A Search Model for Imperfectly Detected Targets

Introduction

Simple models for visual search were developed for the Navy to provide estimates of the mean and standard deviation of the time to find a target in a workstation display. Since the fixation times are relatively constant at around 300 msec, we model the number of fixations required. Our previous models (Ahumada, 2010; Ahumada, Billington, & Kaiwi, 2011) assumed

- the search region has N non-overlapping regions that are foveated sequentially,
- the probability of detection P = 1 if a sub-region is foveated, and
- no visual information is available to guide the search (the target position is completely random).

Two extreme case models, Memory-Free Search and Exhaustive-Search, allow the bracketing of possible results. We describe these models, then extend them to the case where P < 1.

Memory-Free Search, P = 1

The probability that the number of fixations F equals k

$$Pr(F = k) = 1/N\ (1 - 1/N)^{(k-1)},\ k = 1, 2, \ldots$$

The mean and standard deviation of the number of fixations is

$$E[F] = N;\quad std[F] = N\ \mathrm{sqrt}(1 - 1/N) \sim N.$$

This distribution is illustrated in Figure 1 for N = 20.

Exhaustive Search, P = 1

The probability that the number of fixations F equals k

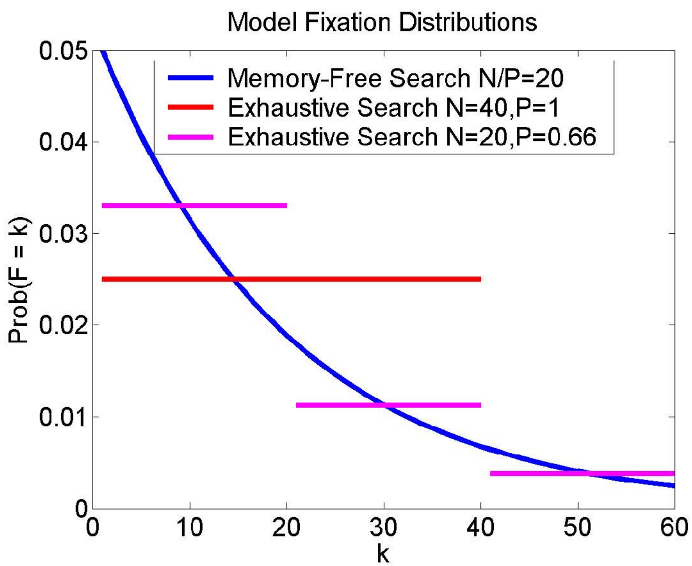
$$Pr(F = k) = 1/N,\ k = 1, \ldots, N.$$

The mean and standard deviation of the number of fixations is

$$E[F] = N/2 + 1/2;\quad std[F] = \mathrm{sqrt}((N^2 - 1)/12) \sim N/3.46 .$$

This distribution is illustrated in Figure 1 for N =40.

Figure 1



Memory-Free Search, P < 1

The probability that the number of fixations F equals k follows the geometric distribution,

$$Pr(F = k) = P/N\ (1 - P/N)^{(k-1)},\ k = 1, 2, \ldots$$

The mean and standard deviation of the number of fixations is

$$E[F] = N/P;\quad std[F] = (N/P)\ \mathrm{sqrt}(1 - P/N) \sim N/P.$$

This distribution is illustrated in Figure 1 for N/P =20. Note that N and P cannot be separately estimated from data generated by this model.

Exhaustive Search, P < 1

If P < 1 but the search is otherwise perfect, all N sub-regions may be fixated repeatedly until detection occurs. The number of fixations is now the sum of two random variables:
N times the number of searches through all N sub-regions, which has a geometric distribution over the integers beginning with zero with success probability P, and
the number of fixations after the failed full searches, which has the uniform distribution over the integers 1 to N.

Let int(x) = largest integer not greater than x.
The probability that the number of fixations F equals k,

$$Pr(F = k) = (1/N)\ P\ (1-P)^{\mathrm{int}((k-1)/N)},\ k = 1, \ldots, N.$$

The mean and standard deviation of the number of fixations is

$$E[F] = N\ (1/P - 1/2) + 1/2;\quad std[F] = N\ \mathrm{sqrt}((1-P)/P^2 + (1 - 1/N^2)/12) .$$

This distribution is illustrated in Figure 1 for N =20, P =0.66.

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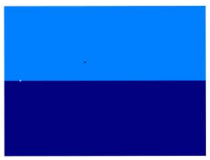
Figure 2



The background image, with sky above and sea below. The mark in the sky shows the location of the pretrial fixation mark on a white background. The mark on the horizon is at the leftmost target position.

The Search Experiment

The data were presented last year (Ahumada, Billington, & Kaiwi, 2011).

Methods

Stimuli: Figure 2 illustrates the background image. The upper region simulated the sky, the lower region simulated the sea. The target was a single pixel in the sky next to the sea with the same color as the sea. The stimuli were shown on a Samsung 910T LCD monitor in digital (DVI) mode. The luminance contrast of the target relative to the sky was -0.84. The screen resolution was 40.6 ppd. The contrast energy of the target (assuming an effective duration of 0.25 sec) was 20.3 dBB. The Watson and Ahumada (2005) standard spatial observer model predicts this target to be 7.6 dB above threshold.

Procedure: At the beginning of a trial, the screen was white and there was a fixation mark as shown in Figure 2. When the observer pressed the space bar the sky/sea scene appeared with the target in a position at chosen at random. In Figure 1 the leftmost position is marked. The observer was instructed to look for the target and when it was found to fixate it and hit the space bar, which ended the trial. A run consisted of 12 trials. A drift correction calibration was done after every three trials. The three male observers, KB, aged 19, JK, aged 67, and AA,aged 69, completed 10, 4, and 3 runs, respectively. An Eyelink (SR Research) recorded the eye positions and the associated DataViewer program summarized the results as a sequence of fixations with x and y pixel values, starting times and durations.

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Results

The fixation distribution for each observer is shown in Figure 3. A striking feature of the distributions is the "blind time" for the first 4 or 5 fixations. Although the first fixation wasusually about a degree above the horizon, the succeeding fixations were on the horizon.

Both of the models were fit to the distributions using the method of maximum likelihood to estimate the parameters and to evaluate the goodness of fit. For the small number of degrees of freedom and the sparse distributions, the values of -2 log likelihood did not follow a X^2 distribution, so the significance was evaluated using 900 simulations of the models using the estimated parameters. The normalizing transformation

$$z = \mathrm{sqrt}(2\,X^2) - \mathrm{sqrt}(2\,df - 1)$$

had the advantage of making the mean and standard deviation of the result relatively independent of the parameter values and the number of degrees of freedom.

Table 1 shows the number of "blind" fixations, the mean and standard deviation of the remaining number of fixations, and the parameter estimates and the significance level of the goodness of fit. KB is well fit by the Memory-Free model, which is actually a special case of the Exhaustive-Search model with N = 1. The Memory-Free model is rejected for the other two observers, while the Exhaustive-Search model is not rejected for any of them.

Table 1

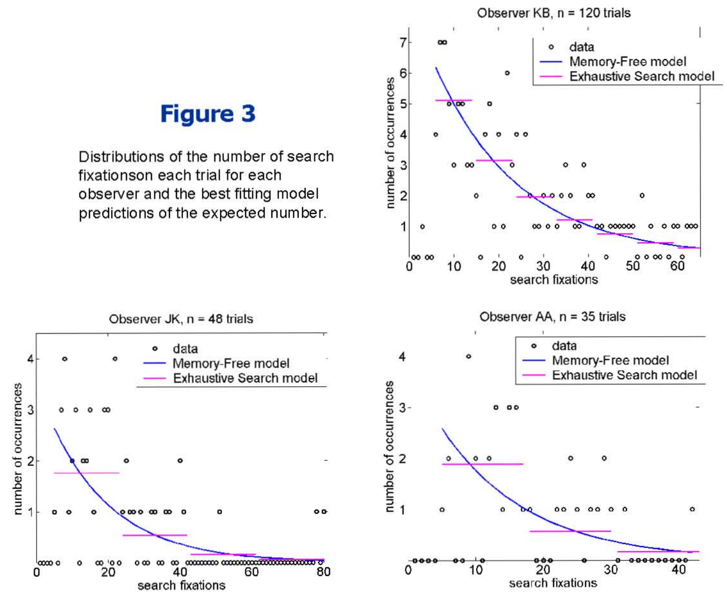
		fixations			Memory-Free		Exhaustive-Search		
obs.	trials	"blind"	mean	std	N/P	p level	N	P	p level
KB	119	5	19.4	15.3	19.4	0.50	9	0.38	0.98
JK	48	4	18.2	13.5	18.2	0.000	19	0.70	0.21
AA	35	4	13.5	8.8	13.5	0.000	13	0.70	0.69

Discussion

The Exhaustive-Search model provides a simple, well fitting model for this data from a search experiment with minimal cues to guide the search. The parameter N corresponds to a reasonable search region size of 3.3, 1.6, and 2.3 deg of visual angle for KB, JK, and AA, respectively.

Figure 3

Distributions of the number of search fixationson each trial for each observer and the best fitting model predictions of the expected number.



References

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