Contributed Numbers

Psychometric function slopes (Burr)

From: David Burr <dave@neuro.in.pi.cnr.it>

What an interesting idea. I'd like to see the list when you've got it.

One obvious number is that the slope of the psychometric function for almost anything (on log co-ords) is 3. (Weibull function) or a sigma of about 4 dBs for a cummulative Gaussian. I guess Pelli showed this for contrast, but it seems to work for orientation, signal-to-noise measures, vernier or whatever, provided you taker logs, although I don't know if it's been formally documented.

Eccentricity (Anderson)

From: cha@shifter.wustl.edu (Charles H. Anderson)

>I am interested in collecting up some experimentally obtained numbers
>concerning human visual performance that people have found useful in
>designing experiments or in thinking about models of human vision.

Brian,

Here are two factors that play a major role in my thinking about human visual performance. The first deals with how visual acuity changes with eccentricity, the second with the spatial extent of the window of visual attention.

The resolution, dE, at the retinal ganglion cell level, primarily Parvo, changes with eccentricity according to the equation, with all units in degrees.

dE ~ a(E+E0) ~ 0.01(E+1.3)

These numbers are for the macaque monkey. My guess for human values is that a~0.006-0.008, and E0 is somewhere between 1.0 and 1.5 for both monkey and humans. Visual acuity drops by a factor of 2 at and eccentricity of E0~1.0 degrees. The linear fall off in resolution reflects the underlying scale invariance of the system.

The anisotropy with angle around the fovea is small except along the horizontal meridian toward the blind spot, where the resolution could be a factor of 2 smaller in size, i.e. higher acuity.

As I recall this is quite good out to 40 to 50 degrees.

One has to be careful not to confuse this equation with grating threshold sensitivity since the Magno system, more specifically the non-linear subpopulation of the Magno system, can respond to higher spatial frequencies, especially in the periphery. This response however is only to the power, all phase information is lost. I have estimated that information carried in the optic nerve as "dynamic texture", i.e. the power of high temporal-spatial frequencies, exceeds that of color. This information is used in manner similar as color is for both searching for targets as well as aiding in recognition. It also bypasses the cognitive system altogether and is used to initiate protective reflexes against in coming objects.

Another interesting numberical factor is the sampling spacing of the Magno system is about a factor of 3 larger than that of the Parvo system at all eccentrities. There is some data, which Van Essen believes, that suggests this rises to about 5 in the center of the fovea.

Reference:

Van Essen, D.C. and Anderson, C.H., ``Information processing strategies and pathways in the primate retina and visual cortex'', in Introduction to Neural and Electronic Networks , eds. S.F. Zornetzer, J.L. Davis, and C. Lau, Academic Press, Orlando, Florida, 1990.

An updated revised version will be available shortly.

The second factor is that the relative spatial extent of the window of visual attention spans a diameter of about 30 nodes, where the absolute spatial size of the nodes depends on the scale at which covert attention is set. I first settled on this factor using the observation that grating sensitivity increases with the number of cycles displayed up to about 10-15 cycles. To first order this is independent of spatial frequency. Using the Nyquist limit, this means the number of samples involved in the analysis is about 20-30. This is much smaller than the number of cycles you can actually perceive. The equation above would suggest that the number of resolvable points would be = 2*E/dE ~ 200!

Since then I have found many examples that show there is something special about a spatial extent of 30 nodes. George Sperling has shown that sign language can be perceived with better than 90% accuracy using a display 28 by 20 pixels in size. Note that this holds irrespective of the distance between the viewer and the screen. We have summarized some of the supporting experiments in

Van Essen, D.C., Olshausen, B., Anderson, C.H. and Gallant, J.L., ``Pattern recognition, attention, and information bottlenecks in the primate visual system.'' In: Proc. SPIE Conf. on Visual Information Processing: From Neurons to Chips, vol. 1473, 17-28, 1991.

The machine vision project I initiated at the David Sarnoff Labs back in 1983 was inspired by these observations. The neurobiological circuitry for processing visual information using a window of attention that can be translated and zoomed in scale have been reported in.

Olshausen, B., Anderson, C. and Van Essen D., ``A neurobiological model of visual attention and invariant pattern recognition based on dynamic routing of information'', J. Neuroscience, {\bf 13},pp. 4700-4719, 1993.

A second more detailed paper has been accepted for publication in the Journal of Computational Neuroscience.

"A Multiscale Dynamic Routing Circuit for Forming Size- and Position-Invariant Object Representations"
Bruno A. Olshausen, Charles H. Anderson, and David C. Van Essen

I believe there will also be a paper appearing in Science shortly by Ed Conner, Van Essen, and Gallant on experiments showing cells in area V4 encode information in a local coordinate frame that moves with covert attention.

Attention (Biederman)

From: ib@rana.usc.edu (Irving Biederman)

Dear Brian:

A number that I have found useful--and an important constraint in trying to understand models of visual recognition--is 100 msec. It is the exposure duration, followed by a mask, required to recognize an object or scene. This value is not noticeablly increased (if at all) if RSVP presentations are employed rather than single trial presentations. Also, in RSVP a negative detection task ("Press the key if you see a picture that is NOT a mode of transportation") is not much more difficult than positively specified basic level classes (e.g., "Hit the key if you see a chair").

References:

Single trial:

Biederman, I., Rabinowitz J., Glass, A. L., \& Stacy, E. W., Jr. (1974). On the information extracted from a glance at a scene. Journal of Experimental Psychology, 103, 597-600.

RSVP (Good review):

Intraub, H. (1981). Identification and naming of briefly glimpsed visual scenes. In D. F. Fisher, R. A. Monty, and J. W. Senders (Eds.). Eyemovements: Cognition and Visual Perception (Pp. 181-190). Hillsdale, N. J.: Erlbaum.

While we are in the temporal domain, another result that I find useful is that cells in the anterior reaches of IT show tuned responding (e.g., if a face cell to a picture of a face) in under 100 msec from the presentation of the picture. Reference:

Baylis, G. C., Rolls, E. T., and Leonard, C. M. (1987). Functional subdivisions of the temporal lobe neurocortex. Journal of Neuroscience, 7, 330-342.

Though these cells will continue to fire for about 400 msec, much of their information (as estimated from a population code of face cells) is in the first 50 msec. Reference:

Tovee, M. J., \& Rolls, E. T. (1995?) Information encoding in short firing rate epochs by single neurons in the primate temporal visual cortex. Visual Cognition, in press (?)

As for a non-temporal constant:

Only two or three simple parts (in their appropriate relation) rather than the whole object are almost always sufficient for basic level classification. Ref:

Biederman, I. (1987). Recognition-by-Components: A Theory of Human Image Understanding. Psychological Review, 94, 115-147.

I liked the two numbers you mentioned. (By the way, is the value for the number of cones per degree of visual angle only at a .5 deg radius around fixation, rather than throughout the cone regions of the eye?)

If it would not be too much trouble, I would enjoy seeing your final collection.

Hope all is going well with you. My best wishes for the New Year,

Irv

Visual angles (Teller)

From: Davida Teller <dteller@u.washington.edu>

Brian -- I don't know if this qualifies, but here is my favorite "Rule of Thumb": your thumbnail at arm's length is a bout a degree of visual angle! Also, the sun and the moon each subtend about 1/2 degree.

In another area, by behavioral testing, an infant's acuity in cycles/degree is roughly numerically equal to its age in months (5 months, 5 c/d, etc). dt

Visual angles (Brown)

From: dsbrown@hkpcc.hkp.hk (Brian Brown)

Brian

Undergraduates (and postgraduates) often have trouble estimating angular subtenses.... the 'Rule of thumb'.. is that the thumbnail at arms length covers about 1.25 degrees (or at least mine does), and can be used then to estimate angular sizes and distances in the real world for any object that can be aligned with the thumb.
And of course 1cm at 57 cm is 1 degree.

Your human lens (60 Diopters) is wrong... that's the total power of the eye, cornea, lens and effectivity of the various optical components.

Here are a few more:

Corneal radius: about 7.8 mm
Corneal power: about 42D (as you see, leaving only 18D for the lens and effectivity of the corneal power and lens power)
Corneal diameter: 12 mm
Axial length: about 25 mm
Change in refractive power: about 3D/mm change in axial length

Time taken for a saccadic eye movement in ms:

20 + twice the amplitude in degrees,

so that a 10 deg saccade takes about 40 ms.

Robinson DA. The mechanics of human saccadic eye movement. J Physiol 180, 569-590, 1964.

Handbook of Ophthalmic Optics, published by the
Carl Zeiss Co
7082 Oberkochen
West Germany

Visual angles (Knoblauch)

From: Ken Knoblauch <Ken.Knoblauch@cismibm.univ-lyon1.fr>

The constant that I run into most frequently lately is 57.3 cm, which is the distance at which 1 cm subtends 1 deg, but everyone knows that.

Units (Mulligan)

From: "Jeffrey B. Mulligan" <jbm@vision.arc.nasa.gov>

candelas per m^2 x area of pupil in mm^2 = photopic trolands

approximate relative luminous efficiencies of typical rgb monitor:
R:G:B = 3:6:1

Cortex and motion (Britten)

From: khbritten@ucdavis.edu (Ken Britten)

10^6 fibers/optic nerve (OK, I don't use it in my work, but it's such a nice round number)

30 cortical areas for vision

approx 1 degree spatial scale for "short-range" motion, centrally. (Braddick)

V1 RF size = .1 * eccentricity

MT RF size = .8 * eccentricity (Maunsell \& Van Essen)

OK, that comes from the top of my head, maybe more will bubble up later...

Chromatic aberration (Howarth)

From: Peter A Howarth <P.Howarth@lut.ac.uk>

2 Diopters .... the approximate amount of longitudinal chromatic aberration of the human eye over the visible spectrum

The reference I like is Howarth and Bradley, Vision Research 26, 361-366, 1986
but probably a better one is Wald and Griffin 1947, JOSA, 37, 321-336

Cortex (Shadlen)

From: mike@monkeybiz.stanford.edu (Mike Shadlen)

Brian,
Here are some #s for you -- I suspect you already know these well.

120,000 neurons per mm^3 in monkey striate cortex
or 200,000 under 1 mm^2 of cortical surface.
(O'Kusky and Colonnier, J Comp Neurol 1982, 210:278)
(see also, Peters' chapter in Cerebral cortex, Vol 6, Joes and Peters eds. 1987, New York, Plenum)

This one's sort of obscure, but I think about it a lot:
150 neurons in a microcolumn of cortex defined by a cylinder the diameter of a layer 5 pyramidal cell's dendritic tree.
The real numbers are 143 for monkey and 203 for cat.
(Peters and Yilmaz, Cerebral Cortex 1993, 3:49-68)
(Peters and Sethares, J Comp Neurol 1991, 306:1-23)

Search (Wolfe)

From: wolfe@search.bwh.harvard.edu (Jeremy Wolfe)

Hi Brian

My favorite number these days is 50 msec/item as an estimate of the rate at which serial attention moves from item to item in visual search. There are various theoretical complications surrounding this but it does useful work for me.

Can I get a copy of the list that you compile? What is it for, anyway?

jeremy

Cortex (Kersten)

From: Daniel Kersten <kersten@mach.psych.umn.edu>

Hi Brian,

I don't know if this really satisfies the "usefulness" criteria as well as #cones/deg. You may be familiar with Cherniak's article below that was stimulated by the discrepancies he noted in the literature citations regarding how big the human cortex is (area estimates differed by a factor of 10, I believe...again this discrepancy probably has more to do with "who really cares", than any inherent difficult in making the estimates more precise.)

If you plan on publishing any of these, they should probably be double-checked. I just pulled them off of an old spreadsheet I filled out when I first read Cherniak's article.

If one assumes 40% of the connections carry visual information (a visual scientist estimate, linguists probably put it closer to 1%), one can calculate that there are 1,990 miles of visual connections--a number neither very useful or very believable--but may be fun to quote.

Cherniak, J. of Cog. Neurosc., 1990, vol 2., pp 58-68

Area of cortex	160000	mm^2		
Thickness of cortex	2	mm		
Volume of cortex =	320000	mm^3	0.32	liters

Cortex synapse density	4000	synapse/neuron
Cortex connectivity	200000000	synapses/mm^3
connectivity/neuron	5	mm
connection length/mm^3	25000	mm
neuron density in cortex	50000	neurons/mm^3
Total brain volume	1.4	liters
Total neurons in cortex	1.60E+10	

Optics (Adams)

From: aadams@garnet.berkeley.edu (Anthony Adams)

Brian,
I'll give it some thought
Incidently 60D is about the power of the human EYE- not the human lens (which is only about 9-11D IN the eye.
Tony

optic nerve head is 5x7degrees angle (Vertical=7)
20/200 letter)'the big E") is just under one degree angular subtense (50 min exactly)

Optics (Levick)

From: William.Levick@anu.edu.au (William Levick)

Brian: You might consider including the following formula, although it is not strictly based on experimentally measured quantities:

B = dE   (approximate, for relatively small E)

where: B (radians)is the angular diameter of out-of-focus blur circle
d (meters) is the diameter of the entrance pupil
E (diopters) is the out-of focus error of the eye.

It is probably well known but I was not aware of a citation when I presented it in:

Levick, W.R. (1972). Receptive fields of retinal ganglion cells. Pp. 531-566 in: Handbook of Sensory Physiology, Vol VII/2. Physiology of Photoreceptor Organs, ed. by M.G.F. Fuortes. Springer Verlag: Berlin.

A simplified form, together with other data is given on pp. 538-539.

Good luck with your collection!

Bill Levick

Visual angles (O'Shea)

From: "Robert P. O'Shea" <R-OSHEA@rivendell.otago.ac.nz>

The visual angle of the first joint of the thumb held
at arm's length is approximately 2 deg.

O'Shea, R. P. (1991). Thumb's rule tested: Visual angle of thumb's width is about 2 deg. Perception, 20, 415-418.

(By the way, if my memory serves, Helmholtz is the source of the number: 120 cones per degree of visual angle.

Helmholtz, H. (1873). The recent progress of the theory of vision. In Popular lectures on scientific subjects (pp. 197-316). London: Longmans, Green \& Co.)

Cheers,
Robert.

Retina (Schein)

From: Stan Schein <stan@psych.ucla.edu>

Dear Brian, 1/5/95

A number that is related to 120 cones/deg of visual angle is foveal retinal magnification, which is about 290 um/deg in human and 210 um/deg in macaque monkey. (I specify foveal, because the distance from the posterior nodal point to the retina declines with eccentricity, so retinal magnification does proportionately.

Stereo, visual sensitivity, many others (Backus)

From: ben@john.Berkeley.EDU (Ben Backus)

Dear Brian,

What a good idea. I hope you plan to make your collection available soon.

Useful vision numbers:
   The stereoscopic threshold for a step in depth on a surface is 3 sec of arc. The threshold for detecting that points are not coplanar is 30 sec. [Stevenson, S. B., Cormack, L. K., \& Schor, C. M. (1989). Hyperacuity, superresolution and gap resolution in human stereopsis. Vision Res, 29(11), 1597-605.]
   The eyes are 6 cm apart
   Best contrast sensitivity is at 3 cycles/deg. [Van Nes, F.L., \& Bouman, M.A. (1967). Spatial modulation tranfer in the human eye. Journal of the Optical Society of America, 57(3), 401-406.]
   Max spatial resolution is 60 cycles/deg [Campbell \& Green, 1965?]
   Visible spectrum runs 400-700 nm

Other useful numbers:
   A 1 cm wide object at 57 cm distance subtends 1 degree of visual angle; the width of one's thumb in cm is its angular subtense in degrees at arm's length.
   Luminance in cd/m^2 of starlight is 10^-3, moonlight is 10^-1, indoor lighting is 10^2, and sunlight is 10^5. [Hood \& Finkelstein, Ch. 5 in some book from which I have an unlabeled reprint. Maybe it's: Handbook of perception and human performance / editors, Kenneth R. Boff, Lloyd Kaufman, James P. Thomas. New York : Wiley, c1986.]

Useful numbers I don't remember but hope will be in your collection:
   The field of view for both eyes together
   The binocular region's field of view
   Axial length of eyeball
   Rod and cone integration times
   Easy way to remember how much light a troland is
   Wavelength of peak sensitivities of L, M, and S cones
   Fastest simple RT for flash detection; Typical V1 neuron's RT to a flash of light.
   Size of a V1 foveal hypercolumn in deg visual angle
   Number of different V1 hypercolumns used to tile retinotopic visual space

Hope I've helped.

--Ben

Time, cones, solid angles (Nilsson)

From: Thomy Nilsson <NILSSON@upei.ca>

Dear Brian,
Here is a less common "fact". The minimum interval at which two brief (1 ms), small (30') pulses of light can be discriminated from a single equal energy pulse is about 15- 20 ms and at photpic luminance seems not to vary with luminance. (Vision Res '79, ARVO '92).

Your data on the number of cones per degree visual angle is not clear. Do you mean the diameters of 120 cones across a distance on the retina subtended by 1 degree or an area on the retinae with a diameter equal to 1 degree?

When it come to solid angles, here is what I've found to be a good approximation for that elusive unite the steradian: Hold your arm straight out infront of you; bend the elbo 90 degrees; now rotate the bent portion as much as possible about the axis of the straight portion. The resulting area that would be swept by a 180 sweep with a center at the mid point of the bent forearm equal about 1 steradian. Surprizingly big. Smaller or larger people's portions of arm lengths seem to maintain this principle.

Would you send me list of the "facts' when it is completed? Thanks,
Thomy

Numbers (Cormack)

From: CORMACK@PSYVAX.PSY.UTEXAS.EDU (Lawrence K. Cormack)

Brian,

I constantly find myself using:
360/2=PI or approx. 57.3

I believe many of us use a multiple of this as the viewing distance in our experiments for obvious reasons. I don't really know a ref., but I suspect it would be Euclid.

-Lar

Lawrence K. Cormack
University of Texas
ph. (512) 471-1649
fax: (512) 471-5935

Optics (Moreland)

From: "J.D. Moreland" <coa09@cc.keele.ac.uk>

Dear Brian,

The use of age-matched controls is good practice in many clinical studies but is not appropriate for diabetes since lens absorbance changes are accelerated. Ideally, lens absorbance should be matched individually but, where the required facilities for this are not available, simple formulae may be utilised to define lens-equivalent age controls.

Thus:

$$E = A + 2.54T - 3.8 \qquad \text{for } 20 \le E \le 60$$

$$E = 0.30A + 0.76T + 40.9 \qquad \text{for } 60 < E < 80$$

where E is the age of a normal lens having the same absorbance spectrum as that of a diabetic patient of age A and with a diabetes duration $T > 1.5$.

For T up to 1.5, $E = A$.

E, A and T are all in years.

See: J D Moreland. "Lens-equivalent age controls for diabetics". Invest Ophthalmol Vis Sci 1993, 34, 281-282. (Letter to the Editor)

With best wishes,

Jack Moreland.

Visual angles (Bach)

From: bach@sun1.ruf.uni-freiburg.de (Michael Bach)

I like the simple equation: at 57cm distance (e.g. to your stimulus) one degree visual angle covers 1 centimeter.

Good idea, greetings, Michael.

Dr. Michael Bach, Dept. of Ophthalmology, University of Freiburg,
D-79106 Freiburg, Germany. ++049(761)270-4060. bach@sun1.ruf.uni-freiburg.de

Eyes (Ahumada)

From: Al Ahumada <al@vision.arc.nasa.gov>

Model number of eyes per subject: 2

Visual angles (Tootell)

From: roger@nmr-m.mgh.harvard.edu (Roger Tootell)

Brian:

A conversion factor that I use alot, and which does not seem to be as widely known as it should be, is:
1 Diopter = 0.57 degrees. Another handy factoid known to most physiologists is that at 57 cm, one degree is one centimeter wide; at 57 inches one degree is one inch wide, etc. If this collection is for your book, it sounds like a good idea.

1 diopter refracts light by 0.57 degrees. Useful when calculating the effect of various lenses and prisms.

Roger

Binocular vision (Pietsch)

From: reading@ucs.indiana.edu

My favorite one involves the enhancement of visual performance gained by going binocular. It applies to absolute light detection thresholds, brightness discrimination, critical flicker frequency, and visual acuity. The gain in sensitivity is always [more or less] equal to the square root of 2! You can arrive at this result through sampling theory,probability summation, or areal summation [an adaptation of Piper's law to binocular vision]. One of the implications of this approach is that a three eyed individual should enjoy an enhancement equal to the square root of three! [as suggested by the late Fergus Campbell}

Optics (Spillmann)

From: Lothar Spillmann <spillman@ruf.uni-freiburg.de>

Gullstrand's schematic eye puts the refractive power of the human cornea at 43.05 dptrs and that of the lens at 20.28 (unaccommodated) and 30.13 dptrs (fully accommodated), respectively. The result of accommodation is to change the EQUIVALENT power of the eye as a whole from 59.60 dptrs to 68.22 dptrs, a difference of 8.62 dptrs.

Source: Davson, H. (Ed.): The Eye, vol. 4, page 105 (1962), Academic Press, New York-London.

Lothar Spillmann, Phone (49-761) 270-9572, Fax (49-761) 270-9500
Arbeitsgruppe Hirnforschung, Institut fuer Biophysik
Hansastrasse 9, D-79104 Freiburg, Germany

Optics (Enoch)

From: jmenoch@garnet.berkeley.edu (Jay Enoch)

In studies where the Stiles-Crawford effect is of importance, or in ocular ray tracing, a simple relationship relating displacement in the entrance pupil of the eye to change in the angle of incidence at the retina is as follows:

1.0 mm in the entrance pupil of the eye = 2.5 degrees change in the angle of incidence

I first encountered this derivation (based on the emmetropized Gullstrand eye) in a monograph produced for the Air Force by Brian O'Brien and Norma Miller (post 2nd World War). I have separately derived it an reported it in many papers (including my book on Vertebrate Photoreceptor Optics). Interestingly, I pursued the issue using the Pommerantzef Schematic Eye derived for wide angle fundus photography. This same relationship holds for the peripheral retina as well for at least 30 degrees eccentricity (i.e., it may vary slightly, but only by a few tenths of a degree per mm displacement).

Hope this helps.

Jay M. Enoch jmenoch@garnet.berkeley.edu

Optics (Mershon)

From: mershon@unity.ncsu.edu (Don Mershon)

I saw your request (for "useful" numbers) which was distributed via CVNet. I am interested in whether you plan to circulate the results of your survey (perhaps to the same audience).

As a suggestion for your endevour: it would probably be most helpful if there were more specific identification of the application of such values. For example, you mentioned the number of cones per degree --- should one assume that the number refers to the fovea? Would it perhaps be a good idea to indicate the limits (e.g., +/- X deg.)? Similarly, you mention that the human "lens" provides about 60 diopters of optical power. Actually, the cornea provides about 40 diopters, while the lens itself provides a variable amount (from 20-32 D), assuming that I am remembering correctly. And, of course, again, one should specify that this would only be correct for a young eye.

Good luck with your project,
Don Mershon (N.C. State University)

Squid's eyes, the brain, subject contours, many (Cavanagh)

From: "Patrick Cavanagh" <patrick@burrhus.harvard.edu>

Brian,

I share some of your numerophiliac tendancies and will give just a stream of consciousness recall of the useless numbers which I can recall, some of which you should verify before using.

Size of giant squid's eye: 19 feet
Percent of all receptors in body which are on the retinae: 70%
Number of moons which will tile the sky: 100,000
Hyperacuity equivalent to: seeing an eye movement at a distance of one mile
Number of neurons in the brain in 1974: 10 billion
Number of neurons in the brain in 1994: 100 billion
Reason mirrors reverse left-right, not up-down: left-right symmetry of body
Earliest subjective contour: 4000 BC
Number of seizures induced by TMS: 2
Number of seizures induced by research fMRI: 0
Duration of Hess positive rod afterimage: 1 minute
Percent of submitted articles which never get published: 0%
Movie image rate: 24 per second
Movie frame rate: 72 per second (each shown 3 times)
Earliest motion model: Al-Haytham, 1024AD
Earliest pop-out model: Al-Haytham, 1024AD

And finally, my question of the day:

Why can lobsters survive out of water for several days? How do they breathe?

Number of watts required to power brain: 10 watts
Percent of total body energy required to run brain: 10%
Percent total input energy from breakfast: 10%
Conclusion: don't forget to eat breakfast
Will computers replace brains: No
Why: brains fit in a shoe box, run on 10 watts, and are easily reproduced with cheap labor

Patrick

Units, levels, optics (Burns)

From: sburns@vision.eri.harvard.edu (Steve Burns)

Brian:

Went over your list (thanks) and have some additions.

1. A troland (td) is produced on the retina when the eye is looking at a surface of 1 cd/m^2 through a pupil of area 1 mm^2. This makes it easy to compute the td value of a surface or TV monitor if you know the approximate pupil size.

2. For a standard eye 1 td produces 0.0035 lumens/m^2 on the retina.

3. From experience with a lot of aged individuals, the steady state diameter of the pupil, even at very high light levels (bleaching), never is less than 2 mm. Transient constriction very occaisionally will make the pupil smaller than this.

Yuks (Groh)

From: groh@monkeybiz.stanford.edu (Jennifer M. Groh)

Hi Brian,

Don't forget my favorite "facts":

1. The brain contains 10^12 neurons, 10^14 of which are in the cerebellum.

Reference: somebody famous.

2. We only use 10% of our brains.

Reference: the popular press.

More on Psychometric function slopes (Eskew)

From: ESKEW@neu.edu (Rhea Eskew)

Dear Brian and David:

I had intended to send you one or two useful vision 'constants', but I didn't get around to it.   Sorry. I'm motivated by your last message, however, to argue against the submission made by David Burr, who said the slope (beta) of (almost any) Weibull psychometric function is 3.

I (and Stromeyer) consistently find lower betas for the detection of spots. Part of the difference is that neither Charles nor I use the best procedures for measuring beta (we pool data across sessions, for instance, which is likely to lower the estimate), but I'm fairly confident that even if we did not do that we'd consistently get betas lower than 3.

More important than the absolute magnitude of beta, however, is the fact that we (and others) have demonstrated that beta varies across spectral conditions and tasks. I'll mention the three cases I've been most involved in: (a) chromatic betas are lower than luminance betas for detecting foveal gaussian blobs (1deg s.d.) (about 1.7 vs 2.4 in my lab -- not a large difference but a very consistent one). We haven't published this work yet but some was reported at ARVO last year. (b) With a 1deg foveal spot, a luminance pedestal approximately halves the chromatic detection slope (from about 2.2 to about 1.3 --ie, near ideal). Eskew et al JOSA 1991 vol 8 p 394-403. In that paper we show that this change in beta isn't simply uncertainly reduction. (c) The slopes for detection of chromatic and luminance spots increases in the periphery (with no pedestals). See the 91 JOSA paper, Fig. 3, and especially Stromeyer et al Vision Research 1992 vol 32, pp 1865-1873, Fig. 7.

I wish the psychometric slope truly was constant -- life would be simpler. But I don't believe it.

By the way, one of the constants I should have sent you before is that red-green chromatic sensitivity is roughly 10X greater than luminance sensitivity when sensitivity is defined as (1/sqrt[L^2 + M^2 + S^2]), and L, M, \& S are cone contrasts -- this is for 200 ms flashes. For flashes shorter than about 45 msec (for our bright adapting conditions), the ratio drops to about about 3X and should stay that way for all shorter flashes, assuming Bloch's law (Eskew et al, Vision Res 1994 vol 34, pp 3217-3137). So half a log unit is due to temporal integration, some is due to spatial integration, and some must be due to other factors.

Best,

Rhea

Optics, retina, cortex, more (Wooding)

From: David Wooding <WDRDSW@CARDIFF.AC.UK>

Dr.Wandell,

Thanks for the summary of numbers. A great idea!

I have been a bit busy of late, but was intending to submit something. Perhaps you would like to include the following, some of which people suggested should be included. I can expand on references if you like.

Thanks,

David.

THE OPTICAL PATH

Amount of light lost through scattering in the eye: 3-4%
Lens absorbance peaks at: 365-368nm (near UV)
   Said and Weale, 1959; Cooper and Robson, 1969

THE RETINA

Thickness of retina: 350 microns

%age of light incident on photoreceptors which is actually absorbed
by them: 10% at 500nm
Maximum rod density occurs: 10-15 degrees off axis
Osterberg, 1935
Position of cones: central 1-2 degrees of fovea
Number of rods in human eye: 110-125 million
Osterberg, 1935
Number of cones in human eye: 6.3-6.8 million
Dimensions of rod: 30 microns long by 1 micron diam
Dimensions of cone: 50-80 microns long by 5 microns diam
Relative abundance of long and middle wavelength to short cones: 100
Amplification of energy provided by rod: 10e4 - 10e5
Short-wavelength limit of visual sensitivity (human lens): 380nm
Peak absorption of Rhodopsin (rod pigment): 500nm
Extent of macular pigment: up to 8 degrees from fovea

THE CORTEX
----
approx %age of human cortex occupied by visual system: 60%
approx no.neurons in human visual system: 10e8
V1 surface area devoted to central 10 degs of visual field: 65%

VISUAL FIELDS

MONOCULAR:
Horizontal dimensions from central fixation: 60 degs nasally,
100 degs temporally
Vertical dimensions from central fixation: 60 degs above,
75 degs below
BINOCULAR:
Horizontal: 200 degrees
Vertical: 135 degrees
Width of area of steroscopic vision: 120 degrees
Height of area of stereoscopic vision: 135 degrees

SENSITIVITY

Dark adaptation (cones): 10 minutes
Dark adaptation (rods): 40 minutes

COLOUR VISION

Incidence of anomalous trichromacy in human popn:
1 in 100 (male), 1 in 10000 (female)

Incidence of protanopia and deuteranopia (dichromacy):
  1 in 100 (male), 1 in 10000 (female)
Incidence of tritanopia (dichromacy):
  1 in 10000
Incidence of rod monochromacy:
  1 in 10000
Incidence of cone monochromacy:
  1 in 100000

EYE MOVEMENTS

Slow drifts: velocity 6mins/s, amplitude 0.8-6.0 mins
Microsaccades: duration 10-20ms, amp < 50mins
  (elicited by positional error of > 15mins)
Tremors: frequency 30Hz+, amp 20mins
Smooth pursuit latency: 120ms (typical)
Smooth pursuit tracking limit: 30 degs/s
Vergence: velocity 15degs/s, latency 160ms, duration 800ms
Maximum size for natural saccades: approx 15ms
  Bahill et al., 1975

Visual sensitivity (Pelli)

From: "Denis Pelli" <denis-pelli@isr.syr.edu>

Subject:numbers 2:39 AM
1/13/1995

hi brian

great list. Here's my contribution:

The contrast threshold (delta L over L) for a static edge at photopic luminances is 1%. This predicts the visibility of a wide variety of large sharp edged objects, including letters.

This is an old result, as John explains:

Robson, J. G. (1993) Contrast sensitivity: One hundred years of clinical measurement. In R. Shapley and D. Man-Kit Lam (Eds.), Contrast Sensitivity (pp. 253-266), Cambridge, MA: MIT Press.

regards

denis

Visual sensitivity (Knoblauch)

From: Ken Knoblauch <Ken.Knoblauch@cismibm.univ-lyon1.fr>

Brian,

Notably missing from your list:

Cut-off frequency for chromatic gratings: ~10-12 c/deg (e.g., Mullen, 1985, J. Physiol).
Minimum bandwidth for optimal reading: 2 cycles/character
(relatively independent of size) Legge et al., 1985, Vis. Res.
(this article and its companions contain a number of fundamental constants related to reading text).
etc.

Other readings (Baker)

Sender: mrbaker@vax.ox.ac.uk (Mark Baker)

Dear Brian,
The list of useful numbers seems a great idea! Have you looked in Wyszecki \& Styles "Color Science."? It is full of gems of that sort and might make excellent additional source material. I've only got the reference for the 1967 edition but I think that there is a fatter even more comprehensive 1988(?) edition too . . .

Incidentally - the Eye-Movement network keeps a number of useful files on the Mailbase fileserver - members can have them e-mailed to them by sending the fileserver a message - would you like to have a copy of your file put there too? I'll put details of joining on the end of this message.

Keep up the good work!
Regards
Mark

Dr Mark R Baker (MRBAKER@UK.AC.OX.VAX)

Optics (Anderton)

From: (Phil Anderton) <P.Anderton@unsw.EDU.AU>

Hi,
I just read your list on CVNet, and one useful number which is not there is an approximate rule-of-thumb for deriving angular magnification by a "spectacle magnifier". This is a lens of high positive dioptric power held at the normal spectacle plane. The object of interest placed close to the anterior focal plane of the lens, and the eye views an enlarged virtual image of the object. Assuming a normal working distance of 250mm (without the lens), the angular magnification induced by the lens is about 1/4 the dioptric power. For example, a 16D lens gives a retinal image about 4 times larger than 'normal'. Beware though, this is very 'rough'.

Philip Anderton.

Visual sensitivity, optics, sampling (Teller)

From: Davida Teller <dteller@u.washington.edu>

Brian -- and of course there's that wonderful convergence of numbers, that grating acuity, the cut-off frequency of the optics, and the Nyquist limit of the foveal photoreceptors are all about 60 c/d. dt

Return-Receipt-To: "M. Angeles Losada Binue" <iodma15@cc.csic.es>

Hi Brian

One of the main lines here has been modeling the eye and measuring the ocular MTF using a double-pass method. I think you may be interested in these two papers:

1. Accommodation-dependent model of the human eye with aspherics. R. Navarro, J. Santamaria \& J. Bescos JOSA A 2, 8 pp1273 (85).
2. Monochromatic MTF of the human eye for different pupil diameters: an analytical expression. JOSA A 11 pp246 (94). Here you can find an analytical expression for the foveal MTF as a function of both pupil diameter and normalized spatial frequency.

MTF(sf,p)=(1-C1+C2*p)*exp[-A1*exp(A2*p)*sf]
+(C1-C2*p)*exp[-B1*exp(B2*p)*sf]

where A1=3.53; A2=0.43; B1=1.69; B2=0.28; C1=0.48; C2=0.037

and 2<p<8 mm; sf=sf0/sflim with sf0<50 cpd and sflim being
the cut-off frequency for wavelegth 632 nm.

I hope this will be useful to you.

Cheers

Angeles

Units (Nilsson)

From: Thomy Nilsson <NILSSON@upei.ca>

Dear Brian,
Thanks for the list. Thought of 2 more:

retinal illuminance = incident luminance X pupil area in mm sqd X .0016

Note that the above has a correction from Judd's constant of .004. (See Applied Optics 1983, p.3462)

When dealing with a round stimulus which is the only scource of light, one can calculate its luminance from a measure of illuminace as obtained with a simple light meter:

luminance (cd/m sqd) = illuminance (lumen/m sqd) / Pi X (sine A/2)sqd

where A is the visual angle of the stimulus' diameter.

Regards,
Thomy

Color (Varner)

From DVarner@swri.edu Fri Jan 13 11:31:29 1995

Hi Brian--

I happened to read your posting of the important numbers for vision. Although I don't do color anymore (or vision either for that matter), I'm still Dottie and Leo's student. So I'd like to add:

Unique blue-- about 475 nm

Unique green-- about 500 nm
Unique yellow-- about 575 nm

With these three numbers and a knowledge of the basic color-opponency relationships, a person can relate spectral wavelengths to color appearance.

denise

Philosophy, numbers, New York running commentary (Graham)

<nvg@psych.columbia.edu> (Norma Graham)

Jan. 14, 1995

Dear Brian,

(1) Re your numbers: To second the point made by one of your repondents. Most numbers that are useful to me have a limited range of applicability, and theis range if frequently difficult to succinctly express.

However, some idea of a number's magnitude is very frequently a whole lot better than no idea. And I very much enjoyed your list of replies. And I hope you can manage some numbers of this sort in your book. And it is great that your book may be getting done!!

(2) Not mentioned in your email summary of other replies you received is one I do find useful (not only quantitatively but also it reminds me of the qualitative relationship). Namely

0.5 db per period is the loss of contrast sensitivity moving away from the fovea (relatively independent of spatial frequency, at moderate temporal frequencies, and for photopic luminances, etc. etc. and so forth).

How good is this number? Asking how the loss depends on number of periods is a whole lot more useful than asking how it depends on distance in visual angle. Actually, there is a loss of between 0.5 and 1.0 log units contrast sensitivity (10 to 20 db) in thirty periods in John's and my data (Fig. 4 from Robson and Graham, 1981, reprinted as Fig. 5.6 in Graham, Visual Pattern Analyzers, 1989). Also see see Fig. 13.5 (section 13.4.3.in the book) showing that this "number-of-periods" rule of thumb is consistent with size-scaled models of the retinal inhomogeneity.

(3) A related point, made with regard to Charles Anderson's window of attention, in particular with regard to his using grating sensitivity as

one support for it: Figuring out the window of attention from the number of cycles over which grating sensitivity increases is problematic unless you get the grating someplace where there is sufficient homogeneity. And if you get someplace where there is uniformity, grating sensitivity increases out to at least 30 (or 60) than 10 or 15 cycles. And we did not test higher. Of course, it may only be a factor of 2 (or 4) different from his estimate, but I am not sure that it wouldn't increase even out to greater distances (for conditions where the observers have reason to spread their window of attention as wide as possible). See FIg. 3 from Robson and Graham, 1981 reprinted as Fig. 5.7 of Graham, Visual Pattern Analyzers, 1989.)

(4) Of course another number which appears here and elsewhere is that the amount by which sensitivity would be predicted if you double the number of things involved. A notice one response dealt with it in the binocular situation. But you might try something more general. Is it dealt with in the text of the book anyway?

(5) I find that remembering contrast sensitivity at the peak of the sensitivity vs. spatial or temporal frequency in typical conditions is something between 100 and 1000 is useful. I usually say 300 for moderate temporal frequencies and moderate photopic but this really does depend on a lot. (Again, however, compared to total ignorance, this is a very useful number!!)

A challenge (Sivak)

From: "Dr. J. Sivak" <jsivak@sciborg.uwaterloo.ca>

To Brian Wandell,

The giant squid eye cannot be 19 feet in diameter (see P. Cavanagh). Even 19 inches sounds big.

A response (Cavanagh)

From: "Patrick Cavanagh" <patrick@burrhus.harvard.edu>

Hmm, well I can't vouch for the accuracy of the eyeball size estimate but the source is "How Animals See" from Facts on File -- I forget the author's name. She has been criticized before for errors but the giant squid is an elusive character (as opposed to the giant squid axon) and I have no idea how to check her information.

Patrick

And a resolution (Cavanagh/Backus)

From: "Patrick Cavanagh" <patrick@burrhus.harvard.edu>

> Dear Professor Cavanagh:
>
> I have "How Animals See" (picked it up for $4, says the sticker still on
> it). "Squid," in the index, leads to page 9, which, I regret to report,
> gives 370 cm (12 ft), not 19 ft, as the diameter of the giant squid's eye.
>
> Sandra Sinclair, 1985
> How Animals See: Other Visions of Our World
> New York: Facts On File Publications.

What cruel tricks time plays on memory. I had remembered the giant squid eye from "How Animals See" as being 19 feet, perhaps I did the conversion wrong. Nonetheless, it is a big eye.

I have been searching for a copy of "How Animals See" for the last 4 years, bookstores, out-of-print books services, everywhere but no luck. Please buy a copy for me if you see another one.

> Re: the bilateral symmetry of the body is responsible for the apparent
> left-right, without up-down, reversal in a mirror. I give you this
> creature in return: shaped like an upright wine bottle, the creature is
> capable of spinning itself about the vertical axis by means of a bent arm
> that sticks out from the side of the bottle, with a jet nozzle at its end.
> Male arms are bent one way, and female arms the other, so that males and
> females spin in opposite directions. In the mirror, a female would see not
> a left-right reversal of herself (though such an identification could be
> made), but surely herself as she would look were she male.
>
> Sincerely,
> Ben Backus
> UC Berkeley graduate student (Marty Banks' lab)

Mmm, a real gender bender. But why make her spin? If she stops spinning and looks at her nozzle organ in the mirror, it will be bent in the male direction (a left-right reversal to us but an embarrassing male-female reversal to her). But rather than a wine bottle body which has an obvious top, imagine a perfectly cylindrical body. Now in the mirror "she" could see herself as a male or "she" could equally well see herself as an upside down female. Which would you pick?

On the other hand, so to speak, up and down would have to be labeled before the gender-specific nozzle bend could be established so there still isn't true up-down symmetry. If sex were designated by, say, the color of the body, the mirror images would only produce an up-down reversal and their species would have lost an endless source of good jokes (eg. No, I don't like your theory but turn over and I'll kiss you).

Patrick

Handsome units (Kooijman)

From: "a.c.kooijman" <a.c.kooijman@med.RUG.NL>

Dear Brian,

I have a paper in front of me with some handsome numbers and relations on light units:

some examples:
*
1 photopic lumen = 1 scotopic lumen for monochromatic light of 555 nm

'lumen' can be replaced by:
lux, candela, nit, troland, apostilb, footlambert (though you have to avoid this non-metric unit)

* in 'free' viewing to a scene or surface:
retinal illuminance [in troland] =
luminance of the scene [in candela/sq m] * pupil area [in sq mm]

* in a maxwellian view condition:
place a lux meter at 10 cm behind the focus of the maxwellian focus
(thus about in the middle of the brains of the subject)
retinal illuminance [in troland] =
10E-4 * the illumination on the lux meter (full illuminated sensor)

best wishes

Aart

Philosophy (Nelson)

From: jnelson@ln.nimh.nih.gov (Jerry Nelson)

17 Jan 95
Dr. Wandell,

What an outpouring you got in response to a request for useful constants in vision. The wonderful replies included much more -- people's pet relationships, perhaps their pet ideas.

Is their an unsatisfied need here? Very good people will complain privately of their inability to pursue questions they consider fundamental. At meetings some very important intellectual work is done outside the formal constructs intended to house them. There is a richness and creativity in all of us which is ill-housed by the usual professional structures.

What did you tap? It was clever to ask for only one number. That kept replies down to lengths under 3 long paragraphs. You tapped a playfulness. And acceptance was contingent on how HELPFUL TO OTHERS the contribution might be -- zero pomposity here.

But without review the contributions were uneven, and without a ritualized structure (INTRO, METHODS, etc) the format is chaos -- charming, but a lot of editing work for you and your book.

Anyway, what fun. After your book is over, fight postpartum letdown by starting a MODERATED newsgroup -- entries come to you, and if a single glance can't quickly reveal humor or helpfulness, then it doesn't go in. Even in mean times, American science has a mutual helpfulness hard to match elsewhere.

Thanks again, good luck with the text.
--jerry

Angles, eye movements, and more (R. Boynton)

From: ps45@sdcc12.UCSD.EDU (robert m boynton)

I was off CV-net for a while for some reason, and missed
the request for magic numbers. I would like to add
a few.

The rule of thumb varies remarkably from one submitter to
another, doesn't it? I really liked Al Ahumada's modal
number of eyes per subject.

Anyway, here are mine:

.3 mm on the retina = 1 degree of visual angle

number of eye movements per second during very intensive visual search: 3 to 5

Nodal point of eye is 7 mm behind corneal vertex
Axial length of the eye is about 1 inch or 25 cm
Index of refraction of eye media (roughly) 4/3
Wavelengths of peak sensitivity: 505 and 555 nm

Maximum density of cones at foveal center: About 130,000,000/mm^2

Time for complete dark adaptation after exposure to a bright
light: 30 to 45 minutes

Cheers,

Receptors, units, behavior (Ross)

From: jr@psy.uwa.edu.au (John Ross)

Brian: Some more (approximate) numbers, all useful I find.

1. Number of rods per (human) eye 120m

   Number of cones per eye 6m

   Number of fibres/optic nerve 1m

   Ratio of receptors to fibres = 125:1

2. 30" of arc = minimum separable; closest spacing of cones (approx.)

3. 100ms = critical duration for Bloch's law (can be less); period of frequency at which flicker and motion are seen best.

4. 3 or 4 = number of cone types.

5. 4 = Jevons number: maximum number of objects countable without error at a glance.

6. 4 or 5 log units: improvement in sensitivity with dark adaptation.

7. 7 = Miller magic number; minimum number of 'stations' for best apparent motion.

8. 500 = best contrast sensitivity.

John Ross

Optics, fun, retina, many (Tyler)

From: cwt@skivs.ski.org (Chris Tyler)

Dear Brian,

Well, I see you received a goodly supply of numbers. Some others that I have come across are:

The human eye is exactly the same size as a quarter.

The rod-free, capillary-free foveola is 1/2 deg in diameter, same as the sun, the moon, and the pinky fingernail at arm's length.

One deg is about .3 mm (300 u) on the retina.

Diameter of smallest cone or rod is 1 u, packed at up to 300 per deg.

Diameter of largest human cone is 10 u, as large as those of any amphibian.

There are 10^8 photopigment molecules per rod. Each one can be photoisomerized in 100 femtosec. They are packed into 800 disks

Density of cones falls with E^-2/3 out to 20 deg eccentricity (not reciprocally).

There are about 4000 cones in the central (foveolar) half degree.

The same number in a 5 deg diameter patch at 40 deg eccentricity.

The range of visible light is 1 octave at around 1/2 the diameter of the smallest cone.

Each human striate cortex is 4 x 8 cm, making a total of 64 sq cm.
There are about 6400 hypercolumns therein.

You can think of this area as spanning 8 octants around the visual field and 8 doublings from 1/2 to 64 degrees eccentricity.

The viewing distance at which an object is projected at veridical size on the foveal representation is 20 cm (I think; you can work it out for your own best foveal magnification estimate).

Foveal cone detection threshold occurs at an average of 1 quantum per cone for extended stimuli.

A comment on Dave Burr's law of Psychometric functions. Mayer and I found that the slope (beta) varied from 2-6 across observers. It is well known that it falls to 1 for suprathreshold discrimination tasks.

Optimal contrast threshold is 1/4%.

Visual apparatus needs to be engineered to 1 part per thousand.

The bandwidth of the visual system is 1 teraHerz (e.g., the raster bandwidth for a panoramic wall panel that looked like a full-field dynamic view of the real world).

The number of possible brain states that we can experience in a lifetime is 10^10^10 (a googol).

The Ferry-Porter Law. In the absence of flicker adaptation, CFF increases directly with log I over 6 log units. (25 Hz per decade in the periphery, 10 Hz per decade in foveola)

The maximum CFF ever reported is 107 Hz from my right eye at 300,000 Td.

The finest Vernier acuity reported was .8 arc sec in Dennis Levi's right eye

Tyler's Law of disparity scaling: The maximum disparity for depth resolution scales linearly with stimulus size. Horizontal binocular fusion follows the same law.

The best stereoacuity reported is 2 arc sec. Contrary to the limited statements in most textbooks, this is sufficient to discriminate the distance of 2 miles from infinity (e.g., distant mountains) or resolve the depth of a human ovum (100 u) at 10 cm.

The vertical horopter is tilted at an average of two degrees, just enough to ensure that it falls in the plane of the ground for an erect observer who is fixating anywhere in the ground plane. Pettigrew showed that the tilt was 20 deg for the cat and ground owl, and zero for the tree owl, so that the horopter fell in the ground plane for all four species.

At a pupil diameter of 3.6 cm, the pupil area is 10 cm, so for normal viewing conditions, Trolands = 10 x cd/m2.

Speaking of units, it should be arc sec, arc min and Td for consistency with the physics and astronomy communities. All units from proper names are capitalized (e.g., Hz, V, etc).

0.1 log unit is 27%

The standard error of a Poisson process (such as light) is equal to the square root of its mean, which is why taking more readings improves S/N ratio. This fact is unknown to most undergraduates, in my experience.

The eyes are half-way down the head - a fact known to most artists.

If the sun's light was blocked, it would be eight minutes before the moon went dark.

I am happy to dig out the references for any of these that interest you, so let me know if you want them. Christopher

Adaptation (Thompson)

From: P Thompson <pt2@unix.york.ac.uk>

I like your useful numbers. I might suggest adding that visual aftereffects reach their maximum 'strength' after an adaptation period of about 60 seconds.

Peter

Visual sensitivity (Klein)

From: klein@adage.Berkeley.EDU (Stanley Klein)

Brian, here are some numbers from Dennis Levi and Stan Klein,

The following numbers are give or take a factor of 2 (or so) to keep the numbers simple:

Detection thresholds:
- edge - about 1%
- line (a pair of adjacent opposite polarity edges) - about 1 %min
- dipole (a pair of adjacent opposite polarity lines)- about 1%min^2
- quadrupole (a pair of adjacent opposite polarity dipoles)- about 1%min^3

1 Td is about 1 absorbed photon per cone per integration time (E100 msec).

The best hyperacuity is equivalent to a retinal distance of one tenth of the wavelength of red light (beat that, Patrick).

One can localize a peripheral point to within one tenth of a hypercolumn.

One hypercolumn is .1 times eccentricity

The best temporal hyperacuity for vernier acuity of moving targets (no tracking) is about 1 msec.

The Weber fraction is crudely about 10% for almost anything (except for position (or size) where one must remember to also divide by 2pi). Too bad the presence of multiple channels makes this number difficult to use.

For a monochromatic display to be able to present perceptually lossless images without halftoning it must be able to display about 100 bits/min^2.

The perceptual information in a monochromatic image is up to about 20 bits/min^2.

People are quite happy with monochromatic images compressed to about 1 bit/m^2.

One can derive Levick's formula (blur angle=pupil size times diopters of defocus) from the following geometric construction. 1) Focus at infinity. 2) Look at something at a finite distance. 3) The linear blur projected onto the object will be the size of the viewer's pupil (about 3 mm) independent of the object distance.

Many psychophysical functions vary with eccentricity according to

$$Th = k(E+E2)$$

where Th is the threshold, k is the slope, E is the stimulus eccentricity, and E2 is the eccentricity at which the threshold is twice the foveal value:
For resolution and contrast senssitivity, E2 is about 2-3 degrees.
For position judgements E2 is about .5 -1 degree.
For absolute motion, E2 is about 5-10 degrees.
What's your favorite E2?
We like the position judgement E2 and are starting to call it L2 (the E2 characteristic of the local sign). It is the value that we expect to be similar to the anatomical cortical magnification factor.

What a great idea to do this.
Stan

Genetics (Piantanida)

From: Tom Piantanida <pianta@unix.sri.com>

Brian, Here are a few more numbers for your survey.

As a rule of thumb, for image stabilization to occur, spatial noise needs to be 1 minarc or less, and latency needs to be 1 msec or less.

The genes encoding rhodopsin and cyanopsis have five exons, those encoding chlorolabe and erythrolabe have six.

The opsin proteins of rhodopsin and cyanolabe consist of 348 amino acids, those of chlorolabe and erythrolabe consist of 364.

The gene that encodes rhodopsin is on chromosome 3 (3q21- 3qter), the cyanolabe gene is on chromosome 7 (7q22-7qter), and the genes for chlorolabe and erythrolabe are on the X chromosome (Xq28).

Panum's fusional area can be as large as about 2 degrees under stabilized-image conditions.

When the fusional limit is exceeded, diplopia occurs, but fusion can
be reestablished at disparities close to 2/3 of the fusional limit
(not 6minarc as Fender and Julesz reported.)

This is a great idea.
Tom Piantanida

Units, references, sensitivity (Meese)

From: tim@vis.psg.bham.ac.uk (Tim Meese)

Here are a few numbers for your list, if your still collecting them (they are mainly obvious, but I find them useful):

1) I prefer to report stimulus contrast in dB (20*log(c)), though my referees often seem to prefer percent or proportion! The conversion is easy however: an increase of 6dB represents a doubling of contrast (or whatever other variable you may have converted to dB). In absolute terms 0dB is a contrast of 1% (if c is in the range 0 to 100%), or 1 (ie. 100%, if c is in the range 0 to 1).

2) Useful stimulus spacing for detection/discrimination experiments etc: about 2 or 3 dB

3) An approximation I find useful: To convert from the spread (SD) of a cummulative Gaussian to the spread (logits) of a logistic curve (1/(Exp[-L]+1)), multiply the former by 0.6. Graphical analysis shows this to be a fair approximation, and it has been reported in a foot note by Taylor and Creelman (1967; JASA, 41, pp782-)

4) There are some more good numbers relating alternative measures of Gaussian widths in Norma Graham's book (p50).

5) Some undergraduates have problems in visualising large numbers. An easy way of making 1,000,000 seem small is to imagine (or build) a cube with sides of 10 cm (ie. something quite small that can easily be held in one hand). However, this cube is also 1,000,000 cubic mm.

6) Percentage of 2AFC trials in which you guess: 0%
(the feedback beeps must be wrong)

sincerely

Tim Meese

Binocularity (Pietsch)

From: PO2::"reading@ucs.indiana.edu" 9-JAN-199

My favorite one involves the enhancement of visual performance gained by going binocular. It applies to absolute light detection thresholds, brightness discrimination, critical flicker frequency, and visual acuity. The gain in sensitivity is always [more or less] equal to the square root of 2! You can arrive at this result through sampling theory,probability summation, or areal summation [an adaptation of Piper's law to binocular vision]. One of the implications of this approach is that a three eyed individual should enjoy an enhancement equal to the square root of three! [as suggested by the late Fergus Campbell}

***

PIETSCH, P. AND SCHNEIDER, C. W., Two-eyed Versus One-eyed Salamanders: Does Binocularity Enhance the Optically Evoked Skin Blanching Reactions of Ambystoma Larvae?   PHYSIOL BEHAV 48(2) 357-359, 1990. A wide variety of visual functions show increases attributable to binocularity, and the question pursued here was whether a second eye enhances the visually stimulated skin blanching reaction of the larval salamander. Dermal melanin spots (melansome aggregations within dermal melanophores), which contract or expand to lighten or darken the skin reflectance, were measured in eyeless (controls), one-eyed and two-eyed Ambystoma punctatum larvae after chronic exposure of subjects to a white background (i. e., stimulus conditions for maximum blanching).   The eyeless subjects showed no blanching (thus remained dark) in white cups, and they exhibited melanin spots 7 or 8 times the size those of the other two groups.   All one-eyed or two-eyed subjects exhibited blanching reactions; planometric comparison revealed a significantly larger melanin spot area for one-eyed than for two-eyed animals; i. e., the binocular condition permitted greater contraction of the pigment spots than did the monocular condition. Analytical data compared favorably with independently ascertained pigmentation indices.   The results indicate that a second eye quantitatively elevates the blanching maximum of a larval salamander.

IF YOU'RE INTERESTED, I'LL SEND YOU A REPRINT OF THE ENTIRE ARTICLE.

PAUL PIETSCH
INDIANA UNIVERSITY, BLOOMINGTON, IN 47405 USA

Philosophy (Cohn)

From: tecohn@mindseye.berkeley.edu (Theodore E. Cohn)

Who could have guessed that numbers would be so much fun? I've been thinking a bit about numbers and it occurs to me there are two categories of same. The first category includes those which represent pschyological (or anatomical or physiological) constants such as the number of foveal cones per square mm. The other category includes numbers we use to divide up continua into easy-to-describe pieces. I heard one of the latter cited the other day...its the distance beyond which we accept the view that image disparity doesn't contribute to depth perception. (a ref is C. Schor and M. Flom "Relative value of stereopsis as a function of viewing distance, Am J Optom 46:805-809, 1968). With respect to the second category, universal agreemnt on the value of a given number would neither be achievable nor expected. In the case of the former, agreement could be reached to within the irreducible measurement error implicit in operations used to define the number.
Ted

Numbers to facts (Ross)

From: jr@psy.uwa.edu.au (John Ross)

Brian:
I would like to add a few more numbers to the beginning of my list:

1 = the number concurrent perceptual interpretations of visual input (as in rivalry, ambiguous figures, but more generally scene interpretations)

2 = Ahumada's modal number (of eyes), but also of receptor systems (rods and cones), major pathways (magno and parvo), and dimensionality of retinal images.

3 (or 4?) = dimensionality of perceived space.

John Ross

Sensitivity, eye movement, color (G. Boynton)

From: boynton@blue.stanford.edu (Geoff Boynton)

One quantum is sufficient to activate a rod. (Cornsweet, Hecht et al)

Average saccade size is about 10' of arc. (Ratliff, F., and

Riggs. L.A. (1950) Involuntary motions of the eye during monocular fixation. J Exptl. Psychol 40 687-701

Pupil size ranges from 3mm under 2.5 log cd/mm^2 to 8mm in darkness (Wyszeki \& Stiles, Color science. New York: Wiley, 1982)

There are 11 basic color names (Boynton, Robert M. Olson, Conrad X. Vision Research. 1990 Vol 30(9) 1311-1317.)

Neural waves (Drosler)

From: <Jan.Drosler@psychologie.uni-regensburg.de>

The velocity of signal propagation in the retina (in radial direction) is one degree of visual angle per millisecond.

It was measured behaviorally by letting the observer synchronize two LEDs flashing at identical periods, one of which is fixated in the center of the fovea. The temporal lead of the peripheral LED necessary for a judgement of synchrony permits the calculation of the velocity stated above. It appears to be constant over a range of zero to 55 degrees of visual angle. The standard error is 0.46 ms at all meridians tested.

Reference: Arch. Psychol. 131, 249 -266, 1979.

Optics/units (Knoblauch)

From: Ken Knoblauch <Ken.Knoblauch@cismibm.univ-lyon1.fr>

Has anybody suggested that 1.13 mm pupil diameter (artificial probably) should give you 1 troland = 1 cd/m^2?

Field of view (Grigsby)

From: Scott Grigsby <SGRIGSBY@FALCON.AAMRL.WPAFB.AF.MIL>

total extent of human field-of-view under optimal conditions: ~200 deg
extent of overlap of the two eye fields: ~120 deg
extent of FOV that does binocular processing: ~40 deg
(see Grigsby and Tsou (1994), Vision Research 34, 2841-2848)

extent of eye movement before a compensating head movement: 20 deg
(Robinson (1979), Human Factors 21, 343-352)

1 microcandle in the plane of the pupil = 1 troland

Cortex (Shadlen)

From: mike@monkeybiz.Stanford.EDU (Mike Shadlen)

I don't know; but here are some other numbers
in a cubic mm of cortex there are
10^5 neurons
10^9 synapses
2 miles of axons

These and several other fun numbers can be found in Stevens CF, 'What form should a cortical theory take' in Large-Scale Neuronal Theories of the Brain, Koch C and Davis JL eds., MIT press, Cambridge, Mass., 1994, pp.239-255.

Saccades (Groh)

From: groh@monkeybiz.Stanford.EDU (Jennifer M. Groh)

Peak saccade velocities in humans can reach 700+ deg/sec, though in my experience tenured faculty are slower by ~250 deg/sec. You can cite

RHS Carpenter, Movements of the Eyes, Pion, London, 1988
p. 70

Bahill AT, Clark MR, Stark L, 1975, Glissades--eye movements generated by mismatched components of the saccadic motoneuronal control signal, Mathematical Biosciences 26:303-318

as a specific reference on the "main sequence", which is the amplitude-duration-velocity relationship of saccadic eye movements.

Another rule of thumb for you:

duration of saccades > 5 deg = 20-30 ms + 2 ms per degree.

This also comes from Carpenter.

Rod circuit sensitivity (Robson)

From: From: John RobsonI have a good number for you. It is 1 and is the number of photoisomerisations per rod required to saturate the retinal rod circuit.

Number of Colors

From: Mark Fairchild> From Wandell to Fairchild:
>
> How many discriminable colors
> are there, and how did people count them? No important reason for asking,
> but I find people are always asking me about this and I always give them
> a vague answer I don't like.
>

I get asked that question alot also and I also give vague answers. I guess I usually get away with something like "it depends on the viewing conditions." I did a little digging and found on page 21 of Hunt's Measuring Colour 2nd Ed. a line saying that 10 million was one reliable estimate and he referenced Judd and Wyszecki. I went to Judd & Wyszecki, Color in Business Science and Industry, 3rd Ed. and found them saying " since about 10 million surface colors can be distinguished by the normal human eye ..." on page 388. They however gave no direct reference. That section was talking about the ISCC-NBS method of color naming so there might be something in the paper that describes that (Judd and Kelly, Method of Designating Colors, J. Res. Netl. Bur. Std., 23 355 (1939).). I'm not going to look that one up. I guess if 10 million is a good enough estimate for Judd, Wyszecki, and Hunt, then it's good enough for me.

From shev@midway.uchicago.edu Fri Oct 25 08:15:55 1996

Mark and Brian, Thanks for replying to my inquiry. The following FYI.

A conservatively low estimate of the number of discriminable colors, ignoring luminance, is 6,000. I arrived at this using two different approaches.

APPROACH #1

1. 10,000,000 colors with luminance included (Hunt, Judd, Wyszecki)
2. 1% Weber fraction from 1 to 1,000,000 trolands (implying ~1620 discriminable luminance steps). This assumption is the conservative part, leading to a low-end estimate.

So, 10,000,000/1620 = 6,173.

The number is 10,800 if the 1% Weber fraction is applied over 1-10,000 td.
The number is 21,500 if the Weber fraction is 2% over 1-10,000 td.

APPROACH #2

This approach takes into consideration that the 10,000,000 colors are *surface* colors but ignores overall level of illumination.

1. 10,000,000 surface colors (Hunt, Judd, Wyszecki), ignoring luminance.
2. Assume incremental and decremental contrast are *each* discriminable with a 1% Weber fraction over a 100:1 contrast range (implying 2x463=926 discriminable contrast steps). Again, this is conservative.

So, 10,000,000/(926) = 10,799.

Another approach is (1) to take discrimination around the spectral locus (using wavelength discrim data) and along the non-spectral purple line, and then (2) to count the number of JNDs from each discrminable point on the locus to EE white. This requires some pretty heavy assumptions in the model of JNDs and will lead to an inflated estimate, because discriminable colors at the spectrum locus may not be discriminable when desaturated. I may try it as an exercise.

..Steve

Location of Optic Nerve Head (Blindspot)

From wsimpson@io.uwinnipeg.ca Fri Jan 10 13:02:15 1997

Dear Brian,

I just looked at your list, which includes

Retina
5. ...size of optic nerve head (optic disc/blind spot)

BUT I always need to look up its location whenever I use a stimulus outside the fovea. Maybe you could add the location? 15 deg nasal.

Best wishes,
Bill

Visual angle of a pencil line

From: "Robert A. (Bob) Morris"

I just worked this out for a course I'm teaching on art and vision: A line drawn by a number two pencil subtends about 1/5 degree when viewed at 18", and so falls approximately at the peak of adult human grating acuity.

I wonder if crayon line widths fall at the peak of 3-year old acuity?

Bob Morris