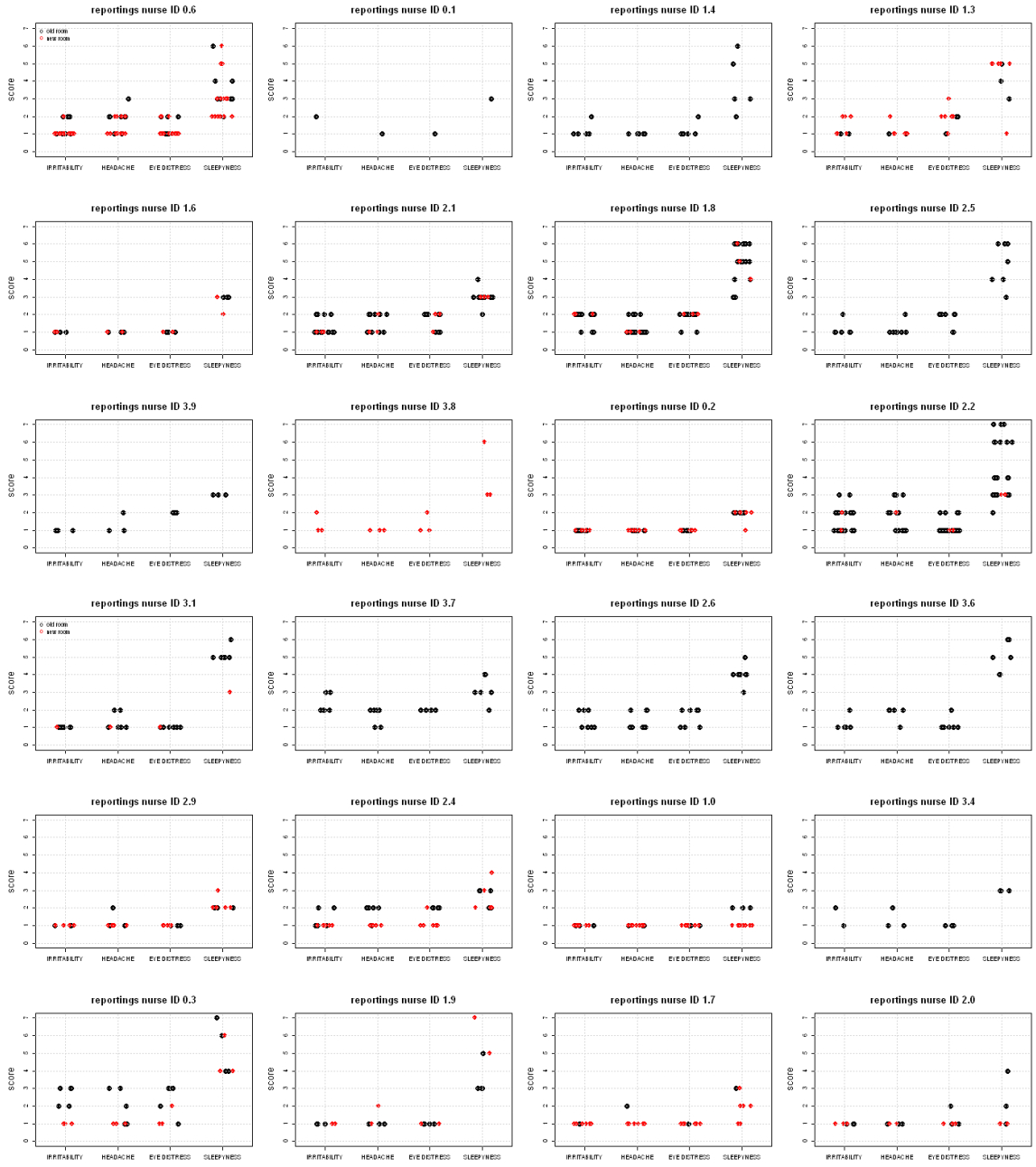
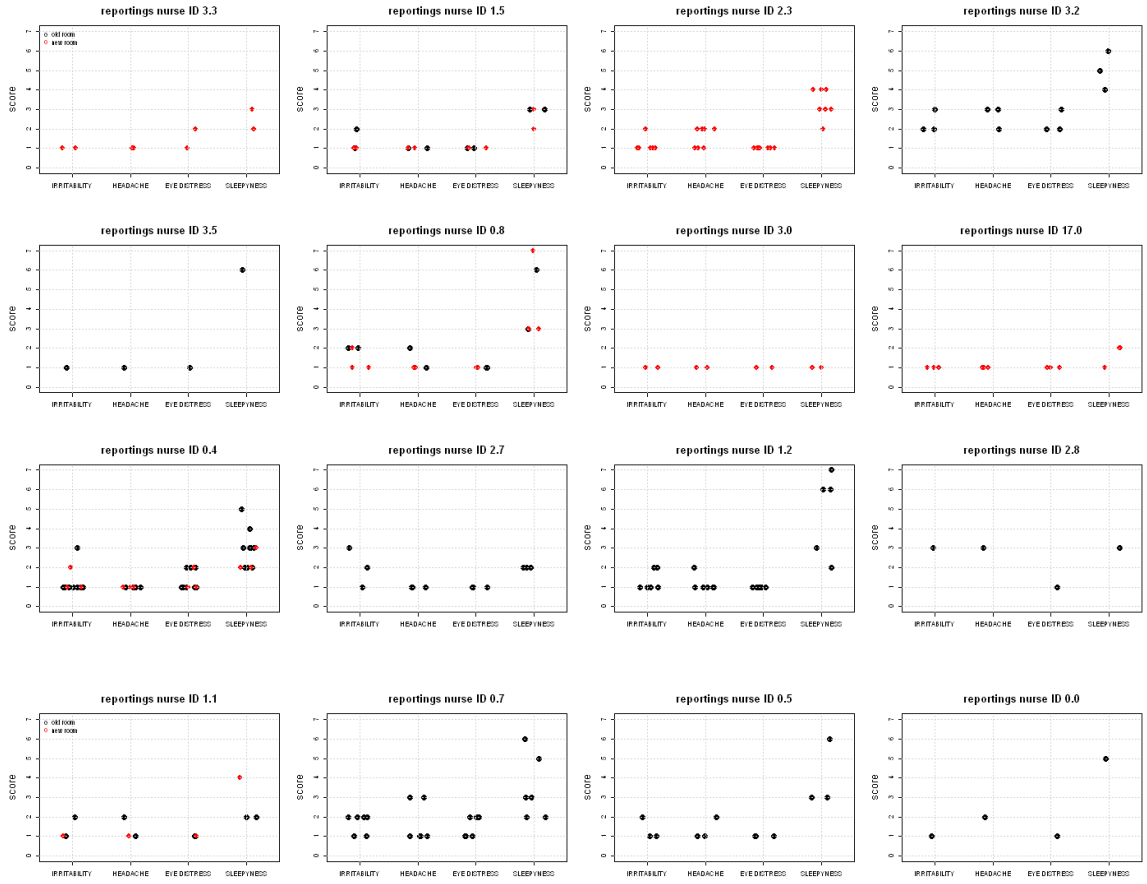
Philips team:
Richard Tandy – Lighting
Barbara Neate - Lighting
Rob Fowler – Healthcare
Sue Harris – Healthcare
David Seidel – Research team
Rob Blake – Research Team
Boris de Ruyter – Research team
Nuwani Edirisinghe - Research team (peer reviewer)

7. APPENDIX

Additional material

The original data and R-scripts used are available from the authors. Results for the 40 individual nurses are below:





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2 Lerner RB, de Carvalho M, Vieira AA, Lopes JM, Moreira ME. “Medication errors in a neonatal intensive care unit”. J Pediatr (Rio J) 2008; 84: 166-170.

3 Pool, J. “St Michaels Hospital – Bristol”, 8.08.2011

4 Akerstedt T, Gillberg M. “Subjective and objective sleepiness in the active individual”. Int J Neurosci 1990; 52: 29-37.

