# Ultra-Low Ultraviolet Radiation in Office Lighting can Moderate Seasonal Vitamin D Cycle: a Pilot Study

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**Abstract**

Background – Ultraviolet-B (UV_B) radiation initiates vitamin D synthesis in skin, making sun exposure a major source of vitamin D. We aimed to determine whether office lighting containing ultra-low levels of UV-B radiation could modify the winter decline in vitamin D status in UK, while being safe and well tolerated.

Materials and Methods – 20 commercial office desk lamps were modified with the addition of UV-B LEDs. Ten hospital office administrative staff received UV-modified lamps with UV-on, and 10 staff received identical placebo lamps with UV switched off, in a double-blind, cross-over pilot study during the winter of 2021/22. Circulating 25-hydroxyvitamin D (25(OH)D) was measured every 4 weeks for 20 weeks: at baseline and during an 8-week trial period, 4-week washout, and cross-over 8-week trial period.

Results –The linear regression combining the complete datasets for phase 1 and 2 of the trial showed that an 8-week UV light intervention significantly increased 25OHD by 7.13 nmol/L with a p-value=0.02 compared to the placebo group. Similar results were confirmed by cross-over analyses using the datasets of those completing both phases of the trial both with and without using the inverse probability weighing method to handle dropouts.

Conclusion – The UV-B-modified lighting was well-tolerated and safe with weekly doses of UV-B of 0.5 – 0.9 SED measured at chest level. This ultra-low dosing was effective in reducing the winter decline in vitamin D status.

## Introduction

The main source of vitamin D for most people is through cutaneous synthesis following skin exposure to the UV-B radiation in sunlight. Modern diets contain only

small amounts of vitamin D, while food fortification and advice on supplementation depend on national policies and personal choice. At mid-high latitudes winter low solar elevation, short daylight hours and cold temperatures result in negligible cutaneous synthesis of vitamin D and vitamin D status declines to a nadir at the end of winter/early spring.

Vitamin D is well known for its importance to the musculoskeletal system, but its active form 1,25 dihydroxyvitamin D ($1,25(OH)_2D$) has anti-proliferative effects, and it has been shown that vitamin D can protect against and improve prognosis across a range of cancers (1). It is also positively indicated in protecting from autoimmune diseases such as multiple sclerosis and asthma, as well as acute respiratory tract infections including covid-19 (2). Therefore, avoiding low or deficient vitamin D status, variously defined in the literature as between 25(OH)D levels <25 nmol/L and <50 nmol/L (3-5), is widely promoted.

Although vitamin D is a major benefit of exposing skin to solar UV-B radiation during daily activities, excess UV-B can also cause skin damage manifested as sunburn and an increased risk of skin cancer. This can lead to confusion and requires careful public health messaging. It further leads to concern about artificial sources of UV radiation in the workplace, home or recreation. The UV-B exposure regime for vitamin D sufficiency (small, sub-erythemal doses on a regular basis) should not contribute to skin damage (6,7), but this knowledge is of little benefit when there is a lack of solar UV radiation (winter months) or when infirmity, or social/cultural conditions, prevent or severely limit sun exposure. Furthermore, vitamin D intake is not a solution for all due to issues of malabsorption from the gut, poor appetite or diet, and cost and compliance of taking supplements. When sunlight is not available an alternative is to provide UV-B radiation from artificial sources in a manner that is

safe and easy for the recipient and does not provide an unwanted UV dose to others. Here we present a pilot study of such a solution, provided as office desk lighting to healthy administrative staff during the winter months.

## Materials and Methods

A double-blind cross-over trial was conducted between mid-October 2021 and March 2022 at Sunderland and South Tyneside NHS Trust hospitals, North East England. Twenty healthy office administrative staff were recruited by open advertisement, exclusion criteria being: pregnancy; malignant skin conditions; a first degree relative who has suffered from malignant skin conditions; photosensitive medical conditions or use of photosensitising drugs; unstable chronic medical conditions including inflammatory and malignant diseases; planned use of sun beds or sunny foreign trips during study period; currently taking oral vitamin D supplements; severe vitamin D deficiency. Participants were split into two groups of 10, matched by age and baseline 25(OH)D status. UV-modified desk lamps were installed over the desks of one group, while the other group received placebo lamps. The first phase of the trial took 8 weeks from mid-October to mid-December 2021. This was followed by a 4-week break over the Christmas holiday period, and a further 8-weeks of desk lighting use with placebo and active UV lighting groups crossed-over in early 2022. Venous blood samples were drawn every 4 weeks throughout the 20 week trial and analysed for 25(OH)D by Roche Total II competitive electrochemiluminescence protein binding assay. Within-run and total variation has been shown to be 5.6% and 8.2%, respectively, at 62.8 nmol/L, while long-term inter-assay variation was 6.7% at 69 nmol/L (8).

The desk lighting was provided by commercially available floor-standing desk lamps (Philips SmartBalance Free Floor Standing FS484F LED125S/840 PSD-T MLO ACL WH. All units were modified. The modifications included a replacement of the light exit window with a UV-B transparent window and the addition of UV-B LEDs with narrow-band output centred at 309 nm. Depending on the group allocation of the participants the units were programmed to either turn on UVB and visible light or only the visible light. All units were programmed to come on at 0850 and go off at 1710 from Monday to Friday: they could not be controlled by the participants and supplemented the normal room lighting that was available. Visually all desk lamps were identical and all provided the same level of visible radiation.

The UV-modified lamps were tested independently at University of Manchester prior to approval of the trial, and again immediately before installation in offices at the start of the trial. Measurements of spectral irradiance were made at a comprehensive series of locations beneath the emitting surface of the lamp with a double monochromator Bentham DTM300 spectroradiometer (Bentham Instruments Ltd, Reading, UK), calibrated to NIST standards of spectral irradiance. Further evaluation was made with polysulphone film badges attached to a mannequin sitting at a desk (Figure 1).

The lamp output was also monitored at the start of each phase and at the end of the trial by Signify. Throughout the trial all volunteers wore a UV dosimeter (polysulphone film badge (9)), using one dosimeter a week worn at chest level (on hospital ID lanyard). A second weekly dosimeter was placed on the desk next to the lamp support as a measure of the full-time exposure available, recognising volunteers were mobile and could leave their desks. Polysulphone film is usually calibrated to measure erythema-effective UV radiation from the sun. The spectrum of

the LED source is very different to that of the sun and an alternative calibration specific to the UV LEDs used was generated by University of Manchester, still in units of erythema-effective UV.

The UV-modified desk lamps received MHRA approval (CI/2020/0033) and ethical approval was provided by Office for Research and Ethics Committees Northern Ireland (RECB). The trial was registered with the ISRCTN registry, trial ID: ISRCTN56526926

Results were analysed using R version 4.0.3. Various analyses were carried out based on multiple linear regression. Missing covariates were assumed to be missing at random and imputed by multiple imputation method (10) using the mice package in R. Late measured outcomes were validated or modified by multiple imputation. Dropouts were handled by the inverse probability weighting method (11).

## Results

1. Characteristics of UV-modified desk lamps

The UV-modified desk lamps were designed and tested to meet European Working Directive 2006/25/EC that addresses health and safety requirements of workers exposed to physical agents – in this case artificial optical radiation (12). The Directive limits exposure to 30 $Jm^{-2}$ of actinic hazard weighted UV radiation over a period of 30,000 seconds (8 hours and 20 minutes). As a more precise measure of skin damage, the limit for erythema weighted UV radiation over the same period was set at 1 SED (where 1 SED = 100 $Jm^{-2}$ erythema weighted UV).

The UV-modified desk lamps were placed such that the active emitting surface was over the desk and area where the keyboard would be, not directly over the chair where a worker would sit (see Figure 1). The minimum distance from the emitting

surface at which the EU Directive is met is 800mm, and the units were labelled with a warning label to this effect. For reference the distance from the emitting surface to the desk top was approximately 1200 mm. The irradiance field on the desk beneath the emitting head was homogenous at the 10% level and then decreased moving laterally away from this area. At a distance of 1.4 m from the centre of the emitting head the irradiance was 10% of the central maximum. This was taken as an indication of the impact of the lighting on other people in the office and was deemed negligible.

2. Trial participants

All participants were female, aged 28-59 (mean 45) years, and all of skin types II and III. Twenty volunteers were initially recruited, with a further 4 recruited for phase 2. Full details are given with the vitamin D results. One volunteer withdrew complaining of headaches, but has a long history of migraines which was not considered to be associated with the trial. The other drop outs were due to job rotation and one was withdrawn due to vitamin D deficiency at week 4. In addition, the individual start dates in Phase 2 varied due to holiday or sick leave. Phase 2 ended 6th March 2022 for most volunteers. The very last blood sampling took place 1$^{st}$ April 2022.

3. UV stability, tolerance and dosing

The lighting units provided a stable output throughout the 20 week trial, with the UV output varying by no more than 5%. All units (active and placebo) performed exactly as programmed, turning on and off at the correct times of day

The UV-modified desk lamps were well tolerated and no adverse effects were recorded. Feedback from qualitative interviews following the end of the study period was very positive with the majority of participants not having any problems with the lamps. A common feeling was that as they were “just there” and automatically

switched on, using the lamp would be something participants would prefer to taking oral vitamin D supplements as it means they wouldn't forget to take them.

The erythema effective doses measured at the participants' chest level are shown in Table 1. Over an 8-week period the intervention (UV) group received 4-7 SED at the chest level dosimeter. This equates to 0.5 – 0.9 SED/working week, which is close to the mannequin tests that delivered 0.6 SED/working week at the mannequin chest. The mannequin test provided for 1.45 SED/working week on the hands at keyboard level, so we might reasonably expect that the hands of the volunteers received a similar dose, and this would also be consistent with the control dosimeter badges placed on the desks.

4. Vitamin D results

Not all participants completed the full trial. Two dropouts in phase 1 result in eighteen complete data sets for phase 1. The data are summarized in Table 2(a). Six dropouts after phase 1 were replaced by 4 new participants and there was one further dropout during phase 2 resulting in fifteen complete datasets for phase 2. The phase 2 data are summarized in Table 2(b). Twelve participants completed the entire trial: these data are summarized in Table 2(c). The results of statistical analyses of the 25(OH)D outcomes for the different datasets are summarized in Table 3.

Table 3 shows that all the 3 analyses gave similar estimates for the effect of UV light intervention. The multiple linear regression for the combined data of the 18 and 15 participants who completed Phase 1 and 2 respectively shows the average impact of low-level UV intervention over an 8-week period is an increase in circulating 25(OH)D of 7.13 nmol/L (p=0.02), compared to the placebo group, after adjusting for age, skin type and baseline 25(OH)Ds at the start of two phases. As shown in Table 2(a)-(c), in phase 1 this was seen as less of a drop in 25(OH)D from end-summer

maximum vitamin D status, while in phase 2 a small increase in circulating 25(OH)D was seen, compared to a continuing drop in the placebo group.

The cross-over analysis for the 12 participants completing both phases indicated an impact of UV intervention of 7.55 nmol/L (p = 0.03). The pattern of dropouts was analysed using logistic regression and weak evidence of association was found between dropout and the last observation of 25(OH)D before dropout (p=0.08) with the group (p=0.09). The inverse probability weighting method (10) was used with cross-over analysis and resulted in a similar estimate of 7.12 nmol/L (p = 0.05). There was no significant carry-over or period effect found, and no significant effect of age or skin type was identified, as one might expect from this fairly homogenous set of volunteers.

**Discussion**

This trial of ultra-low UV-B lighting, assessed on healthy office workers, has shown the lighting units to be stable, reliable, safe and well tolerated. The UV-B doses as measured at the desk level (for hands and arms: ~0.3 SED/day) and at the chest of participants (~0.2 SED) were well below the 1 SED/working day limit defined by the EU Directive. No adverse effects of the lighting were reported; on the contrary participants welcomed the additional lighting and even mentioned to prefer lighting above supplements.

Even these very low doses of UV-B, equivalent to being outside for less than 5 minutes on a sunny summer day at lunchtime in Sunderland, produced a statistically significant effect on circulating 25(OH)D of 7.13 nmol/L when delivered 5 days a week for a period of 8 weeks. While this is a modest result, if it was maintained for the full 20 week winter part of the year (mid-October to mid-March) this would be a

difference of ~18 nmol/L, enough to reduce the amplitude of the seasonal cycle in 25(OH)D, and in many cases prevent vitamin D deficiency in the later winter months. The wavelength of UV-B radiation employed, at 309 nm, is towards the edge of the action spectrum for pre-vitamin D synthesis (13) and moving to a somewhat shorter wavelength could increase the effectiveness of radiation, provided care is also taken to maintain the very low erythema-effective doses. Such a wavelength shift could be even more relevant if the CIE action spectrum should be shifted to shorter wavelengths, as has been suggested (14).

Such a method of low-dose UV-B radiation, delivered on a daily basis through a UV-modified desk lamp that can be employed in an office or home, offers an alternative method of increasing vitamin D status. It is of particular benefit to those who find it difficult to gain vitamin D from the gut and have very limited access to sun exposure. As an alternative to supplementation in for example sheltered accommodation or care homes it offers a cost effective alternative to vitamin D supplementation over many years.

**Conflicts of Interest** Signify financially sponsored the study and provided the lighting intervention. The authors declare no other conflicts of interest.

**Authors' Contributions**

All authors contributed to protocol development and to the manuscript preparation, which was written by ARW. BvdZ, ARW, RK were responsible for installation of the lighting, safety and UV-B stability assessment and characterization of the UV from the ultra-low dose intervention. ARW and RK provided dosimetry. HO'N recruited

and managed the participants in the trial. NL provided independent statistical design and analysis. DW provided access to South Tyneside and Sunderland Foundation NHS Trust for all aspects of the trial.

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**Table 1: Cumulative dose over 8 weeks (sum of 8 polysulphone film dosimeters), measured at the chest of volunteers**

| Cumulative dose (SED), Mean (standard deviation) | | |
|---|---|---|
| | Active | Placebo |
| Phases combined | 5.2 (3.3) | 0.8 (0.41) |
| Phase 1 | 4.2 (1.9) | 0.76 (0.49) |
| Phase 2 | 7.3 (3.3) | 0.79 (0.34) |

**Table 2(a):** Data summary for the 18 participants who completed Phase 1

| Group | Number of Participants | Age (y) | | Skin type: Number of II/III | Difference in 25(OH)D (nmol/L) | |
|---|---|---|---|---|---|---|
| | | | | | Week 8 vs Baseline | |
| | | Mean | Range | | Mean | Range |
| Active | 9 | 45.44 | [28,59] | 5/4 | -11.01 | [-32.4, 0] |
| Placebo | 9 | 45.78 | [28,55] | 4/5 | -16.12 | [-32.7, -9.2] |

**Table 2(b):** Data summary for the 15 participants who completed Phase 2

| Group | Number of Participants | Age (y) | | Skin type: Number of II/III | Difference in 25(OH)D (nmol/L) | |
|---|---|---|---|---|---|---|
| | | | | | Week 20 vs 12 | |
| | | Mean | Range | | Mean | Range |
| Active | 8 | 46 | [24,59] | 4/4 | 3.86 | [-5.2, 17.7] |
| Placebo | 7 | 46.43 | [28,55] | 2/5 | -5.22 | [-18.1, 5.3] |

**Table 2(c):** Data summary for the 12 participants who completed both phases

| Number of Participants | Age (y) | | Skin type Number of II/III | Difference in 25(OH)D (nmol/L) | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Group | Week 8 vs Baseline | | Group | Week 20 vs 12 | |
| | Mean | Range | | | Mean | Range | | Mean | Range |
| 4 | 50.25 | [45,59] | 1/3 | Active | -14.05 | [-2.4, -32.4] | Placebo | -4.48 | [-18.4, 5.3] |
| 8 | 46 | [28,55] | 4/4 | Placebo | -16.45 | [-9.2, -32.7] | Active | 3.86 | [-5.2, 17.7] |

**Table 3:** Results of multiple linear regressions under different analyses and datasets. The response variable is the 8-week change in 25(OH)D. The coefficients are in units of nmol/L representing the increase/decrease in the response variable with respect to the variation in the predictor variables. The corresponding p-values are in parentheses.

| Predictors | Combined analysis of those completing a single phase (n = 18 and n = 15) | Cross-over Analysis for those completing both phases (n = 12) | Cross-over Analysis with inverse probability weighting, both phases (n = 12) |
|---|---|---|---|
| **8-week intervention vs placebo** | 7.13 (0.02) | 7.55 (0.03) | 7.12 (0.05) |
| **Baseline 25(OH)D Phase 1** | -0.23 (0.01) | -0.99 (0.00) | -0.50 (0.00) |
| **Baseline 25(OH)D Phase 2** | 0.00 (0.98) | 0.58 (0.03) | 0.30 (0.04) |

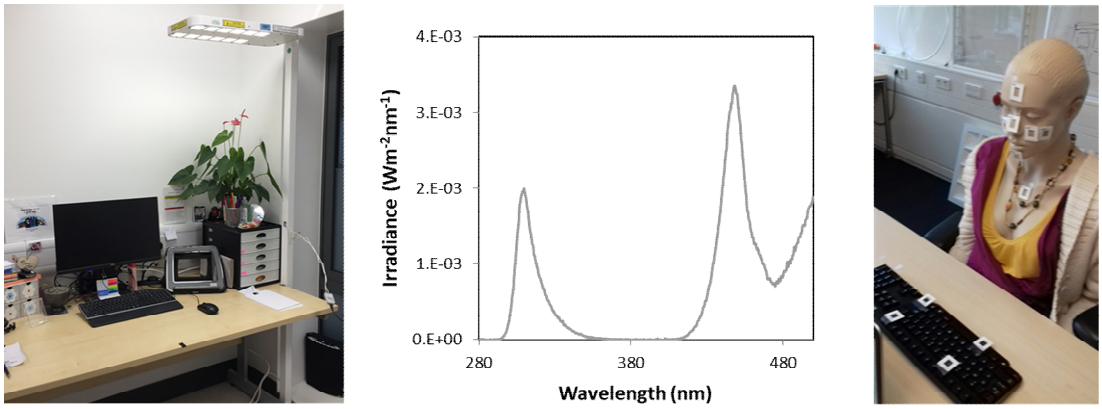


**Figure 1:** Desk lamp installed in an office (left), UV-blue spectrum of lamp showing the 309 nm LED peak (centre) and mannequin tests with dosimeter badges (right).