A model for search and detection of small targets

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Background

Navy wants models predicting target detection times on workstations.

Beau Watson and I have simple models for foveal target detection.

If targets could only be detected in the fovea and there are no other targets, the search model should also be simple.

Summary

Search task: Target on horizon in uniform sky above a uniform ocean

Model: Random search with a saccade-distance penalty and inhibition-of-return with temporal decay

Lesson learned: Pre-detection information accumulation seems to be necessary.

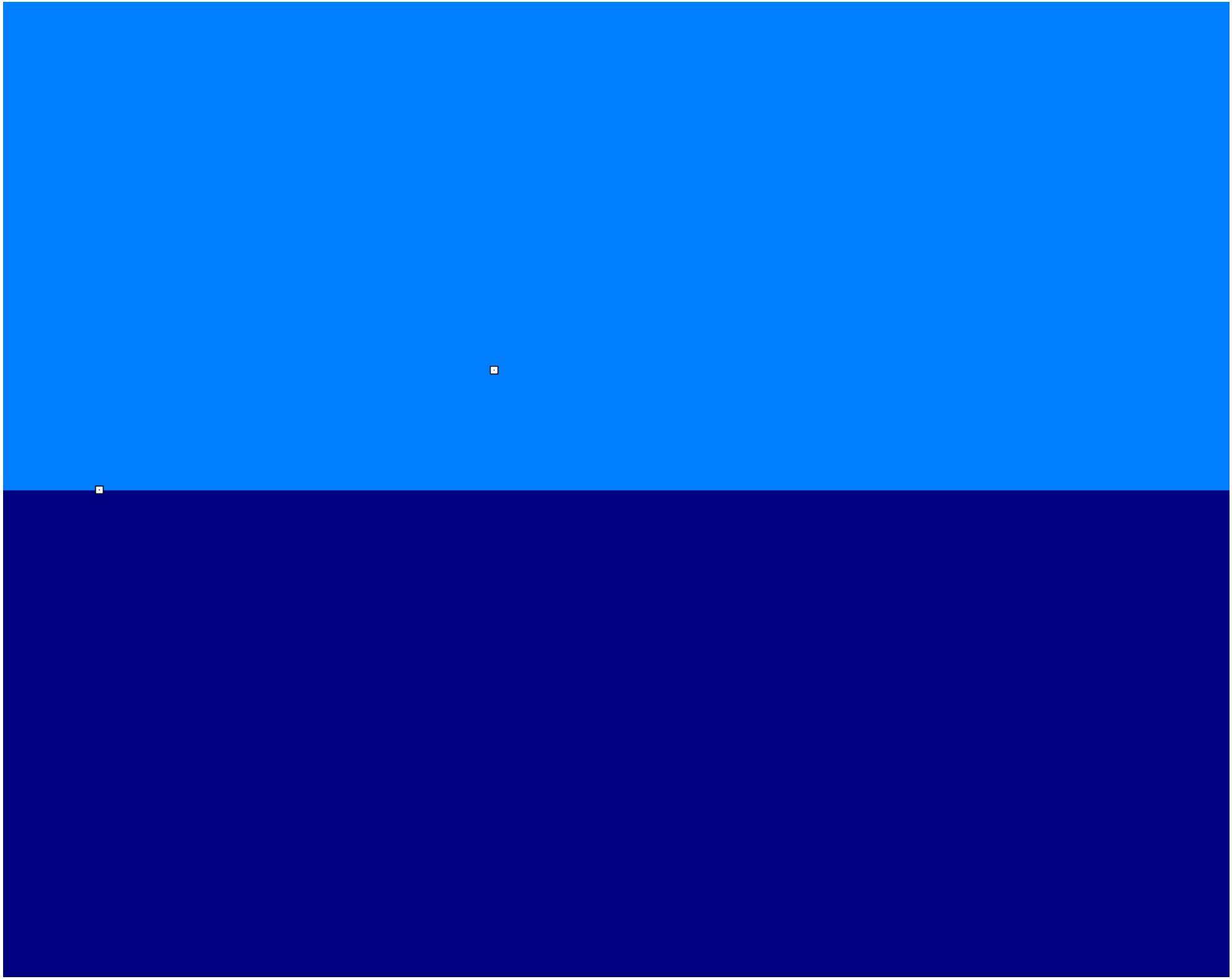
Stimuli

Screen distance: 69 cm Image width: 38 cm
Image size in pixels: 1280 X 1024 (W X H)
Sky y pixel range: 0 – 509
Sky RGB color: 0 128 255 => 45.4 cd/m^2
Target, ocean: 0 0 128 => 6.62 cd/m^2
Target pixel size: 1 X 1
Target y position: 509
Target x positions: i*100, i=1,12
Blank screen fixation cross, x y: 512 384

(Samsung Syncmaster 910T LCD monitor)

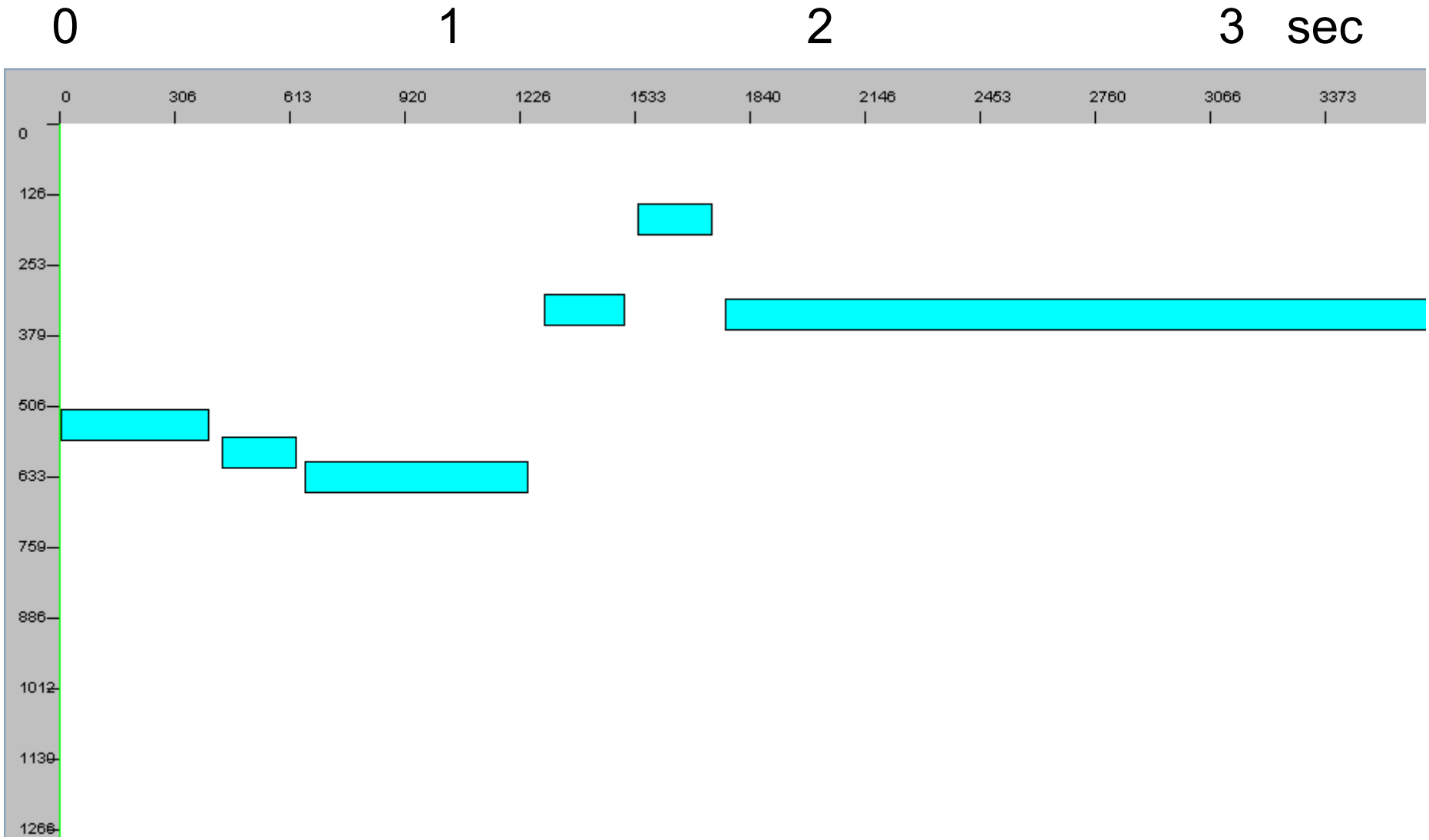
Methods

Eye positions recorded at 250 Hz by an
SR Research Eyelink II head-mounted tracker.
The experiment was controlled by an
SR Research Experiment Builder program.
There were 3 test runs of 12 trials.
Before each 3 trial group a recalibration was performed.
Each test had all 12 positions in a random order.
The sequence of fixations was extracted by an
SR Research Data Viewer program.
The data from the first test run was discarded.

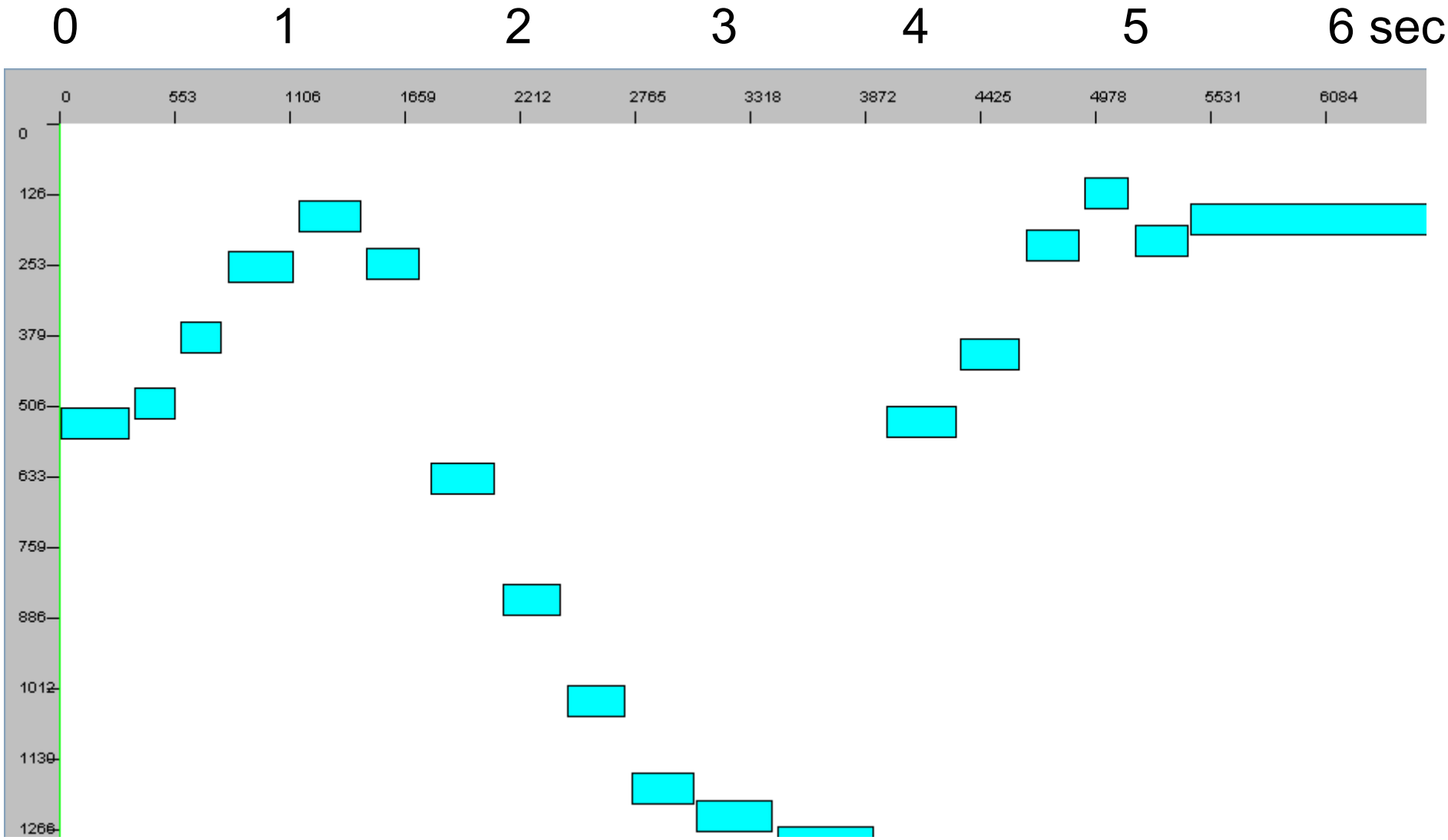


Eyelink II

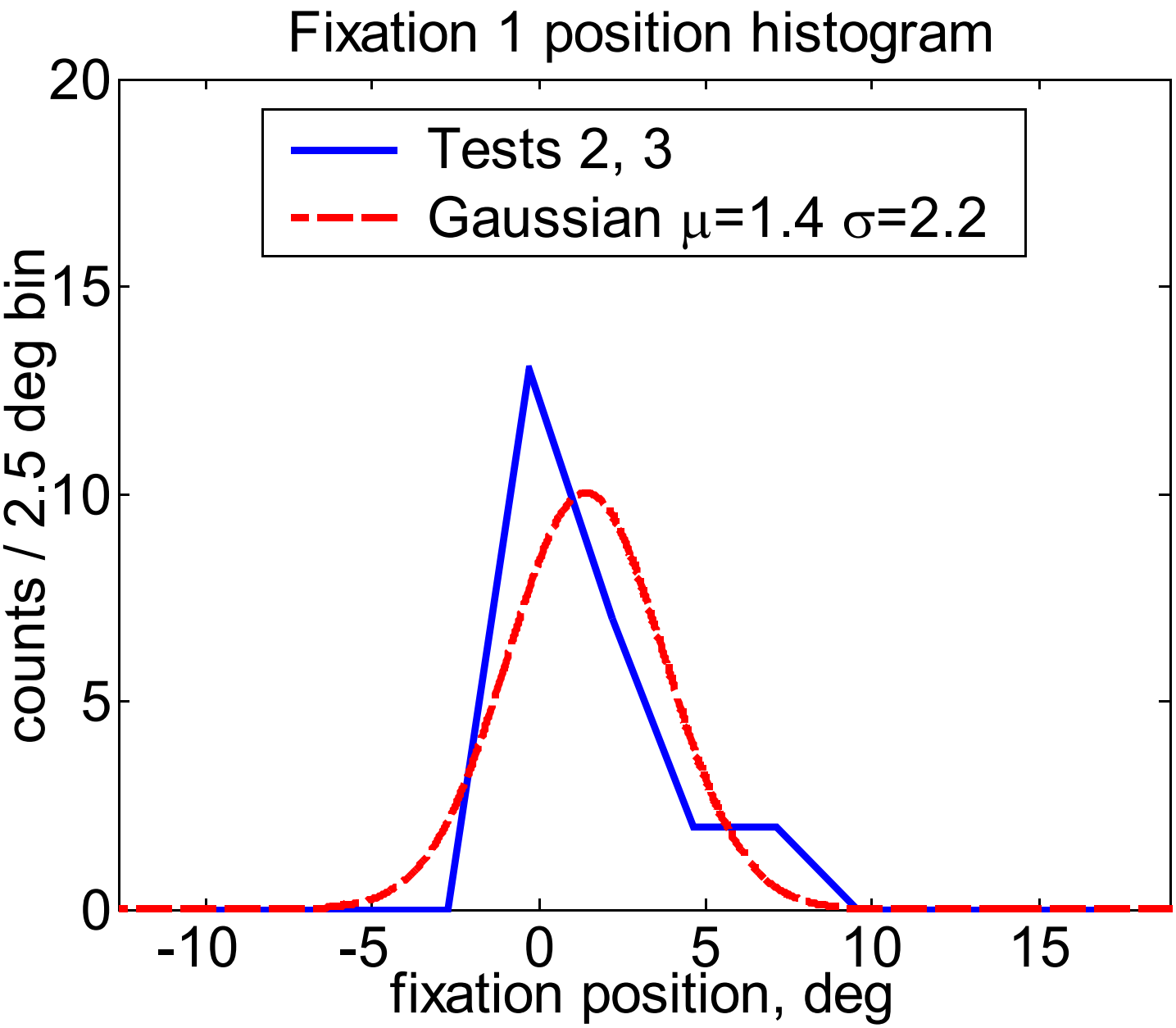
Search data: Test 2 trial 1



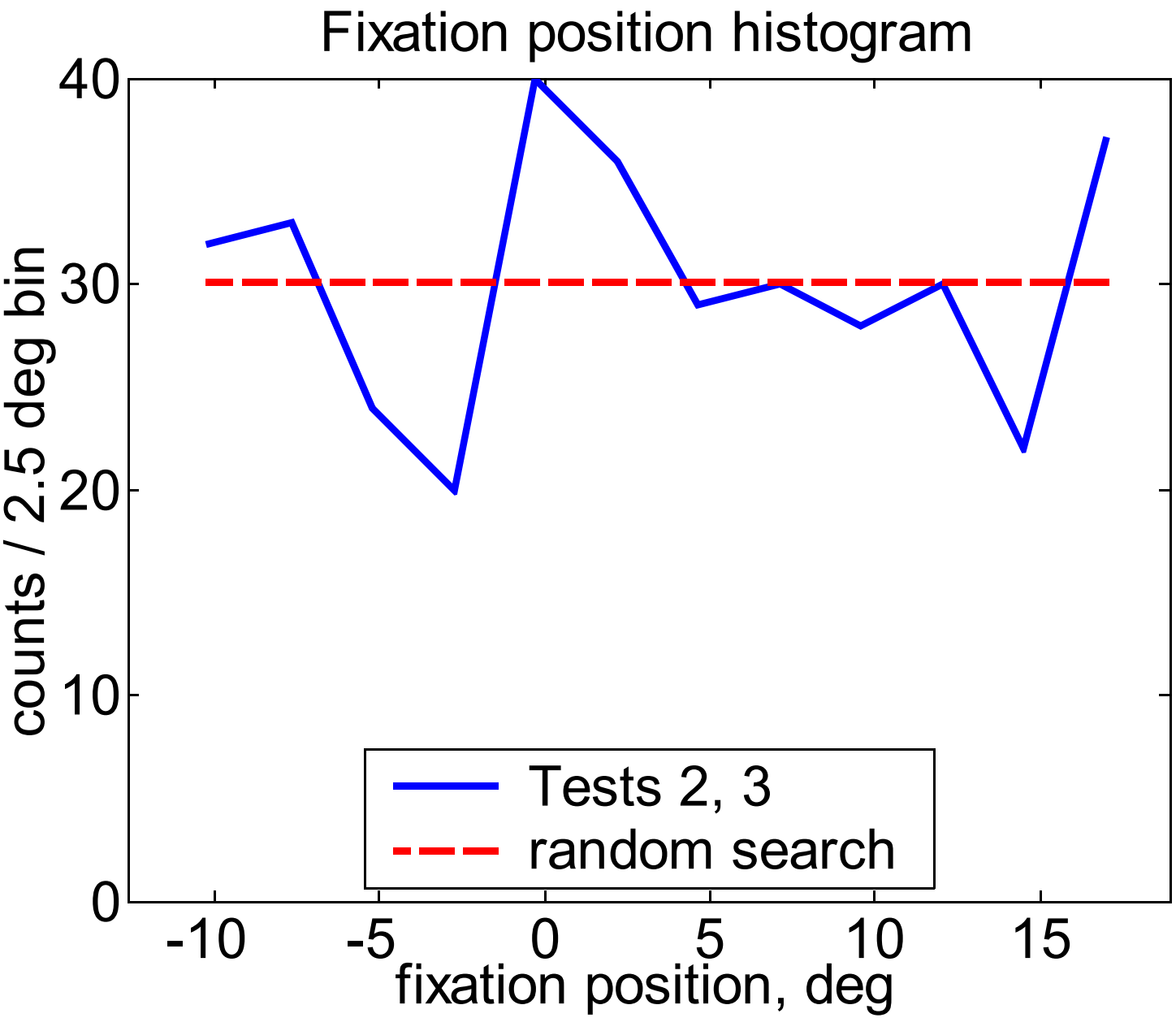
Search data: Test 2 trial 2



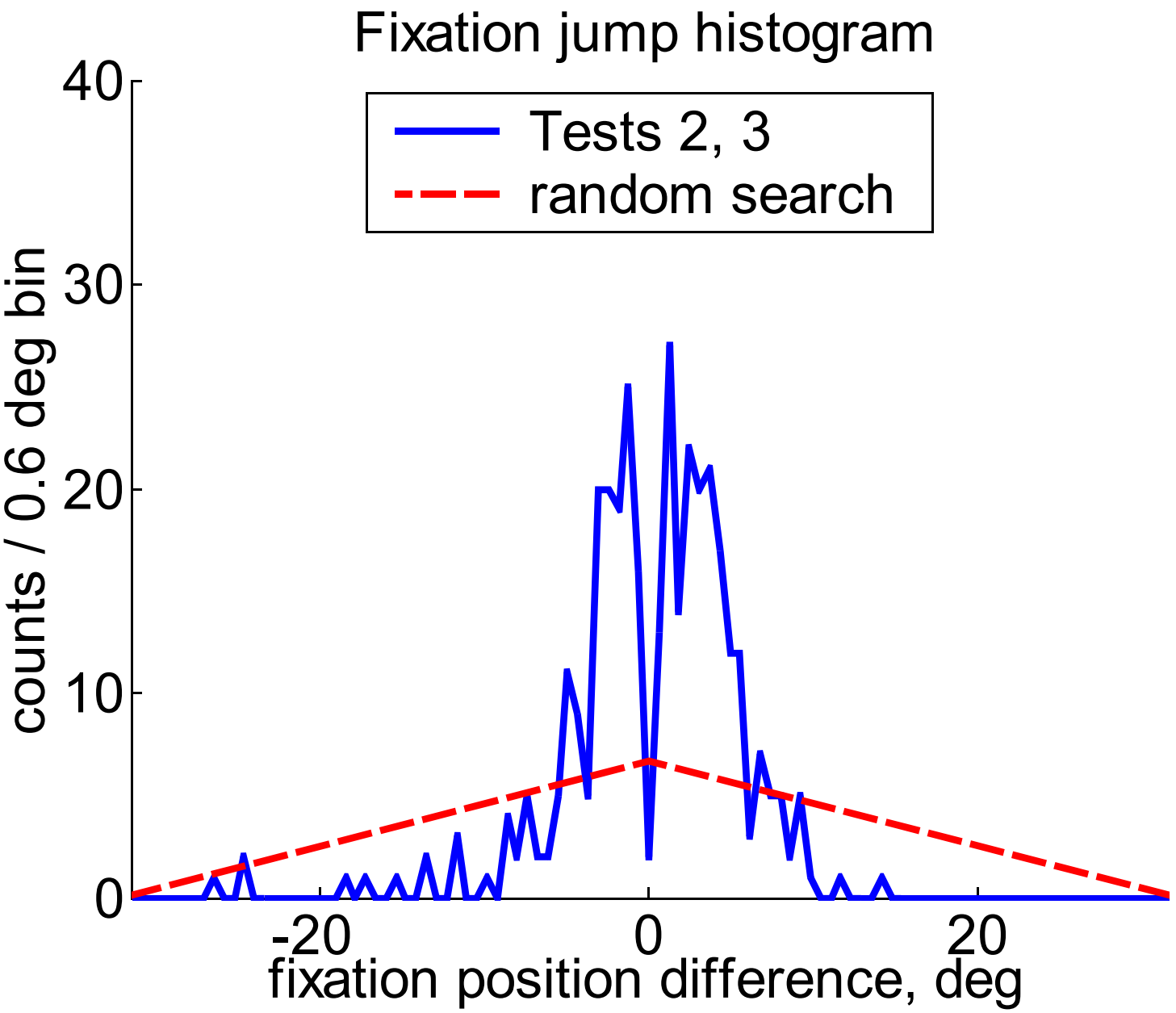
Search data


Fixation 1 position histogram
Tests 2, 3
Gaussian μ=1.4 σ=2.2
counts / 2.5 deg bin
20
15
10
5
0
-10
-5
0
5
10
15
fixation position, deg

Search data


Fixation position histogram
counts / 2.5 deg bin
40
30
20
10
0
-10
-5
0
5
10
15
fixation position, deg
Tests 2, 3
random search

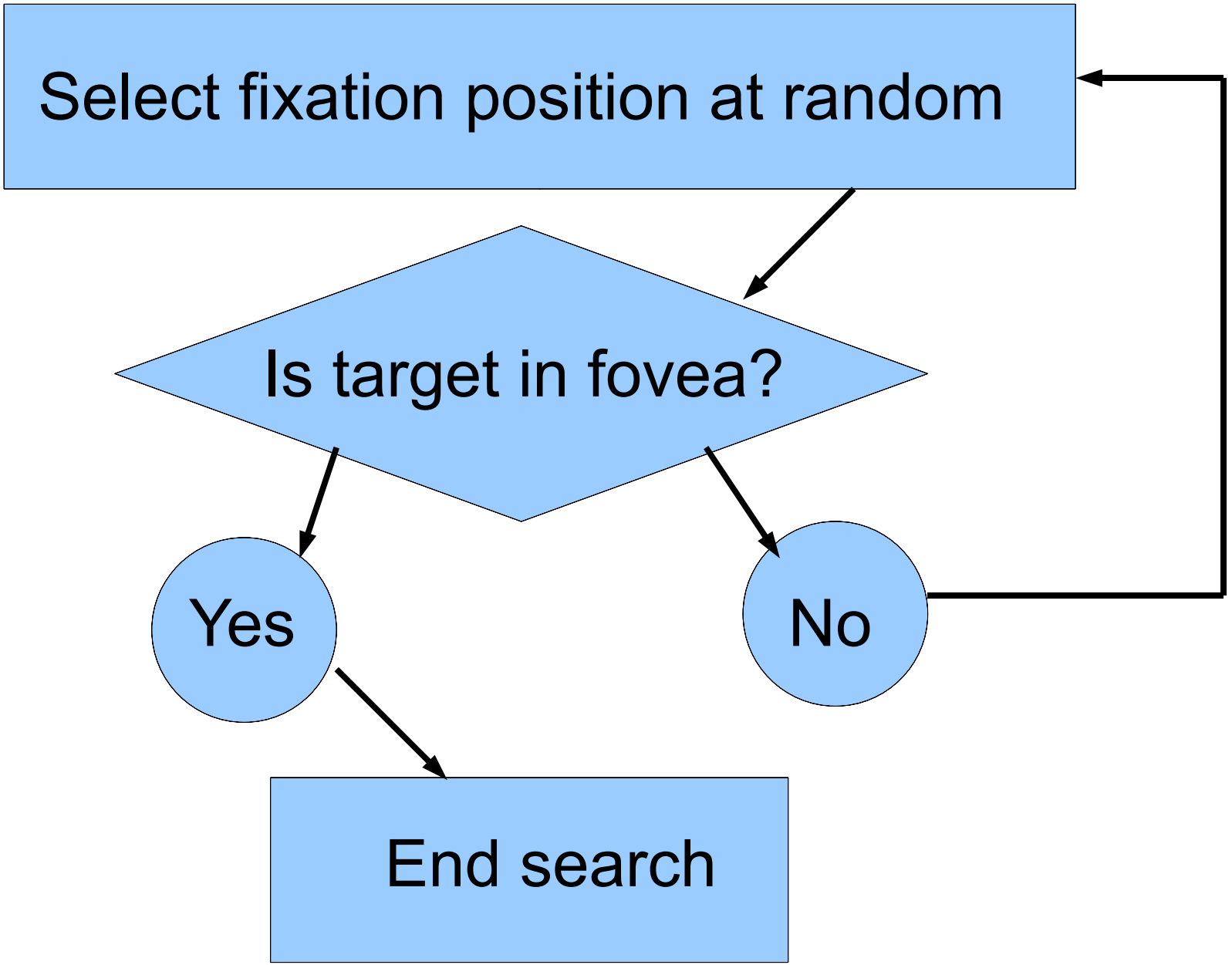
Search data


Fixation jump histogram
Tests 2, 3
random search
counts / 0.6 deg bin
40
30
20
10
0
-20
0
20
fixation position difference, deg

Search data summary

	test 2	test 3	
median fixation duration	300	292	msec
mean fixations per trial	19.0	16.8	
standard deviation	9.4	10.2	

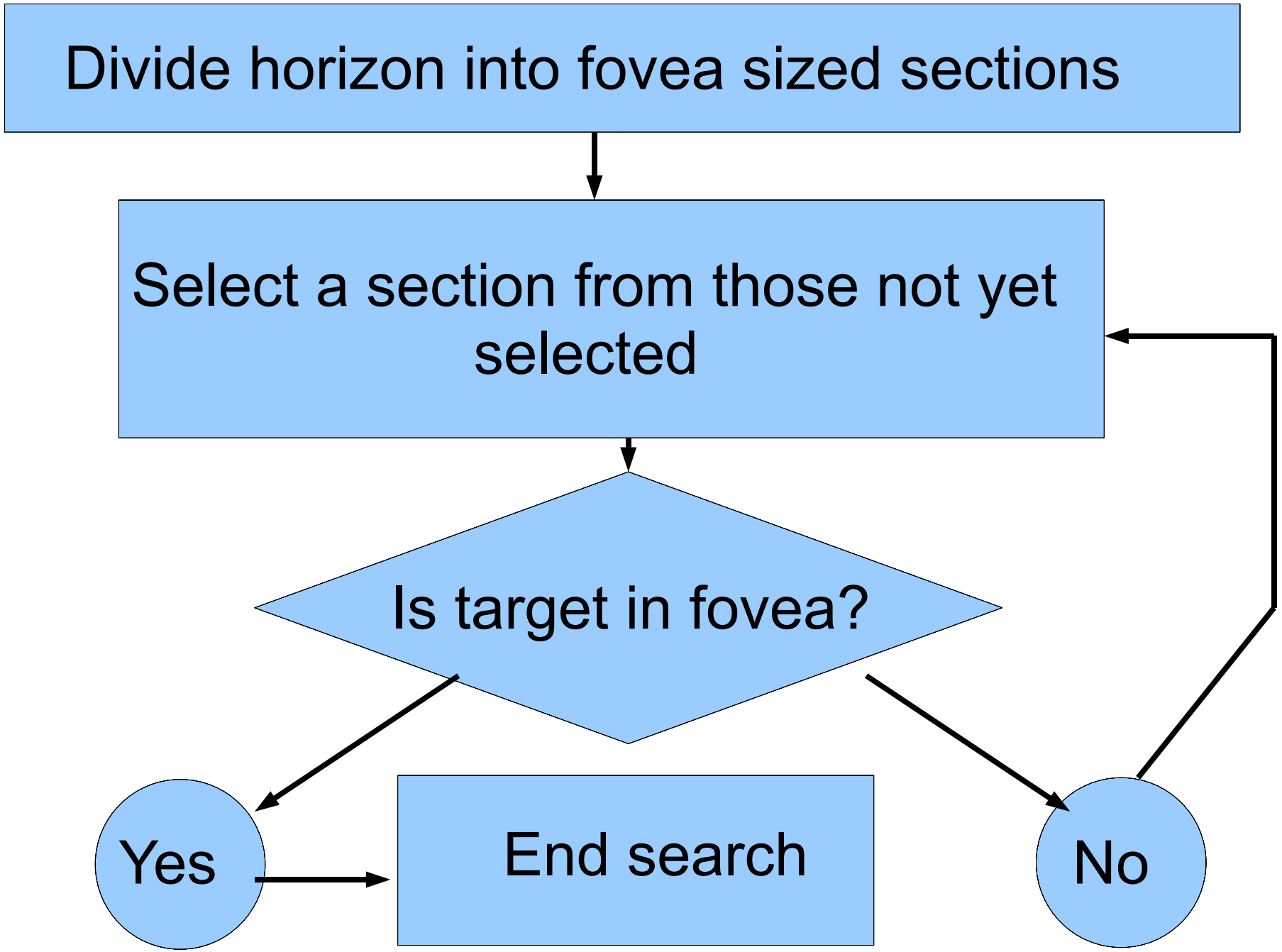
Simplest Search Model



Fixations

	mean	std dev	fovea, deg
test 2	19.0	9.4	
test 3	16.8	10.2	
simplest model	19	19	1.66

Optimal Model



Fixations

	mean	std dev	fovea, deg
test 2	19.0	9.4	
test 3	16.8	10.2	
simplest model	19	19	1.66
optimal model	19.0	9.7	0.13

Simple Search Model

No saliency map

No expectancies

Distance penalty distribution

All-or-nothing fovea for detection and for inhibition-of-return with temporal decay

Distance penalty function

Let D(x) be the probability density distribution of the position of next fixation given that the current fixation is at zero eccentricity and there is no Inhibition of Return.

Let x0 and x1 be the ends of the horizon and
xC be the center of fixation

The the un-normalized distance penalty is
D(x-xC), $x0 < x < x1$

Inhibition of return function

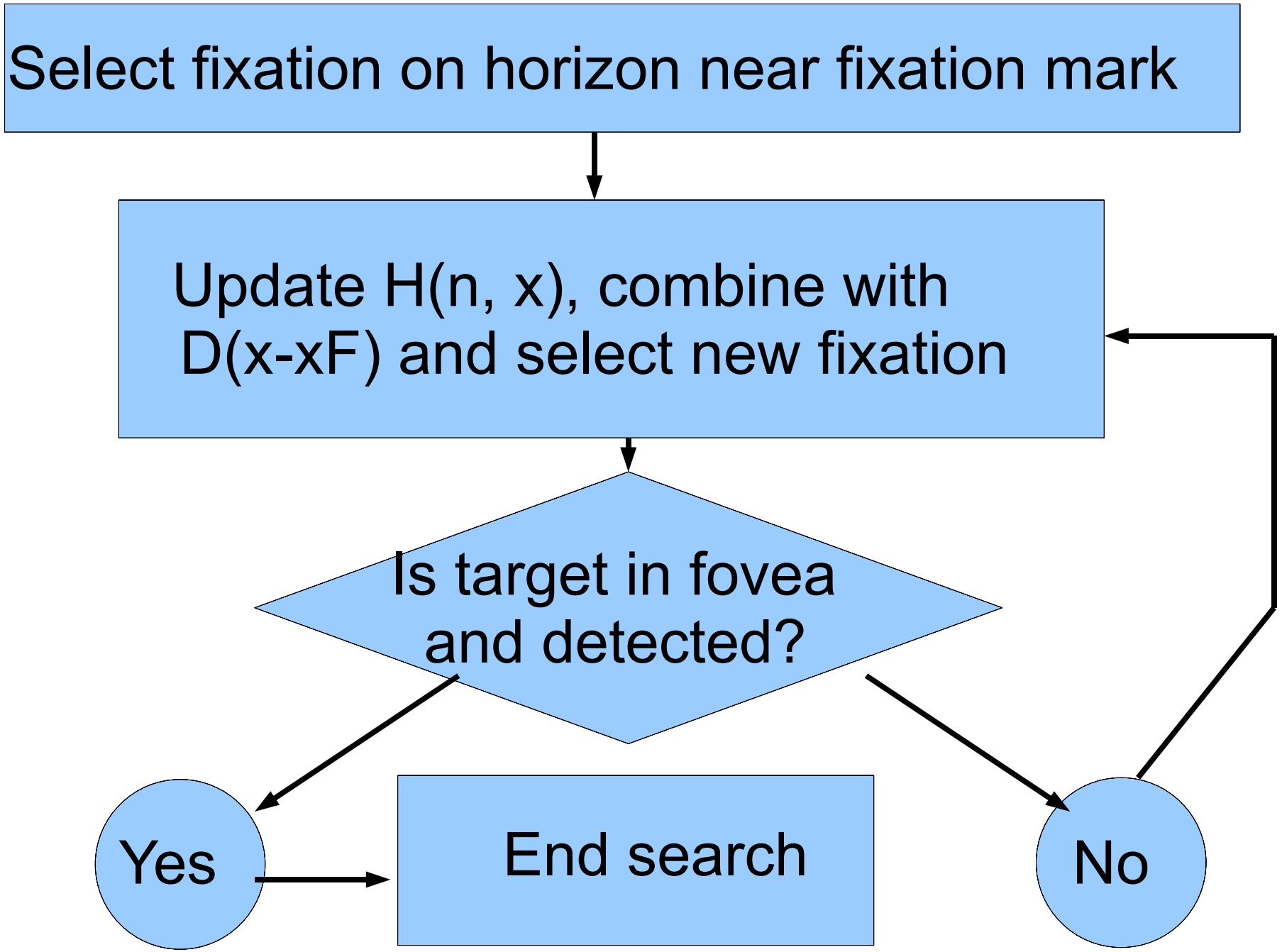
H(n, x) is Inhibition on fixation n at position x
H(1, x) = 0

F(n,x) = 1 if x is in the fovea on trial n,
= 0 otherwise

Update rule:
H(n, x) = min(1, h H(n-1, x) + R(n, x))

Usage: unnormalized distribution is
(1-H(n, x)) D(x-xC)

Distance and Inhibition Model



Fixations

	ave	std	std/ave	fovea, deg
test 2	19.0	9.4	0.49	
test 3	16.8	10.2	0.61	
simplest model	19	17.2	0.90	1.66
optimal model	19.0	9.7	0.50	0.13
inhib & dist	18.2	13.3	0.73	1.02

Evidence function

E(n, x) is target evidence on trial n for position x

E(1, x) = 0

Update rule:
E(n,x) = e + E(n-1,x) if x is in perifovea on trial n,
= E(n-1,x) otherwise

Usage: unnormalized scan distribution is
(1-H(n, x)) D(x-xC) + E(n,x)

Fixations

	ave	std	std/ave	fovea, deg
test 2	19.0	9.4	0.49	
test 3	16.8	10.2	0.61	
simplest model	19	17.2	0.90	1.66
optimal model	19.0	9.7	0.50	0.13
inhib & dist	18.2	13.3	0.73	1.02
inhib & dist & evid	19.6	12.4	0.63	0.97

Parameters

initial distribution: m = 1 deg, s = 2 deg

distance penalty distribution: m = 0, s = 5 deg

inhibition persistence factor: h = 0.99

evidence per fixation: e = 0.2

foveal width: 1 deg
perifoveal width: 3 deg

Detection computation

Filter signal on horizon image S(x,y) with low pass (optical) filter V(x,y) = S(x,y)*O(x,y).

Form local luminance image L(x,y) by filtering with surround filter L(x,y)=V(x,y)*B(x,y).

Compute contrast image C(x,y) = V(x,y)./L(x,y)-1

Compute masked contrast image
M(x,y) = C(x,y)/(1 + k B(x,y)*(C(x,y).^2)).^0.5

Subtract no-signal masked contrast image and compute contrast energy.

Shortcut computation

Ocean luminance = 6.62 cd/m^2
Sky luminance = 45.4 cd/m^2
Local luminance at target = 26.0 cd/m^2
Signal contrast = 6.62/26.0 -1 = -0.75
Signal duration = 0.3 sec
Pixel width = 0.025 deg
Contrast energy = width^2 duration contrast^2
dBB = 60 + 10 log10(energy) = 20
Gaussian low pass exp(-(f/15 cpd)^2)
  attenuation = -7 dB
RMS contrast at target is signal contrast
Masking factor = 1/sqrt(1+(-0.75/0.6)^2) => -4 dB
Effective signal energy = 9 dBB

Sensitivity comparison

Thresholds of 16 Modelfest observers
mean = 7 dBB, std dev = 2 dB

Modelfest threshold was 84% correct in
2 interval forced choice.

2IFC has a d' of root 2 larger than Y/N, i. e.
a 3 dB improvement, so the predicted
Y/N threshold for the Modelfest observers
is 10 dBB

The difference between an 84% and a 75% 2IFC
contrast threshold is about 2 dB *
(z((.84-0.5)/0.5) -z((.75-0.5)/0.5)) = 1 dB

Next Step

Collect more data!

Suggestion

Eye position recorders are usually calibrated with a simple “follow the spot” procedure. Perhaps a short “horizon” search and detection would help calibrate the distance penalty, inhibition, and detection parameters before expectations and stimulus attractors are included.