Title
Spatial attention and subitizing: AN invesitgation of the FINST hypothesis

Journal
Proceedings of the Annual Meeting of the Cognitive Science Society, 10(0)

Authors
Trick, Lana
Pylyshyn, Zenon

Publication Date
1988

Peer reviewed

Spatial attention and subitizing:

An investigation of the FINST hypothesis

Lana Trick and Zenon Pylyshyn

University of Western Ontario

How are visual items counted? It seems obvious. You find an item, augment a counter and then mark the item as counted. When all of the items have been marked you say the counter value. If this were true, counting latency should be a simple function of the number of items. Reaction time should increase a constant amount with every additional item after one. This is not the case, however. Research dating from the 1870's on has shown that the reaction time increase is not uniform. When there are a small number of items, the slope is shallow, at most one tenth second. Thereafter, the slope increases to one third second. The subitizing range, usually 1-4 items, is the range in which the slope is shallow. The subitizing process is rapid, accurate, and effortless. Above the subitizing range, from 5 on, is the counting range. Counting is a slower, more effortful and error prone process.

Why do subitizing and counting differ? First, a digression is required. It is well established that items differing from distractors by a primitive feature such as color, orientation etc., "pop out" in search tasks (Treisman and Gellade, 1980). For example, subjects detect the presence of a red item in a field of blue items in a time independent of the number of items in the display. In contrast, when an item is a different conjunction of features (eg. a red square in a field of red triangles and blue squares) or a subset (eg. an O in a field of Q's), search time depends on the total number of items. The standard interpretation is that a limited capacity spatial processor combines features; an attentional "spotlight" is moved from location to location in order to form an integrated object representation. However, when an item differs from distractors by virtue of a simple feature attention is not required. Features are computed by parallel preattentive mechanisms, and thus "odd man out locations" pop out. Pylyshyn (1987;1986) proposed that a small number of pop out locations can be assigned internal reference tokens, FINSTS. FINSTS remain assigned to a feature cluster though its retinal position changes. Thus, FINSTS permit the construction of geostable spatiotopic representations from the retinotopic output of low level feature extraction processes. According to Pylyshyn, only FINSTED locations can be accessed by the attentive processes that combine features and compute abstract spatial relations (Ullman, 1985). What does this have to do with subitizing and counting? I would like to argue that subitizing is parasitic this preattentive "FINSTING" mechanism. Therefore, subitizing should not be possible when attention is required to disambiguate the items that need to be counted from distractor items. If the items to be counted differ from the distractors by a simple feature, however, subitizing should occur. Counting, on the other hand, a process that by its nature involves moving a spatial processor through a representation (Ullman, 1985), should be unaffected by the type of distractor.

METHOD

Subjects

Nine graduate students, five female, participated for payments of twenty dollars. Each subject participated in every experimental condition.

Apparatus and Materials

Vocal response latencies were measured using a Gerbrands G1341 voice activated relay, while an Apple II+ computer was used to display the stimuli and record the data.

The stimuli were displays of up to 15 white letters on a black background. At most the letter display could cover a 5.97 by 4.2 degree area of visual angle. Letters each occupied .36 by .21 degrees and the minimal distance between letters was .73 horizontal and .36 vertical degrees when the subject was seated 110 cm from the video screen.

Subjects were required to count letter O's in a background of distractor letters. There were, in most cases, 1 to 8 O's and either 0, 2 or 4 distractor letters. Catch trials were also included in which there were no O's or 9 O's, or 1, 3, or 7 distractor letters. In the Pop out condition the distractor letters were X's; pilot studies showed that O's clearly "pop out" of X's in search tasks. In the Attentive search condition the distractor letters were Q's; in accord with Treisman (1985) we found O's do not "pop out" of Q's.

Procedure

The experiment was run in two sessions. In one session subjects were required to count O's in a background of X's (Pop out condition) whereas in the other subjects were required to count O's in a background of Q's (Attentive search condition). See figure 1. Session order was counterbalanced.

Each trial had four stages. First, during the 512 msec pre-trial interval, the screen went white and subjects were required to fixate on a central green dot. The computer then beeped to signal the start of the trial. After 256 msec, the letter display appeared and remained on until subjects made a vocal response. Third, as soon as the timer registered the response the display disappeared and the screen turned white. Finally, after 512 msec subjects were prompted to type in the number that they had said. Accuracy feedback was given.

At the beginning of each session subjects were given 60 practise trials.

RESULTS AND DISCUSSION

To summarize, the ability to subitize seems to be eradicated when subjects have to attentively search for the target letters; when subjects count O's in a background of Q's they no longer seem capable of subitizing. The slope of the reaction time function remained constant throughout the 1-8 range. When the targets pop out from the background, however, the ability to subitize is spared. Thus, when subjects count O's in a background of X's there is evidence of subitizing once more; the slope of the reaction time function in the 1-4 range is different than it is in in the 5-8 range.

Reaction time analysis

Averaged data. As can be seen from figure 2, both the number of O's and the number of distractors yielded effects on reaction time. In fact, analysis of variance revealed all main effects and interactions to be significant. Reaction times increased as the number of O's in the display increased($F(7,56)=515.5, p<.01$). Overall, however, the increases were greater in the Attentive search session than the Pop out session($F(7,56)=48.1, p<.01$). Further, number of distractors also affected reaction time; the more distractors the longer it took to count($F(2,16)=1392.2, p<.01$). Once again, though, number of distractors had a greater effect when the distractors were Q's then when they were X's($F(14,112)=7.8, p<.01$). Finally, the deleterious effect of distractors varied according to the number of O's and the type of distractors($F(14,112)=2.52, p<.01$).

Subitizing ranges were determined empirically through trend analysis. First, in order to determine if subitizing occured, trend analysis was performed on the entire range (1-8 O's) to find out if significant trends beyond the linear emerged. If the reaction time function showed no significant deviation from linearity then it was assumed that subitizing did not occur. However, if there were significant deviations from linearity it was necessary to find out where the trend emerged and if it was in the right direction. The point at which the reaction time function began to show significant positive quadratic trends was judged to be the boundary of the subitizing range.

When there were 2 or 4 Q's in the display with the O's no significant nonlinear trends in the reaction time emerged, although in both cases the linear trends were highly significant(linear $F(1,64)=851.1, p<.01$; nonlinear deviation $F(6,64)<1$; linear $F(1,64)=884.7, p<.01$; nonlinear deviation $F(6,64)<1$ for 2 and 4 distractors respectively). In contrast, when there were 2 or 4 X's in the display, subitizing was observed. Significant linear trends emerged but also significant deviations from linearity and quadratic trends(nonlinear deviation $F(6,64)=2.29, p<.05$; quadratic $F(1,64)=9.8, p<.05$; nonlinear deviation $F(6,64)=2.28, p<.05$; quadratic $F(1,64)=11.23$, $p<.01$ for 2 and 4 distractors respectively). In the two distractor condition the quadratic trend emerged at 5 whereas in the four distractor condition the quadratic trend didn't emerge until 6. Thus, subjects seem capable of subitizing up to 4 O's when there were 2 X's and up to 5 O's when there were 4 X's. Nonetheless, the results support the idea that subitizing items in a background is possible only when the items "pop out" of the background items.

As expected, subitizing was clearly shown whenever there were no distractors. In both the Pop out and Attentive search conditions there were linear and higher order trends (nonlinear $F(6,64)=6.1$, $p<.01$; quadratic $F(1,64)=24.0$, $p<.01$; nonlinear $F(6,64)=4.73$, $p<.01$; quadratic $F(1,64)=11.8$, $p<.01$ for Pop out and Attentive search respectively). In both cases the quadratic trend emerged at 5, indicating that subjects could subitize up to 4 O's when there were no distractors.

Slopes of the functions were revealed through regression analysis. (See table 1). For subitizing, in the pop out condition there seemed to be a steady increase in the slope as the number of distractors increased, consistent with the notion of the cost of filtering(Treisman, Kahnemann and Burkell, 1983). The only significant slope differences were between no distractor and four distractor condition however; in the other cases estimated slopes fell within each other's 95% confidence interval. (For simplicity in the analysis subjects were assumed capable only of subitizing to 4 in the four distractor condition. Later analyses revealed that most subjects subitize to 4 in this condition).

Surprisingly, when the subitizing slopes of the two no distractors conditions were compared, there were significant differences. The subitizing slope was significantly greater when subjects had no distractors in the Q distractor session than when there were no distractors in the X distractor session.

As expected, few systematic trends in the counting (5-8) range slopes. In all cases, counting slopes fell within each other's 95% confidence intervals. Thus, the type of distractor had little influence on the counting slope.

Individual analysis. Given that averaging across individuals might obscure subtle changes in slope, trend analyses were also performed on individual datasets. Results were consistent with findings from the averaged data. (See table 2). None of the subjects showed non-linear trends counting O's in a field of Q distractors. In contrast, most showed non-linear trends when counting O's in X's (Chi square(3)=14.0,$p<.01$).

There are individual differences in where the quadratic trends emerge, however; some people seem subitize larger numbers than others. Although the majority of the subjects subitize to 4, there is some variability, and what's more, the greater the number of distractors the more variability there is.

Error analysis

Subjects made few errors. Nonetheless, condition, number of items, and number of distractors all had effects on the error rate. (See figure 3). Subjects tended to make more errors when counting in the Attentive search condition($F(1,8)=8.9, p<.05$). Also, the probability of error increased with the number of O's($F(7,56)=5.8$, $p<.01$). Distractors also affected error rate($F(2,16)=4.06$, $p<.05$).

Conclusion

As predicted, subitizing was not possible when attention was required to disambiguate items from the distractors but was in evidence otherwise. Subitizing seems to rely on preattentive mechanisms. Counting seems to require localized attention, however; thus distractor type had little effect on slopes.

References

Pylyshyn, Z. (1987). The role of location indexes in spatial perception: A sketch of the FINST Spatial-index Model. Cogmem, 23, University of Western Ontario.

Pylyshyn, Z. and Storm, R. (1986). Tracking of multiple independent targets: Evidence for both serial and parallel stages. Cogmem, 22, University of Western Ontario.

Treisman, A., and Gellade, G. (1980). A feature integration theory of attention. Cognitive Psychology, 12, 97-136.

Treisman, A., Kahneman, D., and Burkell, J. (1983). Perceptual objects and the cost of filtering. Perception and Psychophysics, 12, 527-532.

Treisman, A. (1985). Preattentive processing in vision. Computer vision, graphics and image processing, 31, 156-177.

Ullman, S. (1984). Visual routines. Cognition, 18, 97-159.

Pop out Condition
(2 distractors)

Attentive search Condition
(2 distractors)

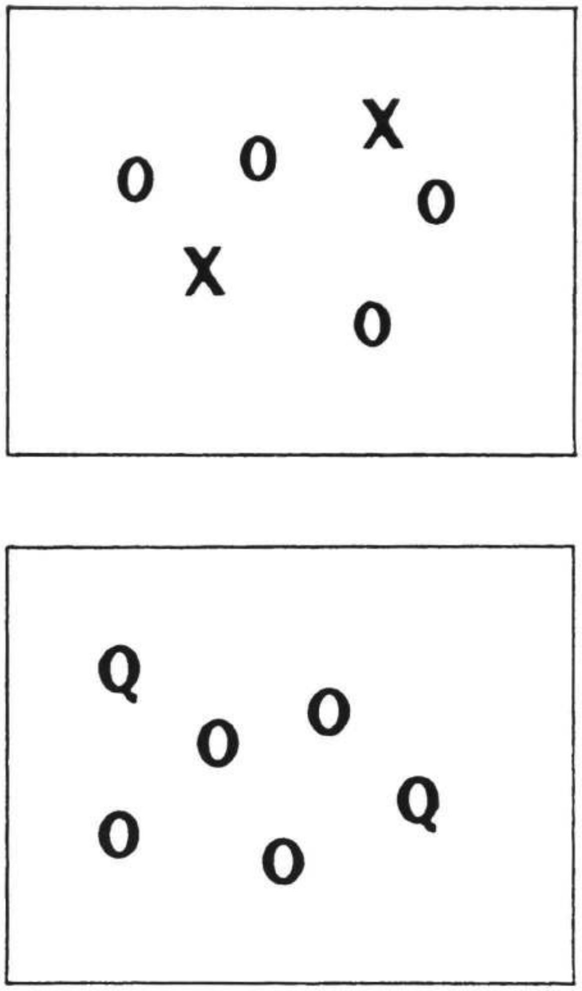


Figure 1. Counting Displays

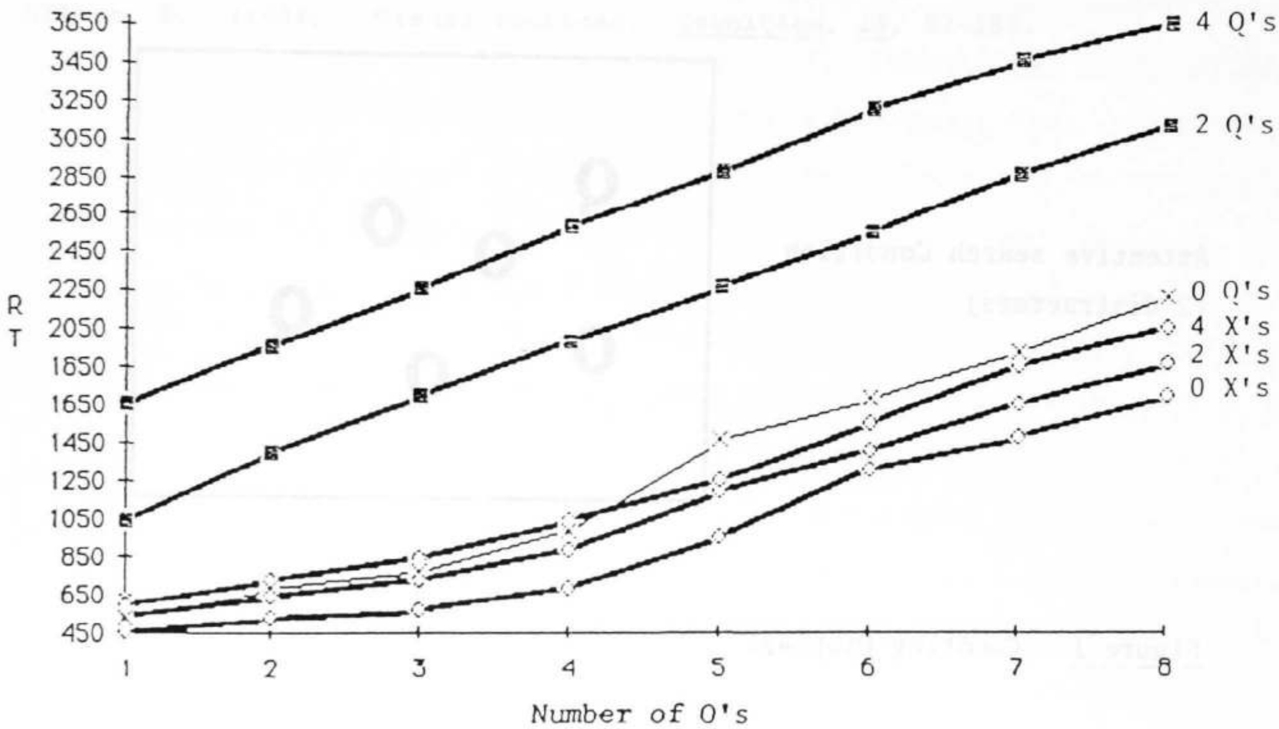
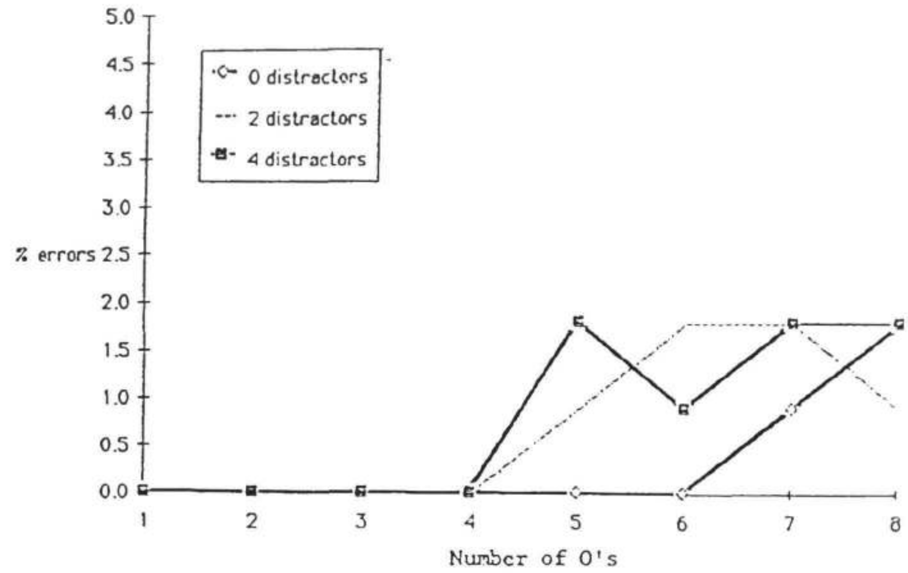
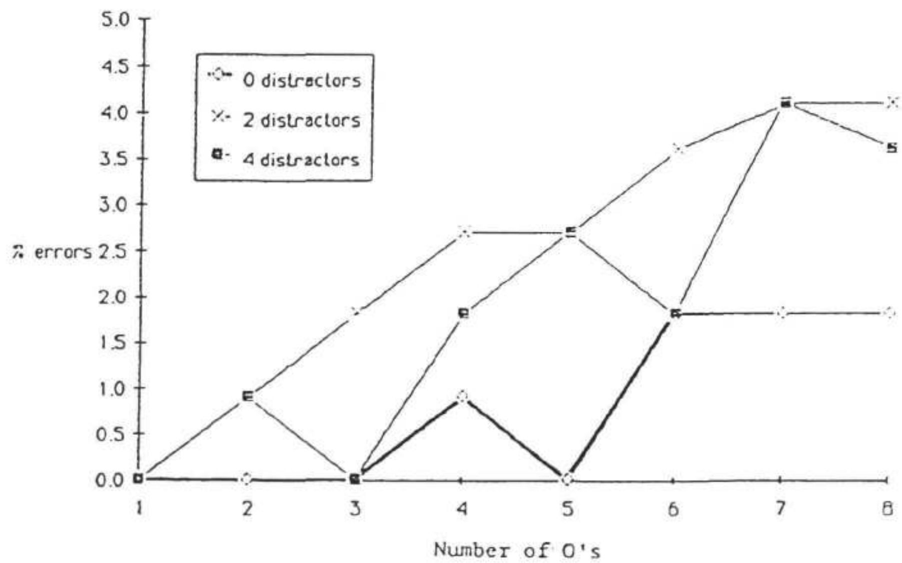


Figure 2 . Counting latency averaged across subjects.



Pop out condition: Counting O's in the background of X's



Attentive search condition: Counting O's in a background of Q's

Figure 3. Average number of errors in counting

Table 1

Regression analysis of averaged counting latencies

	Slope	95% C.I.	R
SUBITIZING RANGE (1-4)			
Pop out condition: Counting O's in X's			
0 distractors	71.3	49 - 93	.75
2 distractors	115.2	85 - 146	.80
4 distractors	143.9	108 - 180	.81
Attentive search: Counting O's in Q's			
0 distractors	148.4	123 - 173	.90
2 distractors	--		
4 distractors	--		
COUNTING RANGE (5-8)			
Pop out condition: Counting O's in X's			
0 distractors	242.7	179 - 306	.80
2 distractors	227.4	164 - 291	.78
4 distractors	272.4	208 - 337	.83
Attentive search: Counting O's in Q's			
0 distractors	252.5	194 - 310	.83
2 distractors*	294.1	275 - 313	.96
4 distractors*	293.5	274 - 313	.96

*Because there was no evidence of subitizing in the Attentive search condition with 2 or 4 distractors the counting range is considered to be 1-8.

Table 2

Trend analysis of individual datasets

Number of subjects showing non-linear, quadratic trends in RT

	Pop out condition	Attentive search condition
0 distractors	9/9	7/9
2 distractors	7/9	0/9
4 distractors	7/9	0/9

Individual breakdown of subitizing range

POP OUT CONDITION	0 distractors	2 distractors	4 distractors
Total subjects	(N=9)	(N=7)	(N=7)
No. who subitize to 3	2	1	1
No. who subitize to 4	7	5	3
No. who subitize to 5		1	2
No. who subitize to 6			1

ATTENTIVE SEARCH	0 distractors
Total subjects	(N=7)
No. who subitize to 3	1
No. who subitize to 4	6