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Selective Attention and Biological Motion

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Abstract. A number of recent findings suggest that attention may play a larger role in the processing of biological motion than has been previously assumed. In the current study we assess individual thresholds for the detection of masked point-light walkers and obtain performance measures on a range of attention related tasks. Our results indicate a strong and consistent correlation between selective attention and the processing of biological motion.

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1 Introduction

Johansson's [Johansson, 1975] [Johansson, 1973] point-light figures remain one of the most compelling demonstrations of dynamic visual processing. In these displays (see Figure 1), observers are able to quickly and easily interpret a range of human actions despite the fact that form cues have been reduced to a few small light sources attached to the major body joints (e.g.,[Ahlström et al., 1997] [Kozlowski, 1978, Kozlowski and Cutting, 1977, Pavlova and Sokolov, 2000, Troje, 2002, Verfaillie, 1993]. The apparent ease with which such moving displays can be processed led a number of researches, including Johansson, to explain performance in terms of bottom-up, passive, processing mechanisms [Johansson, 1973, Johansson, 1975, Johansson, 1976, Giese and Poggio, 2003, Mather and West, 1992, Webb and Aggarwal, 1982]. More recently, several studies have also focused on how top-down mechanisms contribute to the processing of biological motion [Bertenthal and Pinto, 1994, Bülthoff et al., 1998, Thornton et al., 2002]. In particular, several studies suggest that attention might be required to interpret even quite simple point-light displays ([Cavanagh et al., 2001, Battelli et al., 2003]). The goal of the current work was to explore in more detail this potential link between attention and biological motion processing. Studies using both visual search ([Cavanagh et al., 2001]) and dual-task ([Thornton et al., 2002]) methodologies have indicated a role for attention in the detection and interpretation of point-light walkers. What is not as yet clear is the precise nature of this role. More specifically, with reference to previously established "networks of attention" ([Posner and Peterson, 1990]), it is unclear whether attention is used to a) orient to the stimuli b) increase levels of alertness/vigilance or c) to control selection of relevant information in a top-down, executive fashion. Previously, we have speculated that attention may be important for the top-down selection and application of dynamic templates or "sprites" ([Cavanagh, 1993, Thornton and Shiffrar, 1998, Cavanagh et al., 2001]. Such templates are thought to be involved the explicit identification and interpretation of complex motion patterns, processes that may be particularly demanding as they require the selection and tracking of elements across both space and time ([Rensink, 2002]). This role of attention would strongly favor the involvement of top-down, executive control networks. To further explore the relationship between attention and biological motion processing we used a simple three-step approach. First, we developed a technique for assessing individual levels of performance on a biological motion task. Second, we used a range of standard measures to assess general levels of attentional performance in the same set of observers. Third, we examined whether there was any correlation between performance on the biological motion task and the measures of attention. These individual steps are described in more detail in the following sections.

Despite a great deal of research on biological motion, there appears to have been little interest in establishing individual differences and exploring what these might tell us about underlying mechanisms. Here

we used an adaptive staircase procedure to obtain individual estimates of the number of masking elements that led to approximately 71% correct performance in a direction discrimination task (Footnote 1). Success in direction discrimination under masking conditions involves a number of components, including sustained, effortful search to locate the target, segmentation of the global target from local masking elements and identification of walking direction, a decision that requires integration of information across time. The next step in our approach was to take the same set of observers and to assess levels of performance across a range of attention-related tasks. To do this we employed a number of standard tests. The attention network test (ANT) was used to provide independent assessments of alerting, orienting and executive control ([Fan et al., 2002]). The Stroop colour naming task ([Stroop, 1935]) provided an assessment of selective attention and conflict resolution. Finally, we used an effortful, static visual search paradigm ([Wolfe, 1998]). Full details of all of the tasks are given in the methods section. The final step in our approach was to assess whether there was any relationship between performance on the biological motion task and the particular components of attention probed with the standardised tests. Specifically, our goal was to know whether masked direction discrimination performance would correlate with any or all of the sub-components of attention involved in orienting, alerting and executive control. The presence or absence of such correlation could provide useful, additional information about the role of attention in the processing of biological motion.

2 Methods

2.1 Participants

Twelve members of the Tübingen community were paid for participation in this study. All observers reported normal or corrected to normal vision and were naive with regard to the purpose of the study.

2.2 Apparatus.

Stimuli were presented on a 21 inch (37 cm x 28 cm) monitor with a refresh rate of 75 Hz and a resolution of 1152 x 870 pixels. Observers sat approximately 60 cm from the monitor in a dimly lit room. Responses were collected via a standard keyboard.

Biological Motion Task. The task for observers was always to report the left/right orientation of a walking figure that was presented in sagittal view at a random location within a central 9.3 x 9.3° viewing area. Each walking figure consisted of 11 dots (head, near shoulder, both elbows, both wrists, near hip, both knees, and both ankles) drawn in black on a gray background, each dot subtending 0.17 . The figures subtended 3 in height (head to ankle) and 1 in width (at the most extended point of the step cycle) and were animated using Cutting's algorithm (Cutting, 1978). A complete stride cycle was achieved in 40 animation frames with a frame duration of 40 ms simulating a natural walking speed of 38 strides per minute ([Inman et al., 1981]). The starting position within the step-cycle was randomly chosen on each trial. During an initial training phase, the walker appeared unmasked for 100 trials. To assess individual mask thresholds, two interleaved staircases were presented in which the number of scrambled walker dots were either increased or decreased from starting levels of 110 (5 scrambled left facing walkers, 5 scrambled right) and 550 (25 left/25 right) dots respectively. For either staircase, two correct responses resulted in the addition of 22 dots (1 left/ 1 right scrambled walker) to the mask. A single incorrect response resulted in the removal of 22 dots. A reversal occurred whenever the direction of this mask alteration changed, from addition to subtraction or vice versa. A staircase terminated after 30 such reversals. Thresholds were estimated by averaging across the last eight reversal points and collapsing across the two interleaved staircases. This standard 2 up/1 down procedure provides an estimate of the mask level at 71 per cent correct. The entire task took approximately 30 minutes.

2.3 Visual Search Task

Visual search has proven to be a very useful technique for exploring human perception, in particular the relationship between vision and attention ([Wolfe, 1998]). Here we employed a relatively inefficient search for the absence of a feature - the letter "O" compared to the letter "Q" – that is thought to involve effortful, serial deployment of attention. Such a task not only provided an assessment of the ability to shift and selectively deploy attention, but also closely parallels the search component of our main walker task. Observers performed 320 trials in which the presence/absence of the target (the letter O, present 50% of time) and the number of distractors (6, 8, 10, 12 instances of the letter Q) were crossed and randomly intermixed. Target

and distractor letters were drawn in black in a middle gray background, subtended 0.8° visual angle and were spatial distributed within a 16 x 16° viewing square. The main dependent measure of interest was search efficiency, indexed by the increase in target present response time as a function of set size.

2.4 Stroop Task

The Stroop ([Stroop, 1935]) colour naming task provides a simple but highly effective measure of selective attention. Observers are asked to read aloud the ink colour of each item in a list of words or neutral strings of letters (e.g., XXXXX). Even though observers are told to ignore the meaning of the items, when they consist of incongruent colour terms (e.g., the word red presented in blue ink) reaction times are dramatically slowed. The magnitude of this slowing provides an index of how well observers can selectively attend. Here we presented four lists of twelve items and manually recorded the total time taken to read down each list. The words were presented at the centre of the computer screen in a 12 x 3° column. The first two lists consisted of neutral words (e.g., Cat, Star, Poster, Watch) which could be drawn in red, blue, green or yellow. These lists were used as a training phase. A list of neutral items and a list of incongruent colour terms were then presented with the order counterbalanced across observers. The dependent measure was the reaction time difference between the neutral and incongruent lists.

2.5 Attentional Network Test

The Attentional Network Test (ANT) was developed by Michael Posner and colleagues ([Fan et al., 2002]) to provide a fast and efficient attentional assessment technique appropriate for use with children, animals, patient populations and in the context of brain imaging. The name derives from the observation, discussed above, that components of attention, such as alerting, orienting (e.g., selection of information) and executive control (e.g., conflict resolution), appear to be subserved by networks of different brain areas ([Posner and Peterson, 1990]). To provide an assessment of these three functional networks in a single, short (approx. 30 min) task, the ANT combines a Posner cueing paradigm with an Eriksen flanker task ([Eriksen, 1974]). Observers are asked to make a speeded response to left/right orientation of a central arrow that can appear above or below fixation. In some trials the target is preceded by a spatially uninformative (altering) or informative (orienting) cue and can appear alone or in the presence of congruent or incongruent flanking arrows (executive control). The task is run in a single session, with trial types fully intermixed. Appropriate reaction time subtractions are used to derive separate assessments of alerting, orienting and executive control. These subtractions are described in the results section. The task itself and more background information can be obtained from `http://www.sacklerinstitute.org/~jinfan/`

2.6 Procedure

Each task was run as a separate mini-experiment, with written instructions, verbal explanation and relevant training proceeding each period of data collection. Short breaks were provided between each task. The Biological Motion task was always run first, with the order of the remaining tasks counterbalanced across observers. The entire data collection period was approximately two hours.

3 Results

3.1 Biological Motion Task

shows the raw data from two example staircase procedures. The upper panel shows an observer with a relatively low mask threshold of 132 dots (poorer performance), the lower panel shows an observer with a high mask threshold of 286 dots. On average, staircases terminated after 226 trials, which took approximately 20 minutes. The average threshold was 242 mask dots. Of particular interest was the spread of this distribution, which ranged from 114 to 338 dots (see Table 1, Figures 4 & 5), suggesting considerable individual difference in the level of masking that led to 71% correct performance.

3.2 Visual Search Task

Data from the visual search task are summarised in Figure 3. As expected, search was slow and serial, with linear regressions providing very good fits to the average data for both target present (R2 = 0.9912) and target absent ($R^2 = 0.9925$) slopes. To obtain individual measures of search efficiency, linear regression lines were fitted to the search data of each observer. These estimates indicated average target present slopes

of 44 ms/item (see Table 1) and target absent slopes of 76 ms/item, consistent with overall pattern of results shown in Figure 3.

3.3 Stroop Task

Data from one observer was lost due to a technical error. For the remaining 11 observers there was a strong and consistent cost associated with the ink colour/colour label conflict. Specifically, reading times for the colour terms (M = 10 secs) were some three seconds longer than for the neutral letter strings (M = 7 secs), t = 24.6, p ¡ .001. These conflict scores are summarised in Table 1.

3.4 Attentional Network Test

The raw reaction time data obtained from the ANT are summarised in Table 2, as a function of cue and flanker conditions. Three measures of interest were obtained from the ANT (see Table 1). An orienting effect was computed by subtracting reaction times to spatial informative up/down cues from centrally cued trials. This subtraction indicated that observers were on average 41.17 ms faster in the spatially cued trials (M = 570 ms) compared to the central cued trials (M = 612 ms), a pattern that was highly reliable, t = 5.722, $p < .001$. Alerting was computed by subtracting double cue trials (M = 641ms) from no cue trials(M = 602 ms). This subtraction revealed a reliable alerting effect of approximately 40 ms, t = 7.375, $p < .001$. Finally executive control was computed by subtracting congruent (M = 591 ms) from incongruent (M = 683 ms) trials, having collapsed across all cue types. There was a strong (M = 92 ms) effect of congruency which was again highly reliable, t = 11.717, $p < .001$. In general, the raw reaction times and attentional estimates from the ANT were very similar to those previously reported by [Fan et al., 2002].

3.5 Correlation Analysis

To explore the relationship between the biological motion task and the various measures of attention, we constructed the correlation matrix shown in Table 3. Of primary interest is the final column that directly compares biological motion to the various attentional measures. There were only two factors that were significantly correlated with biological motion. Performance on the Stroop task was negatively correlated (r = -0.679, $p < 0.05$), such that observers who performed well on the biological motion task were also less affected by colour conflicts in the Stroop task. Similarly observers who did well on the biological motion task were less affected by flanker congruency in the ANT, (r = -0.753, $p < 0.01$). Scatter plots for these two effects are shown in Figure 4.

Interestingly, the cross-correlation between the Stroop and congruency effects was only marginally significant (r = 0.562, p = 0.07). This suggests that they may be relating to slightly different aspects of biological motion. Consistent with this notion, multiple regression including both the Stroop and congruency effect as independent parameters accounts for a larger percentage of variance (66.3%) compared to separate analysis of these factors (46% and 56.5% of the variance for the Stroop and congruency effects respectively). None of the other cross-correlations reached significance, although the relationship between orienting and congruency was marginal (r = 0.57, p = 0.06).

4 Discussion

The main finding from the current study was that the processing of masked point-light walkers strongly correlates with measures of selective attention. While previous research had suggested an important role for attention during the processing of biological motion (e.g., [Cavanagh et al., 2001, Thornton et al., 2002]), the exact nature of this role was still unclear. As the Stroop effect and the congruency measure from the ANT - the two correlated factors – are both thought to index aspects of the executive control, it appears that top-down selection of information, rather than stimulus-driven selection, orienting or modulations of arousal, is the common factor. Such a finding is consistent with the notion that biological motion processing in the context of masking is not a spontaneous, automatic process, but is rather a cognitively demanding, active process [Cavanagh, 1993, Cavanagh et al., 2001, Cutting and Morrison, 1988, Thornton and Shiffrar, 1998, Thornton et al., 2002].

Given the nature of the current walker task - finding a target in a mask and holding on to the dynamic pattern long enough to determine direction - it is perhaps not surprising that performance is correlated with an ability to selectively attend and to ignore irrelevant items. However, a task analysis might also have predicted that visual search measures would also be highly correlated, which was not the case. Similarly,

the ability to orient attention or individual differences in arousal changes in response to a biologically salient target could have emerged. Again, there was no evidence that this was the case.

What remains to be seen is whether similar patterns of correlation with selective attention can be found in other types of biological motion task, particularly those in which masking is not required. In previous studies we have found that making explicit responses to simple, unmasked walkers does appear to require attention [Cavanagh et al., 2001, Battelli et al., 2003]. It will be interesting to develop tasks in which individual differences in basic walker processing can be established, with a view to correlating these measures with attentional tasks. Additionally, further paradigms that tap into selective attention, such as search for change [Rensink, 2002], attentional blink ([Raymond et al., 1992]) or visual marking ([Watson and Humphreys, 1997]) could be applied to the context of either masked or unmasked biological motion processing. Finally, it seems unlikely that the current findings are specific to biological motion processing. That is, we would expect that the processing of any complex, dynamic pattern under similar conditions would require the intervention of attention ([Cavanagh et al., 2001]). The contribution of the current work is, rather, to add to the growing evidence that our visual system can and does recruit mechanisms at multiple levels in order to ensure the effective processing of motion and change, two fundamental aspects of our world ([Cavanagh et al., 2001, Knappmeyer et al., 2003, Stone, 1993, Vuong and Tarr, 2004, Wallis and Bulthoff, 2001]).

5 FOOTNOTES

- Masking a point-light figure involves surrounding the target by a field of dots which are physically identical (i.e. in shape, size, colour) to the points making up the walker. The local motion of the masking elements, their global structure and global motion (e.g., from single dots, to pairs, to limbs) can all be manipulated to vary the difficulty of detecting the embedded target figure (Cutting, Moore and Morrison, 1988). The current masking technique is described in more detail in the methods section.

- Visual search of this form is generally thought to provide a good index of the efficiency with which attention can be deployed, combining guided shifting of attention, target selection and, possibly, distractor inhibition. Such a test is particularly useful in the current context as it parallels many of the general components of the masked walker paradigm.

6 Acknowledgements

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Table 1: Summary of all tasks. Stroop interference is expressed in Seconds and Mask Density is in terms of total dots. All other measures are Milliseconds.

Subject Id	Stroop	Alerting	Orienting	Congruency	Search Slope	Mask Density
1	4.020	42.000	87.000	121.000	47.590	210.000
2	2.740	7.000	32.000	46.000	25.380	363.000
3	3.060	18.000	55.000	109.000	38.750	238.000
4	3.740	26.000	23.000	106.000	39.090	238.000
5	3.450	56.000	68.000	97.000	84.000	227.000
6	3.460	29.000	64.000	156.000	13.590	143.000
7	2.620	82.000	28.000	76.000	38.310	286.000
8	3.200	78.000	46.000	81.000	62.000	204.000
9	3.380	18.000	19.000	48.000	11.000	275.000
10	3.560	26.000	5.000	93.000	72.000	144.000
11	2.760	46.000	36.000	70.000	58.020	338.000
12		37.000	31.000	99.000	53.300	239.000
Mean	3.272	38.750	41.167	91.833	45.252	242.083
Stdev	0.422	22.480	22.498	29.453	21.271	63.915

Table 2: Mean reaction times (ms) for various cue types and congruency conditions from the Attention network test. Standard deviations are shown in parentheses.

Congruency	No Cue	Double Cue	Center	Spatial
Congruent	628(100)	592(101)	593(95)	549(88)
Incongruent	700(125)	677(113)	700(111)	654(111)
Neutral	595(99)	538(101)	543(97)	510(76)
Mean	641.15	602.42	611.99	570.86

Table 3: Correlation matrix. Mask Density, the column of most interest, has been shaded.

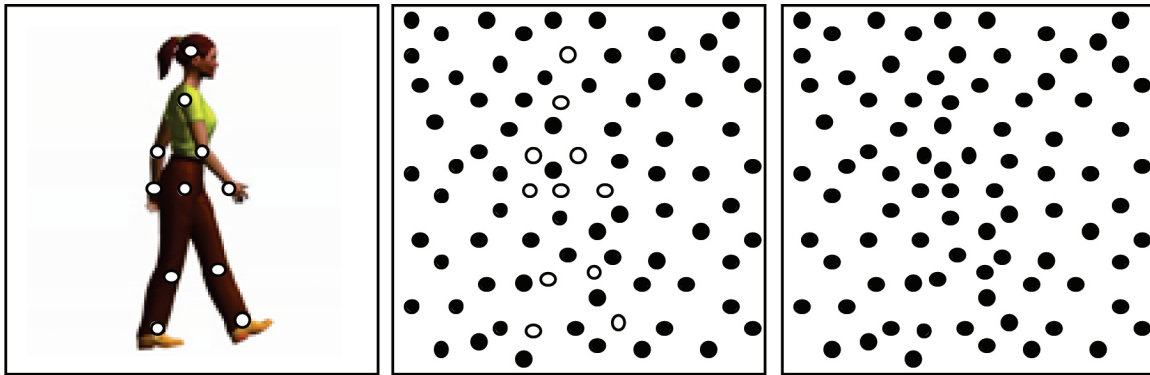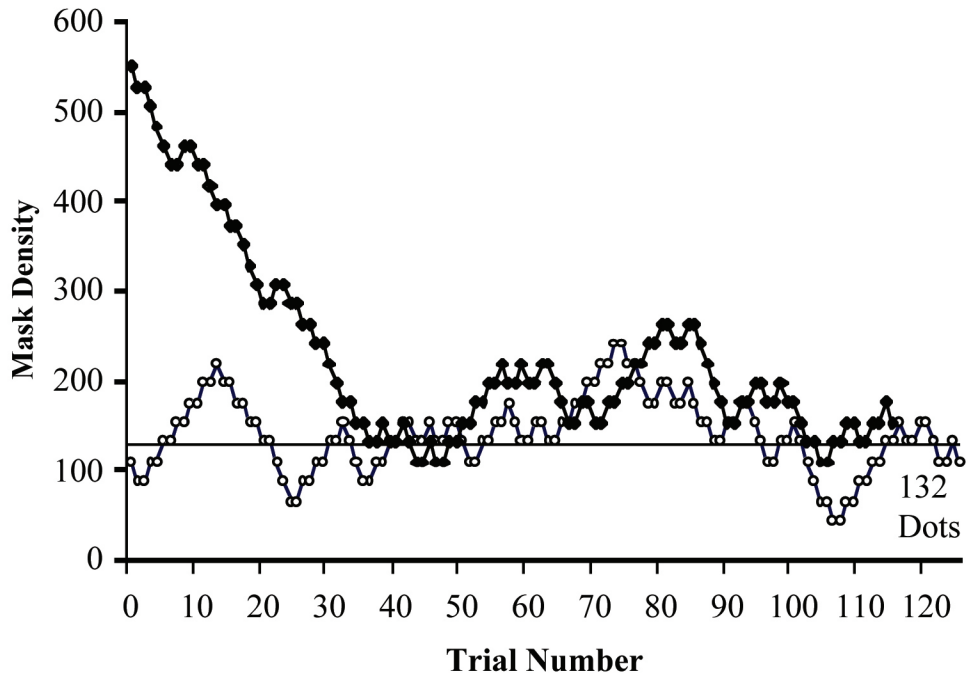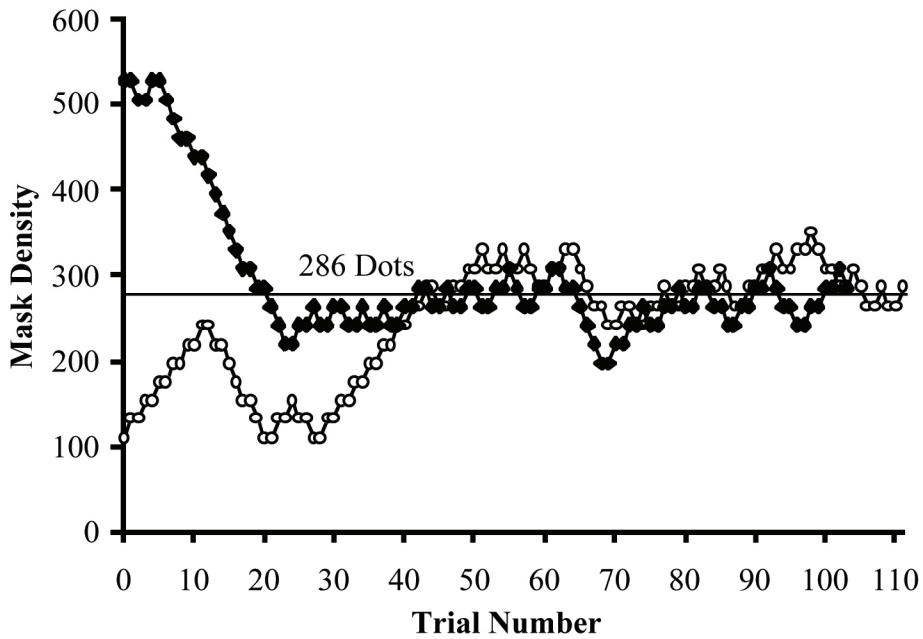| Condition	Stroop	Orienting	Alerting	Congruency	Search	Mask
Stroop		0.32	-0.19	0.56	0.12	-0.68*
Orienting			0.18	0.57	0.09	-0.22
Alerting				0.01	0.46	-0.08
Congruency					0.02	-0.75*
Search						-0.21
Mask						

Figure 1: Three static views illustrating the construction of a masked point light walker display. The form of the human body and the white dots (middle panel) are never shown in experimental stimuli. When presented statically, the display on the far right is difficult to interpret. However when set in motion, observers are easily able to organise the complex patterns of point motion into a coherent percept of human locomotion despite the masking dots. In the experimental stimuli, the walker points and mask points are identical.

(a)

(b)

Figure 2: Staircase data from one subject. Filled circles show points for the descending staircase. Open circles show data from the ascending staircase. The threshold was measured as the average of the last 8 reversal points (solid line). The subject shown in panel A has a threshold of 132 dots. The subject shown in panel B had a threshold of 286 dots.
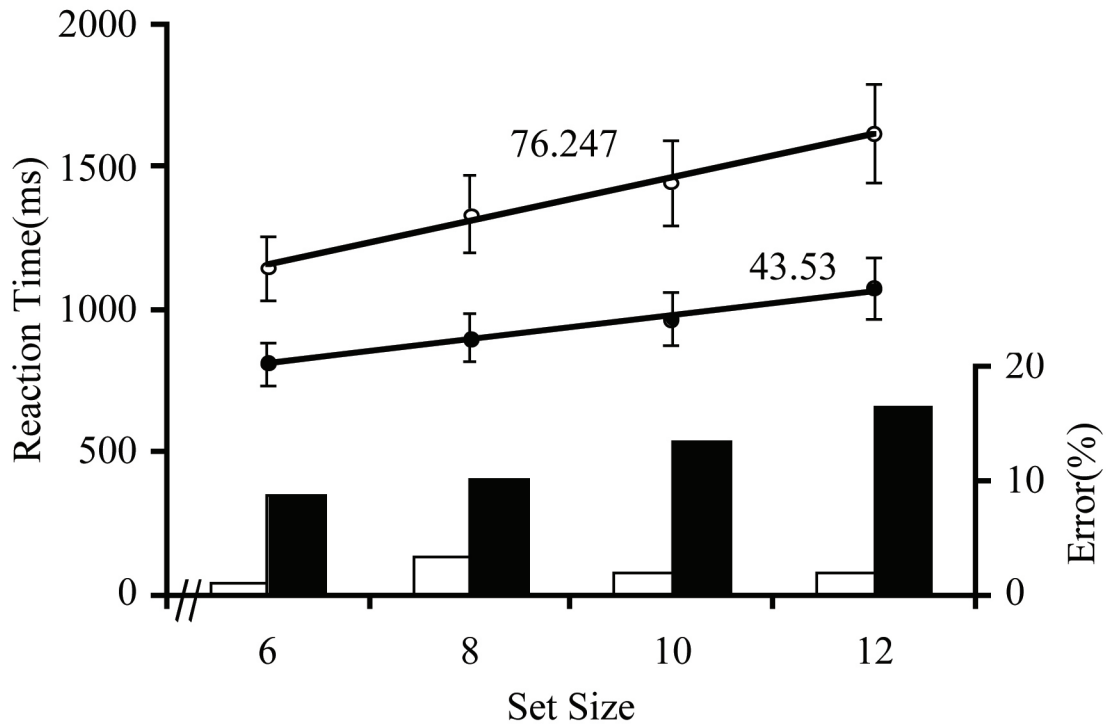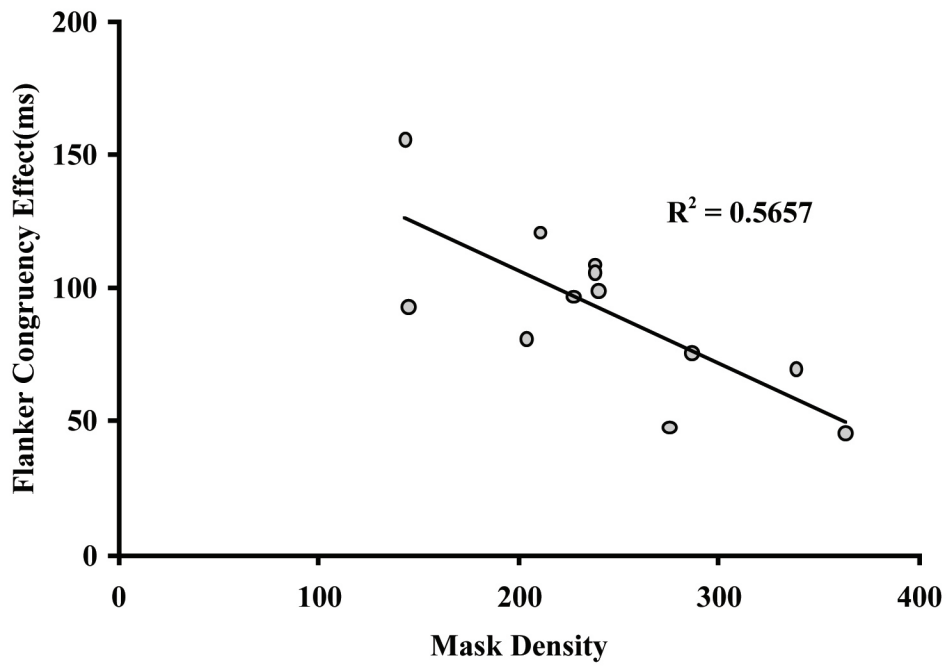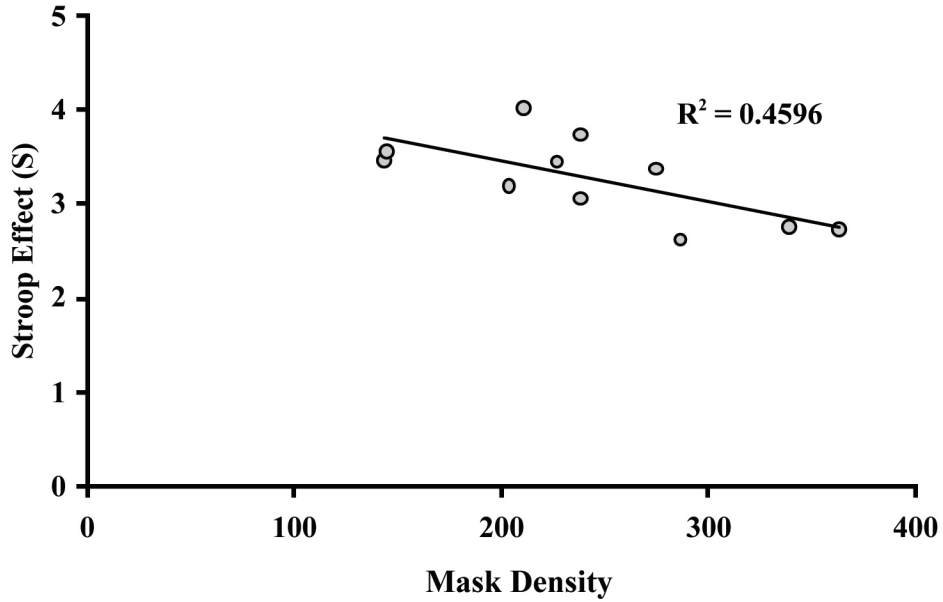
10

Figure 3: Summary of visual search data. Reaction time in milliseconds (left hand vertical axes) is shown as a function of set size. Target present responses are shown as filled symbols, and target absent responses are shown as outline symbols. Standard errors of the mean are shown as vertical bars. The solid lines show the linear regressions for both target present (y = 43.53x + 543) and target absent (y = 76.247x + 698.33) trials. Note that the X-axis is broken, so that intercept values cannot be read directly from the graph. The figures adjacent to each line shows the average slope in ms/item. Error rates (right hand vertical axes) are shown as histograms at the bottom of each panel with outline bars for target present, and filled bars for target absent trials. The data are averages for 12 observers.

(a)

(b)

Figure 4: Correlation analysis for Mask density versus Flanker Congruency (top) and Stroop effect (bottom). Filled circles show data from each observer. Solid line shows linear regression fit to data.