



Characterization of Light Sensor Performance for Three Models of Actiwatch

Actiwatch-64, Actiwatch 2 and Actiwatch Spectrum

Introduction

Respironics is offering three wrist-worn activity loggers, the Actiwatch 2, Actiwatch Spectrum and Actiwatch-L. An Actiwatch device is an ambulatory physiological data logger used in research and clinical settings to detect and record motion on humans during wake and sleep periods. In addition to activity recordings, the Actiwatch-L and Actiwatch 2 are equipped with an on-board miniature photodiode for measurement of the amount and duration of illuminance. Actiwatch Spectrum is equipped with multiple sensors for measurement of irradiance and photon flux in three color bands as well as illuminance.

To illustrate the relative performance of these devices, we characterized these light sensors in laboratory testing using National Institute of Standards and Technology (NIST)-traceable light sources and testing apparatus. The measurements for each device were compared to an NIST-traceable photometer and a spectroradiometer.

Light sensor description and measurement definition

Prior to the availability of Actiwatch Spectrum, light exposure recordings from wrist-worn devices had been expressed in illuminance (lux/m^2). Illuminance is an expression of the apparent brightness of a light source as observed by the human eye under normal to bright light conditions. The sensitivity of the human eye to light varies with the wavelength and peaks at 555 nanometers (nm). Illuminance measurements are generally obtained through the use of a broadband photodiode. The spectral responsivity curve is similar to the photopic, or CIE-Y, curve and approximates the spectral responsivity curve of the human eye.

The most common use of illuminance measurements in clinical research is for establishing when lighting sources are turned on or off in reference to a sleep period. In some cases, illuminance measurements are also used to quantify the amount of time in which the wearer is exposed to light in excess of a specified illuminance threshold. Actiwatch 2 and Actiwatch Spectrum support these common uses.

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In the case of Actiwatch Spectrum, three independent sensors are used to provide irradiance and photon flux recordings for three color bands within the visible spectrum as well as an illuminance measure in lux/m². The recorded light bands correspond to the red, green, and blue color regions. Each color sensor provides irradiance information over a range of wavelengths. From this, photon flux and illuminance measures are calculated. Table 1 contains the definition of each color band for the Actiwatch Spectrum.

Table 1. Actiwatch Spectrum color band definitions

Color Sensor Type	Color Band Definition (nm)	Color Band Width (nm)
Red	600 – 700	100
Green	500 - 600	100
Blue	400 - 500	100

Actiwatch Spectrum records irradiance as photon flux may be calculated from this measure. Photon flux (photons/cm²/sec) is a more appropriate method than illuminance for estimating the actual impact of incident light on the human eye. Irradiance is defined in units of μW(Microwatts)/cm² and is a measure of the power of light impacting the surface of the sensor rather than an estimate of the intensity of white light at the source. Within the Actiwatch Spectrum, irradiance is used to calculate the photon flux within each color band.

Because light has a major influence on circadian phase, it is important to have information about the duration, intensity, and color content of common ambient light sources for studies in which circadian phase is important. Photon flux (photons/cm²/sec) is a more appropriate means of assessing the circadian impact of light than either irradiance μW(Microwatts)/cm² or illuminance (lumens/m²). Actiwatch Spectrum is the first device available with this capability for use with ambulatory research subjects.

The Actiwatch Spectrum system also calculates white light illuminance (lux) by integrating the input from the three colored light sensors. Illuminance and irradiance are related by the variable spectral sensitivity of the human eye. The relationship between irradiance and photon flux is defined by the energy per photon.

Methods

Illuminance Recordings

Samples of the Actiwatch-L, Actiwatch 2 and Actiwatch Spectrum activity monitors were selected at random and configured (via reader, communication docks and Actiware software) for ambient light recording. Samples were placed in a Gretag-Macbeth Spectralight Jr. light booth and exposed sequentially to four commonly-used types of “white light”: CIE:A, CIE:Daylight-65, Horizon, and Fluorescent. In the case of A and D-65, the light illumination is in accordance with the international standard ISO-10526 (CIE-S-005) for light sources.

Additionally, to illustrate the performance of the light sensors in Actiwatch 2 and Actiwatch Spectrum in real world conditions, measures of illuminance from Actiwatch 2 and Actiwatch Spectrum were compared to NIST-traceable photometer results after exposure to light sources commonly encountered in the typical human environment. These sources included: a laptop in a dark room, a laptop and Apollo P2 light box in a dark room, a laptop with overhead fluorescent lighting, the reflection of incandescent light from a book, a sunlit conference room and an overcast day.

Irradiance and Photon Flux Recordings

Samples of Actiwatch Spectrum activity and light monitors were selected at random and configured for data collection. Actiwatch Spectrum was exposed to specific colored light sources produced by illumination with light-emitting-diodes (LEDs) and color filters illuminated by the NIST-traceable CIE:A source.

Additionally, to illustrate the performance of the colored light sensors in Actiwatch Spectrum in real world conditions, measures of irradiance from Actiwatch Spectrum and an NIST-traceable spectroradiometer were made after exposure to

light sources commonly encountered in the typical human environment. These sources included: a laptop in a dark room, a laptop and Apollo P2 light box in a dark room, a laptop with overhead fluorescent lighting, the reflection of incandescent light from a book, a sunlit conference room and an overcast day. The resulting data demonstrate the colored light recording performance of the Actiwatch Spectrum and the subsequent importance of these recordings as compared to a single white light measurement.

Results

Actiwatch-L, Actiwatch 2 and Actiwatch Spectrum Illuminance Measurements from Standard Sources

Figure 1 shows the illuminance recordings from several “white light” sources measured by the Actiwatch-L, Actiwatch 2 and Actiwatch Spectrum. Also shown are the illuminance measures from an NIST-traceable photometer. Because the Actiwatch-L and Actiwatch 2 were calibrated to the CIE:A source, the best agreement is obtained with that source. However, agreement is consistent for the other sources as well.

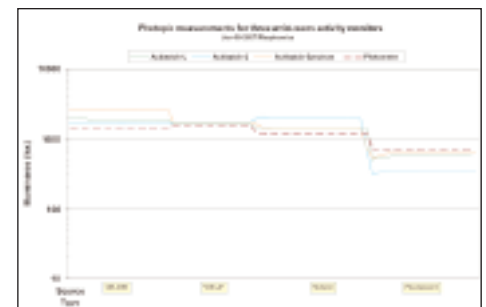


Figure 1: Actiwatch 2, Actiwatch-L, and Actiwatch Spectrum’s white light measurement performance compared to an NIST-traceable photometer.

Actiwatch 2 Illuminance Measurements in Real World Conditions

Figure 2 displays illuminance of each white light source as measured by Actiwatch 2, which has been calibrated using a CIE:A source relative to an NIST-traceable photometer. Actiwatch 2 performance is in agreement with the photometer when used with light sources other than CIE:A.

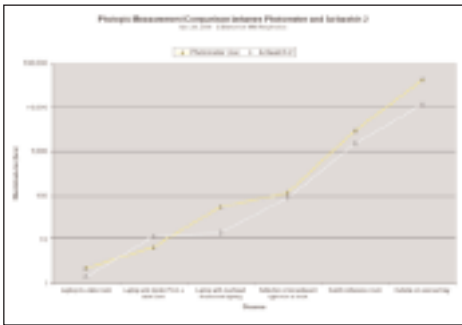


Figure 2: Actiwatch 2 performance compared to a photometer for multiple, common light sources.

Actiwatch Spectrum Irradiance Measurements from Standard Sources

Figure 3 displays the irradiance of each “white light” source as measured by Actiwatch Spectrum and an NIST-traceable spectroradiometer. Because Actiwatch Spectrum is calibrated for the CIE:A source, it most closely matches the irradiance of that source, but also provides good agreement with the spectroradiometer when measuring irradiance from other sources.

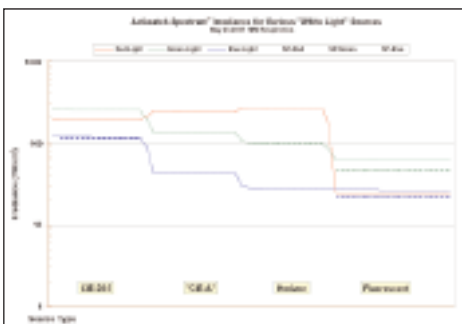


Figure 3: Actiwatch Spectrum irradiance measurements from standard light sources compared to an NIST-traceable spectroradiometer.

During normal daily life, individuals are exposed to light from a variety of different sources. Sunlight, incandescent lamps, fluorescent lights, computer monitors, and light-emitting-diodes (LEDs) all commonly exist in our home, office, recre-

ational, and industrial environments. Each source provides differing intensity and color content. Because light is a major input into the setting of circadian phase, information about duration, intensity, and color content of common ambient light sources is important in understanding circadian response. Actiwatch Spectrum colored light measurements illustrate that not all light sources are the same and that white light recording may not be a sufficient reference for truly understanding the effect of light on circadian phase. Actiwatch Spectrum provides the most comprehensive colored light exposure data recordings available from any wrist-worn ambulatory monitoring device.

Actiwatch Spectrum Illuminance and Irradiance Measures in Real World Conditions

Figure 4 contains irradiance measurements for the three color bands made by Actiwatch Spectrum. Additionally, white light illuminance measures are reported from Actiwatch Spectrum and a traceable spectroradiometer. Measurements were made across a range of common light sources of various illuminance: a laptop in a dark room, a laptop and Apollo P2 light box in a dark room, a laptop with overhead fluorescent lighting, the reflection of incandescent light from a book, a sunlit conference room and an overcast day.

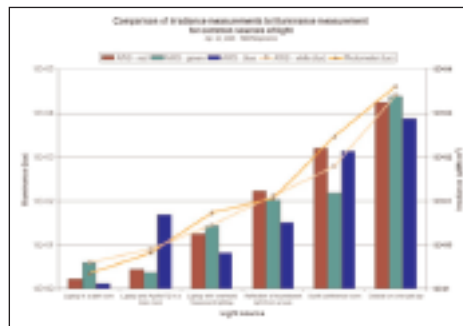


Figure 4: Actiwatch Spectrum's free-living white light illuminance measurement performance as compared to a photometer as well as colored light irradiance measurements of those white light sources

Actiwatch Spectrum colored light measurements show that commonly encountered light sources contain differing levels of colored light. Illuminance alone is not a reliable indicator of irradiance. This is particularly evident when comparing the results from the laptop and Apollo

P2 light sources to the reflection of incandescent light from a book. In these two cases, irradiance in the blue color band is higher in the former even though total illuminance is an order of magnitude greater in the latter.

Conclusions

The data collected illustrate the excellent performance and concordance of the Actiwatch-L, Actiwatch 2 and Actiwatch Spectrum to record illuminance under controlled laboratory conditions and real world lighting conditions that span a range of commonly encountered illuminance levels. Comparison of the illuminance results from these devices to an NIST-traceable photometer shows that the Actiwatch devices are able to provide good relative measures of illuminance for ambulatory light recordings.

Because illuminance is not the most appropriate measure of ambient light for the purposes of understanding actual exposure, Actiwatch Spectrum has been designed to record irradiance and photon flux. Actiwatch Spectrum irradiance measures showed a similar response to an NIST-traceable spectroradiometer when exposed to standard light sources under controlled laboratory conditions.

When exposed to real world lighting conditions that span a range of commonly encountered illuminance levels, Actiwatch Spectrum was able to show that the various sources contain varying levels of light in the three wavelength ranges corresponding to red, green and blue light.

Humans are exposed to a variety of artificial light sources at highly variable times of the day; therefore, the use of an overall illuminance measure is not the most appropriate method for understanding the impact of light on circadian physiology. Because it collects a time series of irradiance and photon flux measurements, the Actiwatch Spectrum is a useful tool for increasing the understanding of incident light on human research subjects in their daily life and how light sources may impact the resetting of the circadian phase.



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