The Effect of Tinted Light On Tinnitus Perception: A Preliminary Study

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Results

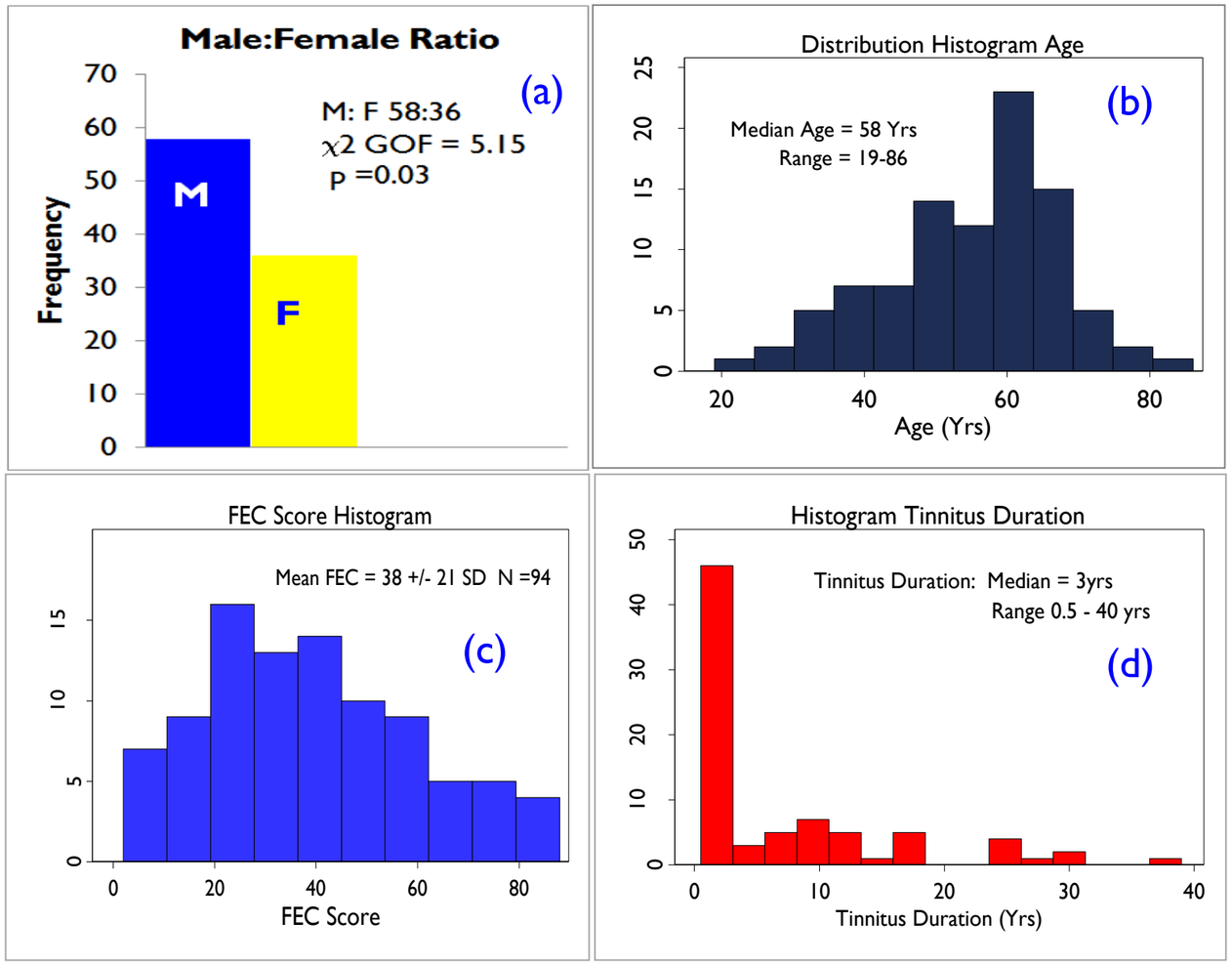


Fig. 1 (a-d). Some exploratory results for the demographics and main tinnitus descriptors.

(a) ***Male:Female Ratio*** was about 60:40 % reflecting sex ratio of tinnitus patients attending clinic. **(b)** ***Age range*** was 19-86 yrs with a median of 58 yrs. **(c)** ***THI FEC scores*** ranging from 2 to 88 with a median of about 40. About 1 in 5 reported tinnitus as severe or unbearable. **(d)** ***Tinnitus duration*** exhibited an early 2 year mode with a tail stretching out to 40 yrs.

About 45 % (41/94) of Patients Reported a Positive Effect of Tinted Light on Tinnitus

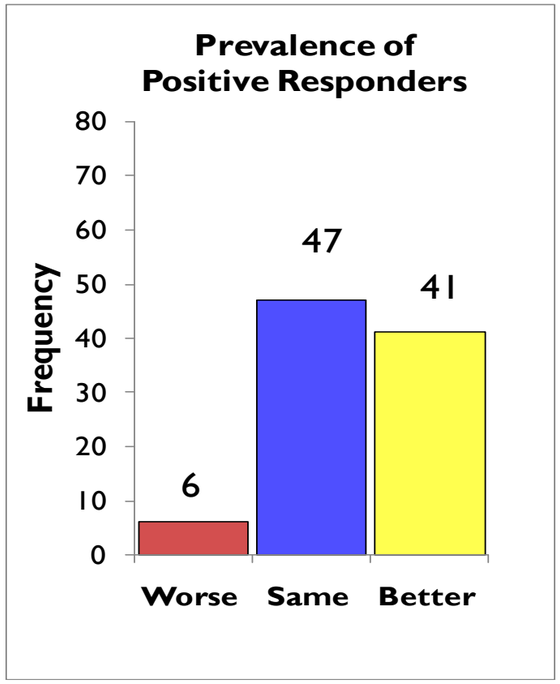


Fig. 2.
Prevalence of Different Effects of Light on Tinnitus

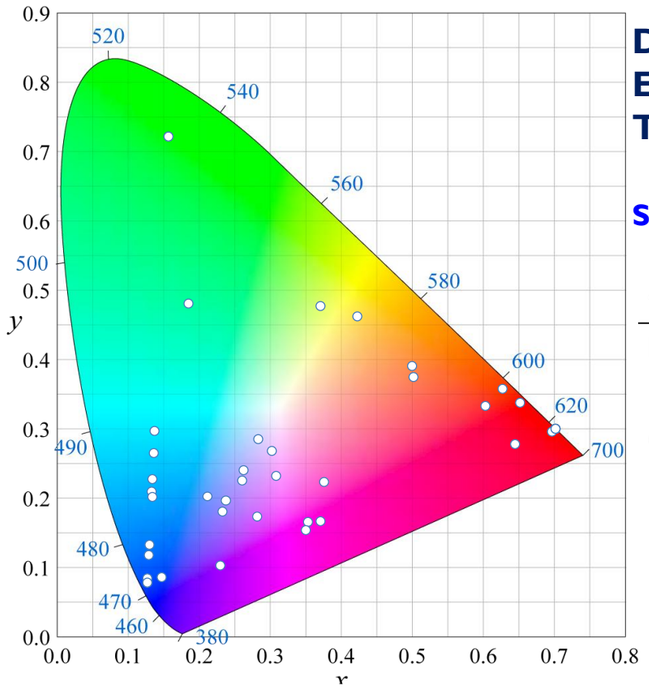
44% (41/94) – **Improved**
50% (47/94) – No change
6% (6/94) – Worse
'Worse' was combined with 'No Change' for analysis.

Distribution of Optimal Points in Color Space

Fig. 3. shows the distribution of optimal points in colour space for improving tinnitus. Proportionately more reports of improved tinnitus occur within predominantly 'blue' color space. The proportions in percentage terms for Blue:Red:Green = 29:8:4 ≈ 70%:20%:10%.

Reported Non-Auditory Effects and Color Space

Fig 4. shows that about a third of subjects (N= 30) reported non – auditory effects on mood, such as 'relaxing' and 'calming'. These reports showed an overall pattern not dissimilar to that seen for positive effects on tinnitus.

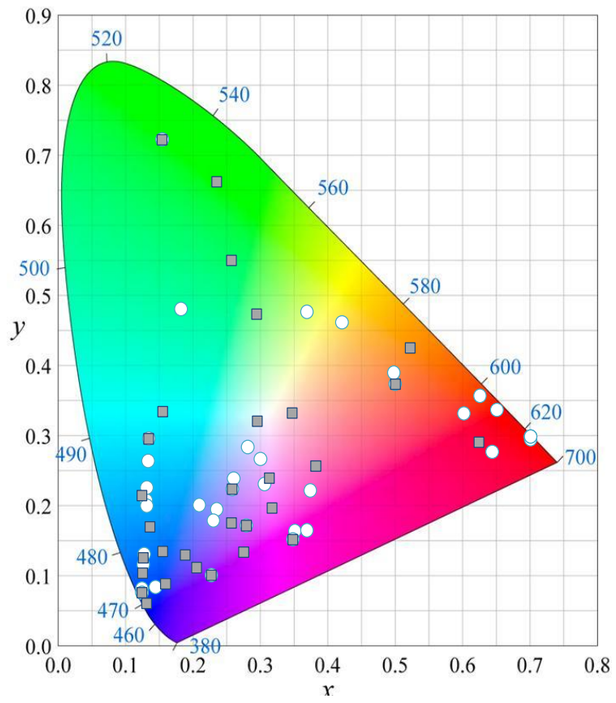


Distribution of Positive Effects of Light on Tinnitus

Single Optimal Points

Color 'Zone'	Proportion
Blue	70% (29/41)
Red	20% (8/41)
Green	10% (4/41)

Fig. 3 Distribution of Positive Effects on Tinnitus in Color Space & Prevalence



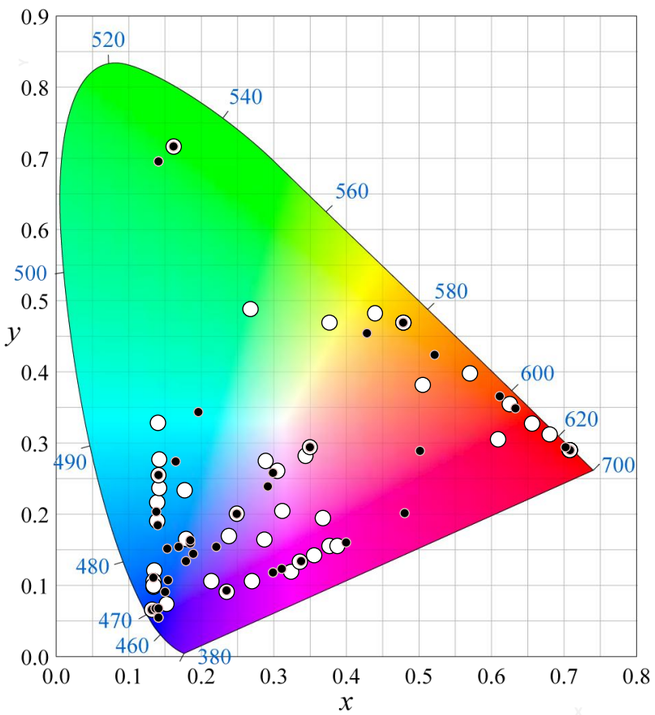
Auditory and Non - Auditory Mood Effects

O Auditory N =41

■ Non - Auditory 'Mood' N=30

Non-Auditory Effects have similar distribution in colour space

Fig. 4 Distribution of Non –Auditory Effects in Color Space



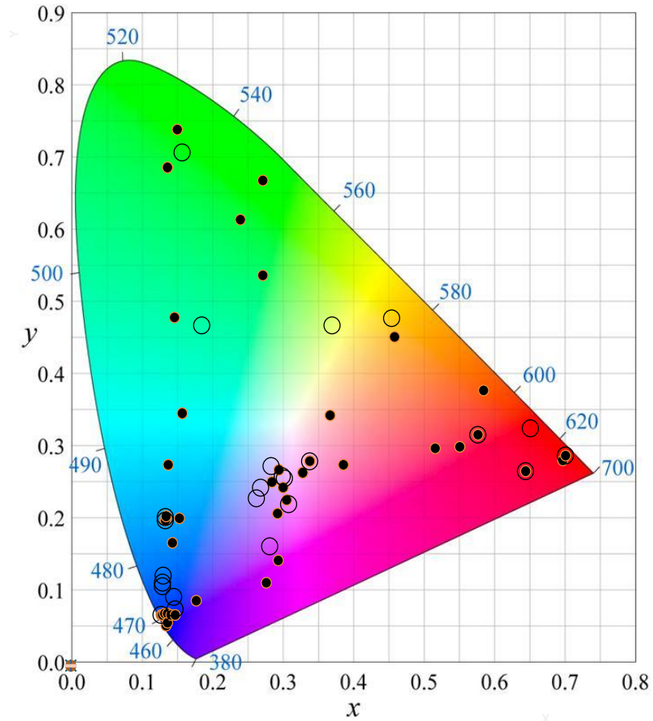
Acute Repeatability and Variability (N = 23)

All Response Points
Second Test at 60 - 90 mins

○ First Test

● Second Test

Fig. 5 Acute Repeatability Plot



Chronic Repeatability and Variability (N =15)

All Response Points
Second Test 6-24 months

○ First Test

● Second Test

Fig.6 Chronic Repeatability Plot

Acute Repeatability Over 60-90 mins was 55%

Fig. 5 shows all the points chosen by the 23 subjects carrying out acute repeatability and variability testing, as some subjects reported more than other points in colour space that also appeared to improve their tinnitus. Their best or *optimal* point alone was used for the prevalence part of the study (Figs. 2 & 3). Identification of multiple ameliorative points was important, as estimates of repeatability could be affected by this phenomenon in individual tinnitus patients. 13/23 or 55% of subjects identified the same X:Y point in color space. This is summarised in the upper row end histogram in Fig. 7 for acute repeatability.

Chronic Repeatability Over 6-24 months was 60%

Fig. 6 shows all the points chosen by the 15 subjects carrying out chronic repeatability and variability testing. 9/15 or 60% of subjects identified the same point in color space after this much longer period. This is summarised in the lower row end histogram in Fig. 7 for chronic repeatability.

Saturated Color Tints Chosen by 60% of Subjects

Figs. 3-6 show that many subjects (23/41 or 60%) chose tints at the performance edge of Read Eye along the blue-green and blue-red axes. This effect was only apparent post-analysis and is suggestive of some selection mechanism within the visual pathway.

50% of Repeat Subjects Respond to More Than One Point in Color Space

The histograms in Fig. 7 show the results for acute and chronic repeatability and variability. The top row is for acute testing and the lower row for chronic testing. The First and Second tests are indicated sequentially for each column. At least 50% of subjects overall reported more than one point in colour space that ameliorated their tinnitus.

The Peak Median Decrease In Tinnitus Perception is 50%

Fig 8 show the results from the 31 positive responding subjects taking part in acute longevity testing, where changes in reported Visual Analog Score were recorded over three minutes. The test began with 30 seconds in the dark, when they then reported their reference VAS. Their optimal colour for improving their tinnitus was introduced gradually over 30 seconds then

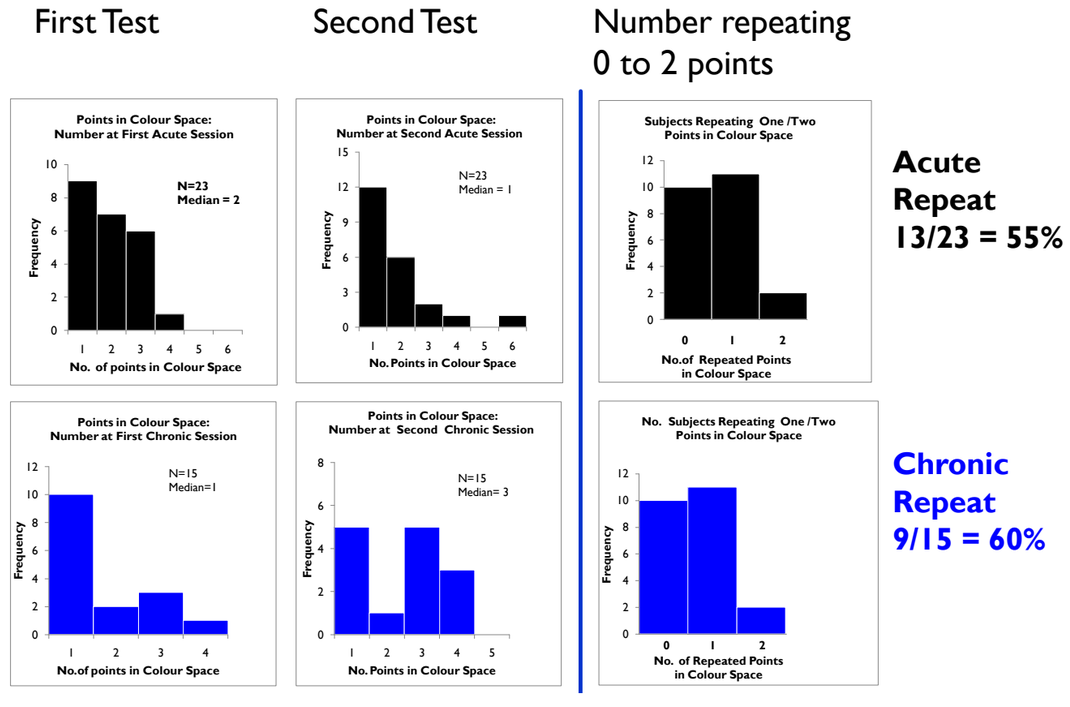


Fig. 7. Acute and Chronic Repeatability and Variability Histograms

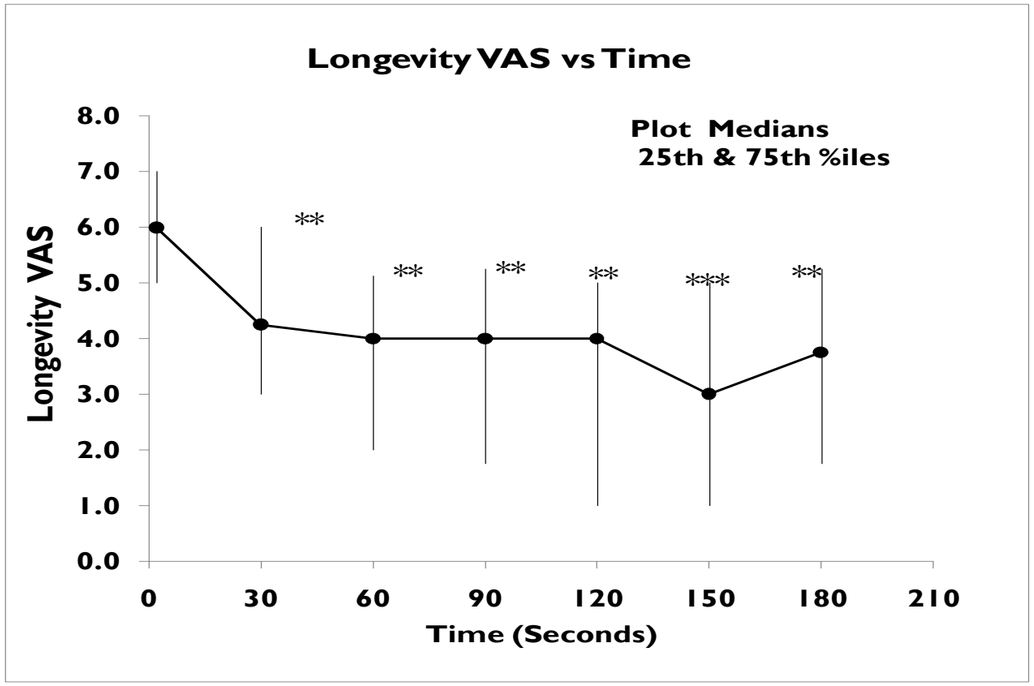


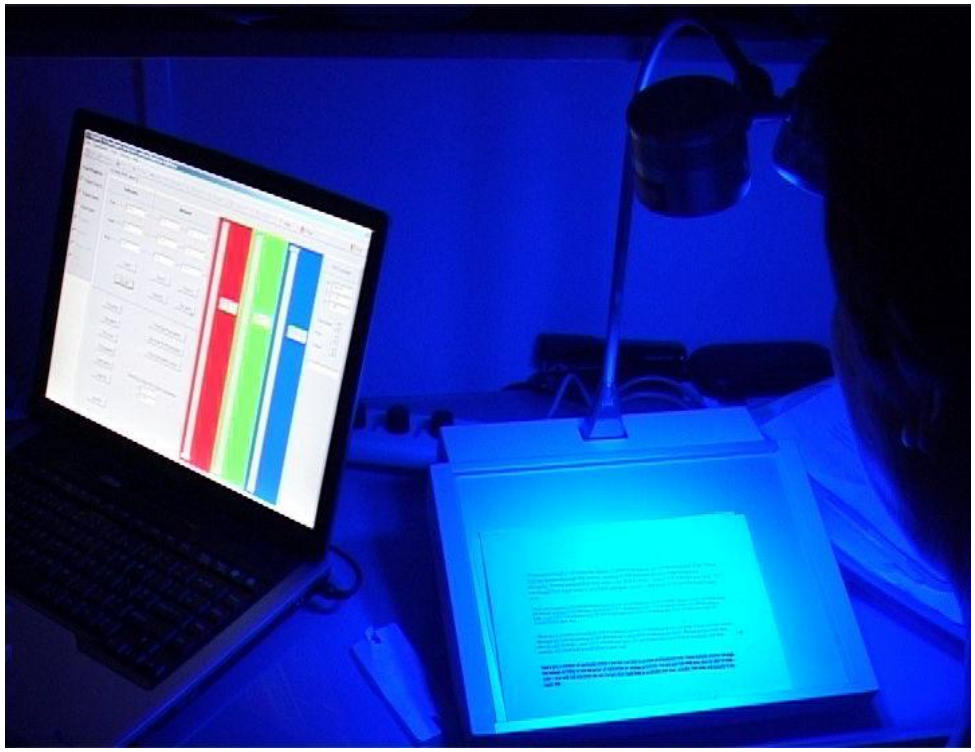
Fig.8. Reported Improvement in Tinnitus: Acute Longevity

Introduction

Neurosensory Integration is a Central Theme in Tinnitus Research

One of the most exciting developments in tinnitus research is the emerging theme of neurosensory integration.[1] Our increased understanding of how cross sensory stimuli can modulate tinnitus perception provides the basis for potential therapeutic intervention.[2] This integrative approach has included investigation of interactions between the auditory and other sensory systems and other processing centres within the CNS. However, no previous studies have looked at the interaction between narrow waveband light and tinnitus.

This study came about following discussions with Orthoscopics, a UK optical technology company, who had developed a calibrated colour lighting source called 'Read-Eye' (shown in Picture 1). This was used in optometry clinics for customising tints on prescription lenses. During use of Read-Eye, some patients independently gave unsolicited reports of improvements in their tinnitus.



Picture 1. A Read Eye lamp producing narrow band blue light at about 470 nm. This saturated hue is unusual in terms of sensory experience.

The Eye Codes over a Million Colors using only Three Detection Elements

The retina at the back of the eye uses only three broadly tuned detection elements, the cones, to code for at least one million hues as shown in Picture 2. Color is determined by the ***relative*** output of the three 'Red Green Blue', (RGB) cones. The lower left image in Picture 2 also shows the filter shapes and peak wavelengths of the three narrowly tuned RGB LEDs used in Read-Eye.

The usual linear spectral representation of color is shown at the top left of Picture 2. By varying the ***relative*** output of the three RGB LEDs output relative to one another, the broadly tuned cones can be effectively driven through a defined region of color space that result in perception of specific hues.

The CIE 1931 Map of Color Space is an X:Y Transformation of the Linear Color Spectrum

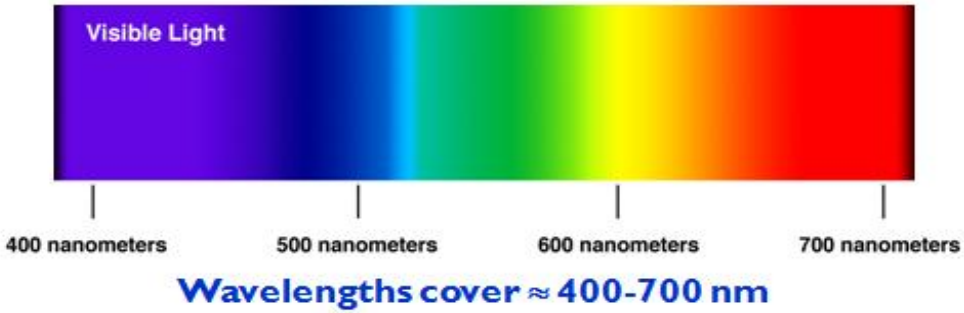
These hues are best mapped on the 1931 CIE map of color space which is a transformed version of the usual linear spectral representation over 400-700nm.[3] The region of color space that can be generated by Read-Eye is shown in the right of Picture 2.

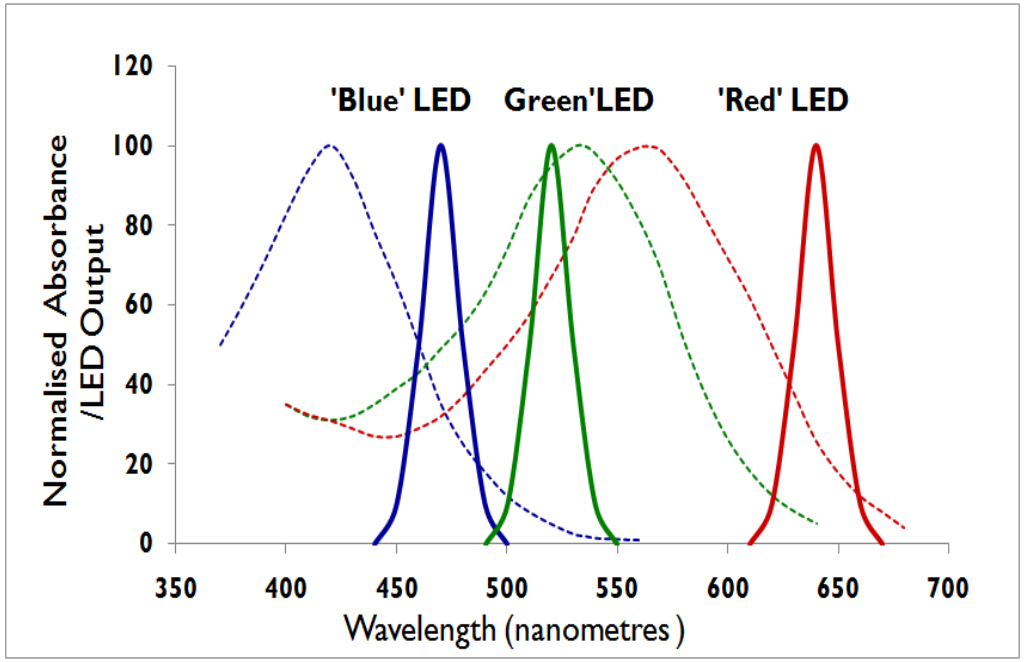
The 1931 CIE color space map uses X:Y co-ordinates as transforms of the color spectrum based on the blue–red and blue-green axes. As Picture 2 shows, the linear spectrum is represented as an arc on the red –green – blue locus. The balanced stimulation of all three cones results in white, which is represented as X:Y 0.333;0.333. In this study, the 1931 CIE X:Y co-ordinate system was used to map the response of tinnitus patients when they reported a positive effect of tinted light on their tinnitus or for other non-auditory effects.

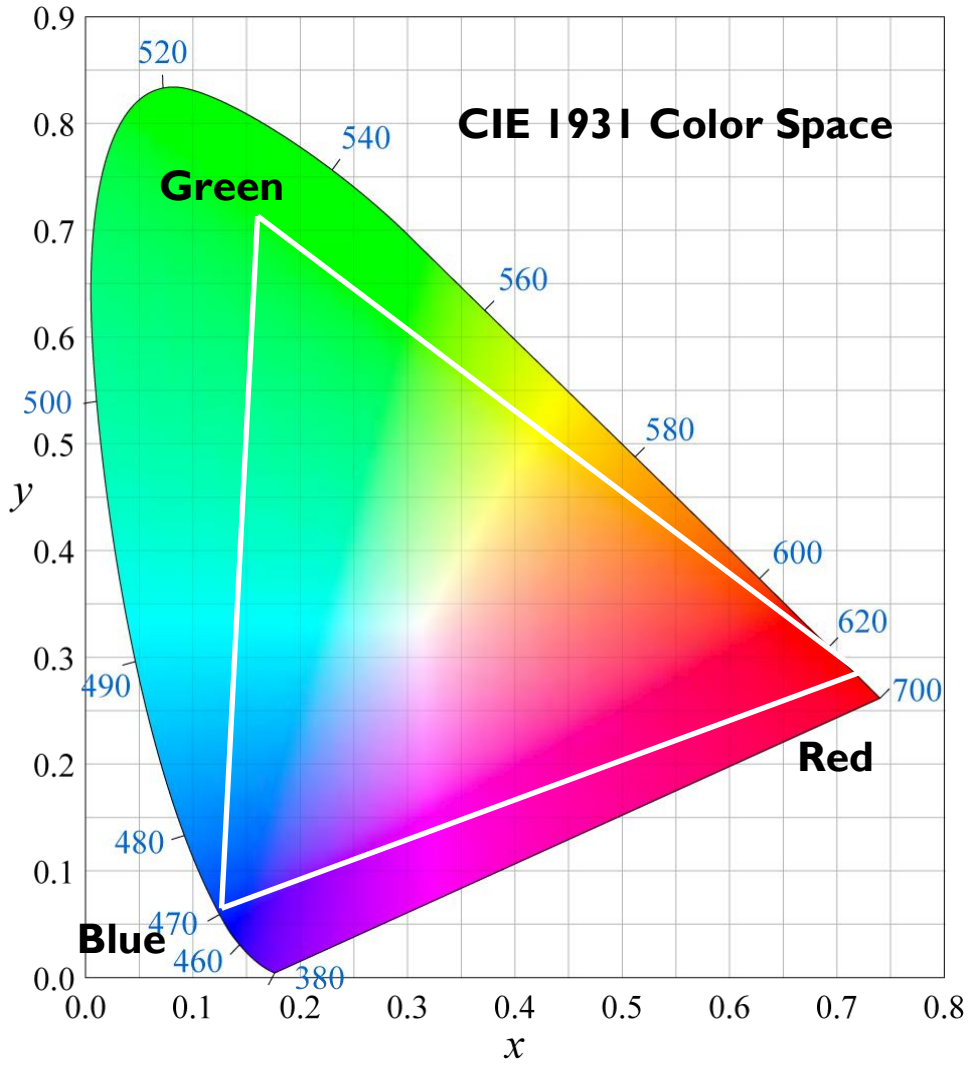
Aims of the Study

Following the unsolicited reports of an effect of tinted light on tinnitus a study was designed to provide the following.

- Establish if tinted light generated by narrow band LEDs caused reported changes in tinnitus perception in chronic tinnitus sufferers
- An estimate of prevalence of the phenomenon, assuming it to be real
- Establish if these reported effects were repeatable both acutely and chronically
- To see if the effect was restricted to one or more points in color space
- Obtain semi-quantitative estimates of the magnitude of any acute effect
- To identify any significant covariates associated and incorporate these into a predictive logistic regression model







Picture 2. The upper left image shows the normal linear representation of the visible light spectrum. The lower left shows the tuning curves (dotted lines) for the Red Green and Blue retinal cones. The solid lines represent the narrow band tuning of the Read-Eye RGB LEDs.

The mapping of CIE 1931 Color Space above and the mapping limits of the three LEDs are;

Wavelength	CIE 1931 X:Y
470 nm (Blue)	0.129, 0.071
540 nm (Green)	0.160, 0.720
640 nm (Red)	0.706, 0.294

Conclusions

Are results simply due to a placebo effect ?

This study provides preliminary evidence of some effect of tinted light on perception of tinnitus. The prevalence estimate of a positive effect is about 44%. This could, however, be a sophisticated placebo effect.

What militates at least partly away from a complete placebo effect is the paucity of other sensory cues during the trial. Whilst viewing the tinted light, there were no effective clues as to color space location, especially in a completely naïve population sample.

The reporting by at least 50% of subjects of a number of precisely repeatable points suggests either a very well developed color memory in continuous color space (unlikely) or the use of an additional sensory cues guiding them to a precise location – such as a mechanistic modulation in tinnitus. It also appears that memory recall of saturated colors hue is especially difficult to perform.[4] Estimates that the number of successful *precise* repeats based on very good color memory would be at least 10^{10}. This assumes subjects could remember and identify a 'near hue' space of 100x100 pixels.

This performance level of saturated color idenitification by memory recall is very unlikely.[4] But the model here very conservatively reduces the region of color space to be recalled by those repeating the task. In fact, they were almost always accurate to the same CIE 1931 X:Y pixel value.

However, the results also revealed that others subjects did not repeat the identification of the same color acutely or chronically. This does not necessarily mean that these results should be automatically attributed to placebo effect. It may reflect a real dynamic variability in the response of either of the senses in tinnitus amelioration.

Mechanistic Clues: Color Space Edging ?

The distribution of optimal points along the limits of Read-Eye color space was unexpected. This preference for saturated colors could be interpreted as mechanistic - even if as a placebo mechanism for selecting favourite colors.

When the wavelength regions of many of these points are plotted out against the standard linear spectrum as in Fig.10, 60% of points occur around the overlap of 'Red', 'Green' and 'Blue' cone absorbance at about

470-490 nm. Those on the 'Red-Green' saturation edge are largely away from tail of the 'Blue' cone filter.

The covariates in the Logistic Regression Model were highly significant and the shape of the predictive curve would at least suggest a well defined model even if describing placebo effects.

Relevance to US Department of Defense: Therapeutic Potential of Tinted Light in Treating Tinnitus

This study provides the first body of evidence that tinted light may have some utility in ameliorating tinnitus. This utility may extend to US Military Personnel experiencing tinnitus resulting from intense and often unavoidable noise exposure in the course of duty.

From the current predictive model this would be more likely to work in younger personnel with an upper probability of 70-95% dependent on age and gender. The technique enjoys the advantage of being non-invasive and technologically straightforward.

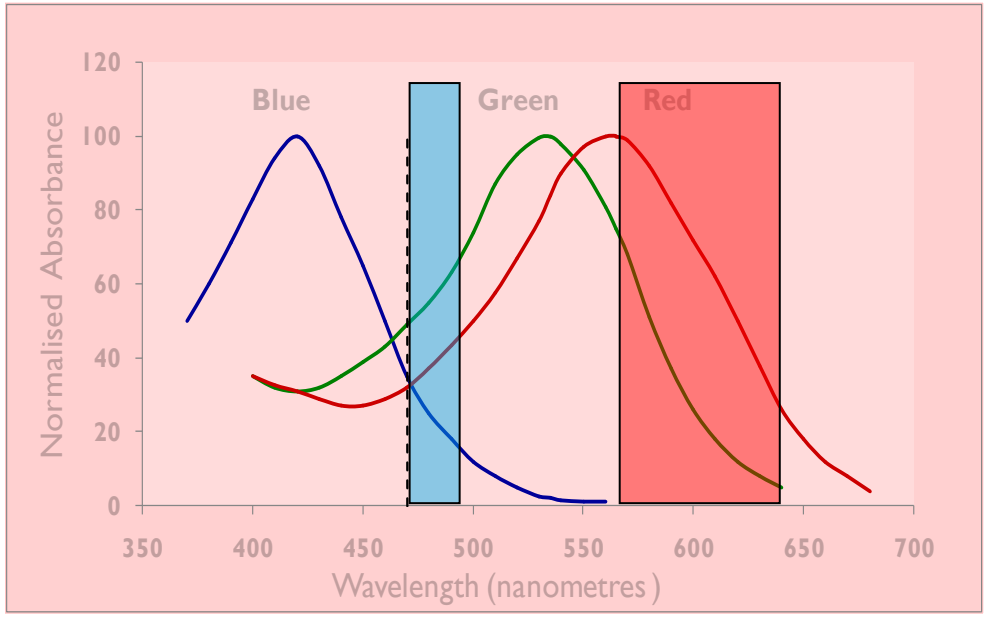


Fig. 10. Location of 60% of CIE 1931 X:Y points Read- Eye color space limits.

Trials to replicate these findings are being planned and development of the technology for personal use is being taken forward, with programmable lamps in prototype.[5] The possibility that prescription tinted lenses may also be effective in tinnitus patients is also being considered.[6] Commercial partnerships with companies that could act as potential licencees are also being actively sought.

Results - Continued

held constant for 150 seconds, then gradually reduced. The median VAS at the start was six which dropped to a median of four and a maximal median drop to three at 150 seconds. There was a rise back to four at 180 secs. By Friedman's ANOVA, all these drops were significant at $p<0.01$. Back in lighted conditions post-test tinnitus was reported to be 'back to normal'

Logistic Regression Modelling of Tinnitus Modulation by Tinted Light

Exploratory Analysis

Exploratory univariate analysis with all the predictor covariates only returned three as significant; sex, age; non auditory 'mood'. The unadjusted Odds Ratios were all highly significant as shown in Table 1.

The Optimal Regression Model

The equation for the three term adjusted model is given in Table 2. The three terms remained highly significant providing a provisional predictive model.

Table 1 Significant Predictor Covariates

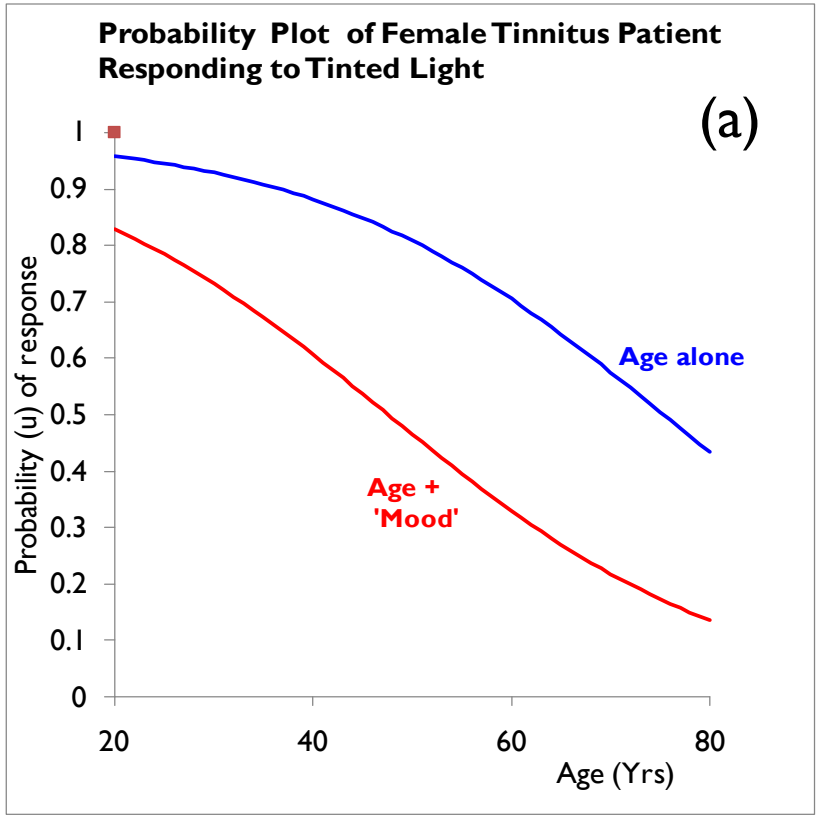
Covariate	Odds Ratio	95% CI	Significance
Sex (Male)	0.21	0.08, 0.55	0.0004
Age	0.94	0.91, 0.98	0.003
Mood	0.21	0.062, 0.62	0.0016

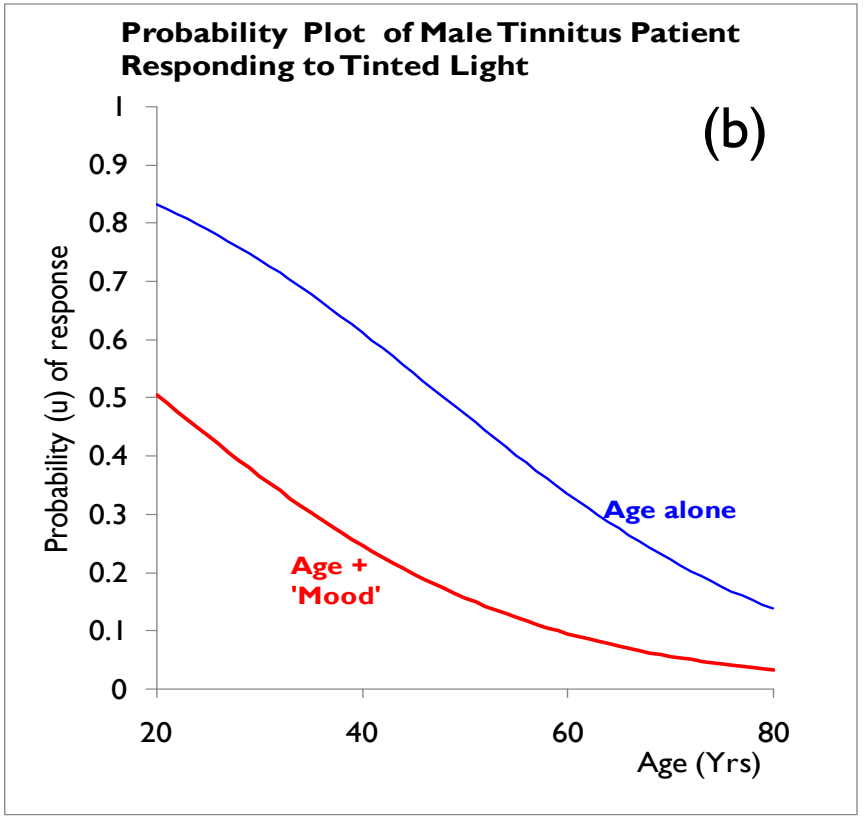
Table 2 Logistic Regression Equation Predicting Positive Response Likelihood

$$Pr(\mu) = \frac{e^{(2.58 - 0.057*age - 1.55*sex - 1.58*mood)}}{1 + e^{(2.58 - 0.057*age - 1.55*sex - 1.58*mood)}}$$

Gender and Age are Significant Predictors in the Model

The probability $Pr(\mu)$ of being a positive responder based on the model derived from this study is shown in Figs. 9 (a&b). Fig 9(a) shows that female gender is associated with a higher probability of being a responder. At age 20, $Pr(\mu)$ is nearly 1. This decreases with each year of age by 5%, but the chances of being responsive are still high at 60yrs with with $Pr(\mu) = 0.7$.





Figs. 9(a&b). Logistic Regression Probability Plots for: (a) Females; (b) Males

Fig 9(b) shows that young males with tinnitus still have a high predicted probability of responding. Over age 20-30 yrs, Pr(μ) falls between 0.83 - 0.7 and is about 0.5 at 50 yrs.

Reporting Non–Auditory Mood Effects is a Significant Negative Predictor in the Model.

Both Figs 9(a&b) illustrate that reporting of mood changes decreases the likelihood of a positive response. This is particularly marked in males but the probability is still reasonably high at 20 yrs; Pr(μ)= 0.5.

Methods

Ethics & Recruitment

Local Ethics Committee Approved

Subjects recruited from ENT clinics

18 yrs age minimum

Stable tinnitus > 6 months

Exclude serious pathology

(eg neuroma psychiatric illness)

N = 94 subjects

Predictor Variables 1

Demographic

Sex Age

Tinnitus Descriptors

THI Score Duration Dominant Ear

Perceived Intensity/Distress

Tinnitus Tonal Category:

PureTone; Bandpass; White Noise; Mixed

Predictor Variables 2

Hearing

Exposure to potential ototrauma.

Noise: Occupational; Leisure; Head Injury; Surgery; Ototoxins

Audiometry

Hearing Loss / Deafness Middle Ear Function

General Health History

Serious Acute/Chronic Illness

eg Meningitis/Diabetes

Non-Auditory Effects of Colour

Reported Effects on Mood.

Other Sensory Effects

Experimental Procedure

Performed in darkened sound proof room.

Subject instructed to change Red Green Blue LEDs via three dials to move thru color space.

Subjects asked to report any type of change in tinnitus when moving thru color space.
No feedback given to subject on performance

Any changes in tinnitus – then CIE 1931 X:Y color space co-ordinates recorded

Sessions typically last ≈ 5-10 minutes free to verify optimal points

Dependent Variable - Binary Coding

Improved = 1
No Change = 0
* Worsened = 0

** For Logistic Regression Analysis*

Acute & Chronic Repeatability

Acute - Positive responders (n=23) repeat test 30-90 minutes later.

Chronic - Positive responders (n=15) repeat test over 6-24 months later.

Procedure per first measures. CIE 1931 X:Y color space co-ordinates recorded

Acute Longevity Testing

Positive responders (n=31) presented 'best' color for tinnitus over three minutes

Qualitative Dependent Variable

VAS Scale - Subject reports VAS every 30 seconds

'Tinnitus Completely Gone' = 0
'Tinnitus Worst Imaginable' =10

Calibration LED Light Source

RGB LED output diffused through Fresnel lens.

Projected on 20x30 cm white platten at 30 cm.

Maximal output:

CIE 1931 X:Y = 0.333, 0.333; White; 800 lux.

Viewed ≈ 40-50 cm from subject eyeline

Statistical Analysis

Exploratory Analysis

Predictor Variables Distribution / Odds Ratio Tables / Univariate Logistic Regression

Model Building

Predictive Multivariate Logistic Regression with adjusted parameters for significant variables

Non-parametric Repeated Measures

Friedmans ANOVA for acute longevity

P <0.05 significance level throughout

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