Exogenous Cuing and Perceptual Matching Judgments of Orientation and Motion

by

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I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

A series of experiments is described which uses a perceptual matching approach to study the effect of exogenous visual cues on perception of static and dynamic stimuli. Analogous experiments were carried out for orientation judgments of rotated Gabor patches and for direction of motion of coherent dot motion. Response time effects of cuing were found in all conditions. Cuing was found to improve accuracy of orientation judgments, while the effects on motion judgments were less reliable. Cuing was found to have substantially larger effects on quality of orientation judgments at low contrast levels. Other analyses performed found sequential trial effects and qualitatively different effects of canonical directions on orientation and motion judgments.

Acknowledgements

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Chapter 1

Introduction

Everyone knows William James' observation that "Everyone knows what attention is" (James, 1890/1983). However, as with so much in attention research, whether we all share the same notion of attention is disputed (Anderson, 2011). I will sidestep the topic of what attention is, but instead discuss what attention is good for.

Attention refers to an allocation of limited visual resources, generally in the service of appropriate action. If attentional processes are in the service of action, it is reasonable to think that attentional mechanisms should aid performance on multiple measures.

In many attentional manipulations and visual tasks there is evidence for effects on reaction time—typically in a high-attention condition or a cued condition, detection of stimuli is faster (though note the phenomenon of inhibition of return; Klein, 2000). Whether these effects are mediated by changes in sensory systems or motor systems is an open question.

Ultimately, if attention is related to a scarce allocation of visual resources, it would prove useful if it could also improve the perceptual representation of stimuli. This improvement could occur at multiple levels. If perceptual representation is improved, is it simply due to the exclusion of distractors and external noise, or is it also thanks to a better signal? Of course, these are by no means mutually exclusive.

There is a debate on this issue going back over a century. Recently, there is renewed interest as to whether attention actually alters or shifts stimulus perception, such as by increasing apparent stimulus contrast (Carrasco, 2011). For most aspects of our visual environment, a systematic bias in our perception would be maladaptive. If attention increased brightness contrast, the result would be a skewed perception relative to the veridical. This runs counter to the general improvement due to attention, though perhaps for stimulus detection the overall benefit might be positive.

I am interested here in attentional effects on perceptual quality. For most research on attention, performance differences due to response type, cues, and noise do not directly bear on the question of the accuracy of the perceptual representation. In addition, if attention supports action, the nature of the sensory information may determine attentional consequences—it is reasonable to predict different patterns of performance attributable to attentional processes for different stimulus types and sensory modalities.

Although there are many ways to manipulate attention, the present work uses only noninformative exogenous peripheral cues. These cues are able to "automatically" capture attention (Jonides, 1981), and to do so at short timescales. The short timescale allows for investigation without the need to control for eye movements, and it limits the role of higher-level processing prior to response. This kind of cuing is a base case for an attentional effect—it removes many potential higher-level influences in the experiment. While reducing attentional cuing to a minimal form could prevent the observation of attentional effects, this was not the case in the present study.

Most studies on attention, including those using noninformative exogeneous cues, use response time (RT) and detection as their principal performance measures. Recently there have been a few studies that have considered the impact of cues on measures of perceptual representation. Pestilli and Carrasco (2005) conclude that perceptual representation is improved due to noninformative cues, while Prinzmetal, McCool, and Park (2005) and Prinzmetal, Park, and Garrett (2005) claim that only informative spatial cues can affect accuracy measures. I will return to this discrepancy in the discussion section.

Prior work on accuracy in attention has typically used forced-choice measures, the coarseness of which limits the ability to observe effects. Removing the constraint of discrete response categories can provide greater power to demonstrate accuracy effects.

In the present work, I introduce a continuous response task to investigate the impact of cuing on perceptual representation. The task uses the same sensory judgment for two different varieties of visual stimuli, one static and one dynamic. Just as the cue used is at its most basic, so is the display presented to participants. Only one stimulus is presented at a time, with no masking and no spatial uncertainty at the time the perceptual report is made. Cue and stimulus presentations are brief, and are followed by a perceptual matching task of orientation. An oriented line presented at the stimulus location is adjusted by the participant to match their impression of stimulus orientation. For static stimuli the judgment is for the orientation of a grating. For the dynamic stimuli it is of the orientation of coherent dot motion. The report and judgment of orientation is identical for both types of stimuli.

Experiment 1 tests the effect of cuing on perceptual judgment performance for static and dynamic stimuli, using two separate participant cohorts. I find a general pattern of cuing improving response times as well as accuracy, though the accuracy effect is less pronounced for dynamic stimuli.

The continuous response method results in a richer data set than two-alternative forced choice procedures or simple stimulus detection. For example, following Fischer, Shankey, and Whitney (2011), I observe sequential dependency in judgments between trials, with judgments biased towards the previous stimulus orientation. I also detect an oblique angle effect, with participants preferentially choosing canonical oblique angles, and with judgment accuracy better for orientations closer to the canonical vertical, horizontal, and oblique angles. Interestingly, there is a difference between frequency of near-horizontal judgments for orientation versus those for motion.

Experiment 2 addresses whether cuing effects on accuracy in Experiment 1 are reflecting a difference in the quality of early perceptual representations, or whether they reflect a difference in rates of eidetic decay. I ran an experiment similar to Experiment 1, but with the addition of two new, longer intervals between stimulus offset and the response start. Responses were prevented until a pre-specified amount of time had elapsed. The effect of cuing replicated Experiment 1, but even though responses in the longest interval were delayed by ~110 ms (for static stimuli) or ~180 ms (dynamic stimuli), I found neither an effect of the interval on accuracy nor an interaction with cuing. This suggests that the cuing effects are reflecting differences in early perceptual representation, rather than decay of the representation.

Attentional effects, particularly for neural responses but not only, are often framed as being due to response gain or due to contrast gain (e.g. Ling & Carrasco, 2006). Rephrasing this in a way that is applicable to an accuracy measure leads to the question of whether the cuing effect applies to all stimuli equally or particularly to those of high intensity (response gain) or low intensity (contrast gain).

In Experiment 3, I carried out a similar procedure as before but with degraded stimuli. For static stimuli I varied the contrast level and for dynamic stimuli I varied the coherence of the dot motion. Experiment 3 replicated Experiment 1 in both accuracy and response time effects of cuing. Response time increased with contrast (static stimuli) but decreased with coherence (dynamic stimuli), however in neither case was there an interaction with cuing. However, I observed different patterns for accuracy—for static stimuli, the accuracy effect of cuing is much larger for degraded stimuli, while there is no such interaction for dynamic stimuli.

The organization of the balance of the thesis is as follows. The methods chapter explains the general approach used for all six experiments, as well as the minor differences between them. A consistent approach to statistical analysis is used throughout the paper, which is also described in the chapter. The results section reports the findings for three pairs of experiments, with separate experiments for static and dynamic stimuli. The first experiments are the basic test of cuing, as well as peripheral analyses afforded by the rich data set. The second pair of experiments tests whether cuing is affected by delay of the participant response. The last set of experiments tests the pattern of cuing across varying levels of stimulus quality. Finally I interpret the present findings of accuracy benefits due to noninformative cues in the context of earlier literature.

Chapter 2

General Method and Analysis

All of the experiments were similar in structure. Differences between the experiments are reported when they departed from this general procedure.

2.1 Participants

Participants were recruited from the University of Waterloo and were compensated with course credit. All experiments were conducted in hour-long sessions. There were 20 participants for each of Experiments 1a, 1b, 2a, 2b, 3a, and 3b.

	Experiments					
	1a	1b	2a	2b	3a	3b
Number of participants:	20	20	20	20	20	20
Mean age:	18.9	21.2	19.4	20.5	20.1	19.8
Age range:	17–24	17–48	18–25	18–23	18–23	18–23
Gender:	12 M, 8 F	7 M, 13 F	7 M, 13 F	9 M, 11 F	11 M, 9 F	7 M, 13 F
Number right-handed:	18	19	14	18	18	17

Table 2.1: Participant characteristics.

2.2 Materials

The experimental set-up consisted of a computer and CRT display set up in an individual fluorescent-lit room. All experiments were programmed using Python and the PsychoPy package (Peirce, 2007, 2009).

Participants were instructed to sit with their eyes at a distance of approximately 57 cm from the display, which was 33 cm x 26.5 cm and ran at 85 Hz and a resolution of 1280x1024. Participants were instructed to look at the centre of the screen throughout the experiments. Eye movements were not monitored and no chin rest was used.

2.3 Method

Each experimental session consisted of five blocks of 150 trials, with a shorter practice block of 100 trials at the beginning.[1] The screen was grey throughout the experiment. A trial began with a black fixation cross (1.2°) appearing at the centre of the screen; after 500 ms, a white cue box appeared (4.4° by x 4.4°, 6° away from centre). The white box immediately surrounded the stimulus location, as this supports a larger cuing effect than would a larger cue (Henderson, 1991). This exogenous cue could appear on the left side of the screen, the right side of the screen, or both sides for a "neutral" cue.

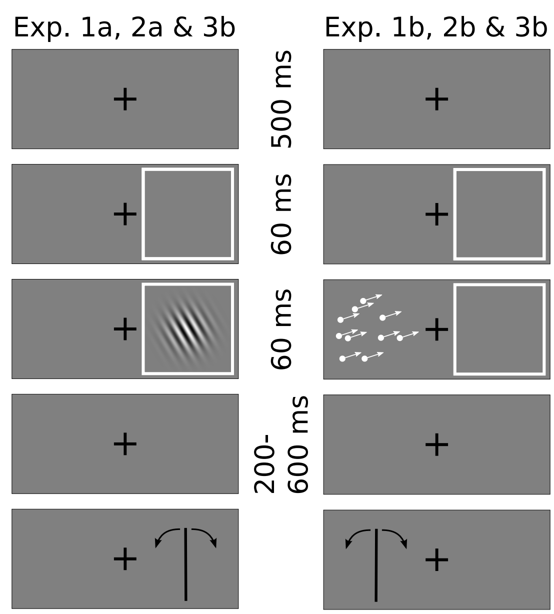


Figure 2.1: The general method. On the left is a trial with a validly cued Gabor patch stimulus. The right side represents a trial with an invalidly cued dot-motion stimulus.

The stimulus itself was 4° in diameter and would appear centred either 6° to the left or to the right of fixation; no stimuli were presented at the centre of the screen. Stimuli were equally likely to appear on the left or the right side of the screen, and cue position

[1] One participant in Experiment 2a finished only 663 trials instead of 750. Their data is included in all analyses.

was not informative of stimulus position. In Experiments 1a and 1b, 20% of the trials had neutral cues, with the exogenous cue appearing on both sides of the screen.

The cue was presented for 118 ms total, and the stimulus was displayed for the last 59 ms of that interval. After the simultaneous cue and stimulus offset, there was an interval before the response line appeared and could be adjusted. This was 200 ms for Experiments 1a and 3, and varied between 200 ms, 400 ms, and 600 ms for Experiment 2.

The stimuli in Experiments 1a and 2a were static Gabor patches generated using the PatchStim function in PsychoPy - grayscale circular patches at 50% contrast, with a sine-wave texture (four cycles along one dimension) and a Gaussian mask. In Experiment 3a, contrast was varied and a circular mask was used instead of the Gaussian. The latter was done to ensure equal contrast at the stimulus centre and edges, in order to avoid confounding contrast with apparent stimulus size.

Stimuli in Experiments 1b and 2b were coherent random dot motion displays generated using the DotStim function in PsychoPy. These were circular patches with 20 dots (4 pixels in diameter, or 0.1°) all moving in the same direction at a fixed speed (0.15°/frame, or 12.75°/sec.). Dots were alive for the entire length of the stimulus display, with ones that moved off the patch regenerated in a random position. The stimuli in Experiment 3b were random dot motion displays with a manipulation of the proportion of the 20 dots that moved coherently.

Orientations for both static and dynamic stimuli were uniformly chosen between 0 and 180 degrees, with 0 degrees indicating horizontal orientation and rightward motion. There was no downwards motion.

The response was visualized using a black line (2° long, about 0.07° thick) at the location where the stimulus had been presented. It always started out vertical, and participants used the right and left arrow keys on a standard keyboard to tilt the line clockwise and counter-clockwise, respectively. Participants pressed the up arrow key to indicate a complete response. In Experiments 1a and 1b, when participants held down a right or left arrow key, the speed of the rotation was 85°/second (geometric angle, not visual angle), which could be sped up to 255°/sec by simultaneously holding the down arrow key. Few participants found the latter function useful, so only one speed was used in the other experiments. That speed was set at a middle ground of 170°/sec for Experiment 2a, but due to higher error rates it was reverted to 85°/sec for Experiments 2b, 3a, and 3b. Tilt was always adjusted in whole degrees.

Participants were instructed to focus on accuracy, and were provided auditory feedback after each trial to encourage accuracy. This was in the form of a positive "ding" or a negative "donk" sound (sourced from freesound[2]) within 400 ms after the response was completed. In Experiment 1a and 1b, the error threshold for feedback was 12°; in subsequent experiments, the threshold was 10°. During practice trials, participants were at this point also provided with visual feedback as to the correct response in the form of a line similar to the response line, but oriented correctly and coloured white.

With a long-gone stimulus there is no new information to be gained from lengthy deliberation. Thus it was suggested to participants that they may find the task easier if they respond while the stimulus was fresh in their mind.

After the computer task, participants filled out a self-report questionnaire to gauge their impression of the effect of cuing.

2.4 Analysis

All data analysis was carried out using the R Project for Statistical Computing (R Development Core Team, 2012) with the "plyr" package (Wickham, 2011b), and all data figures were created with the "ggplot2" package (Wickham, 2009, 2011a).

Unless indicated otherwise, statistics were computed using analysis of variance of individual participants' median error or response times. This allows for a way of avoiding arbitrary choices about outlier removal. No participants or trials were excluded from analyses.

The absolute deviation of judgment orientation from the stimulus orientation is used as the measure of error rate and variability. Response time (RT) is defined as the time elapsed from the appearance of the response line to the completion of the response.

All error bars shown represent standard error of the mean. All p-values in post-hoc tests are adjusted using the Bonferroni correction for multiple comparisons. Any post-hoc tests not mentioned out of a set of pairwise tests were not significant at the adjusted level.

Analysis of trial-to-trial priming only includes trials which have a trial preceding in the same block.

[2]These sounds from freesound were used: Chip050 by HardPCM (`http://www.freesound.org/people/HardPCM/sounds/32950/`) and Fisher Price5 by tombola (`http://www.freesound.org/people/tombola/sounds/49219/`)

Chapter 3

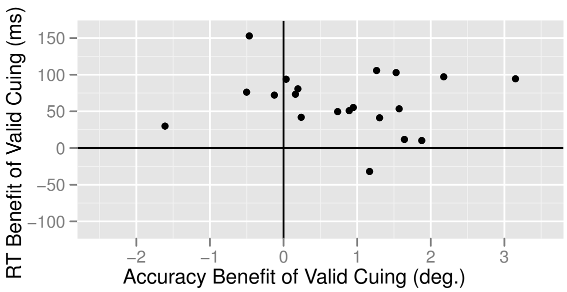
Experiments

3.1 Exogenous Cuing of Stimuli

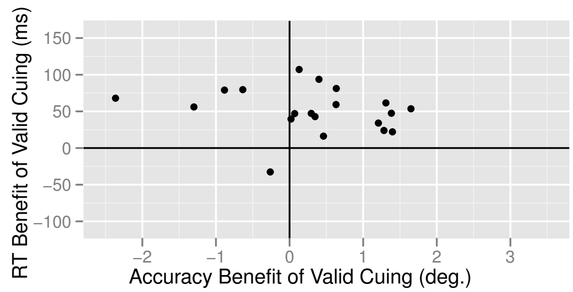
The first pair of experiments was aimed at addressing the basic question of whether non-informative exogenous cues can affect the quality of perceptual judgments, and evaluating the perceptual matching task. Cues in the form of white squares on the left or right of fixation appeared prior to the stimulus and stayed on throughout the brief stimulus presentation. In validly cued trials (40%), the cue would appear on the same side as the stimulus, while in invalidly cued trials (40%) it would appear on the opposite side. The remaining 20% of trials were neutral, with the cue appearing on both sides of the screen.

As described in Chapter 2, participants in Experiment 1a viewed rotated Gabor patches (static stimuli) and made judgments of orientation. In Experiment 1b, participants viewed coherent dot motion (dynamic stimuli) and made judgments of the direction of motion.

There was no reliable difference in accuracy between Experiment 1a ($M = 8.6°$) and Experiment 1b ($M = 9.0°$; $t(38) = -0.5$, $p = 0.61$), suggesting that the two tasks were approximately matched in difficulty. Likewise, there was no difference in response time between Experiment 1a ($M = 791$ ms) and Experiment 1b ($M = 794$ ms; $t(38) = -0.03$, $p = 0.97$).



(a) Exp. 1a: Static stimuli



(b) Exp. 1b: Dynamic stimuli

Figure 3.1: Experiment 1: Individual benefit to validly cued over invalidly cued trials, in accuracy (x-axis) and RT (y-axis). For both experiments, 15 out of the 20 participants are faster and more accurate on valid trials.

Orientation judgments to validly cued trials were more accurate than responses to neutral trials, which in turn were more accurate than responses to invalidly cued trials. The pattern of response time was the same, with fastest responses to validly cued trials.

Dot motion judgment quality was less affected by exogenous cuing. The same analysis failed to show a significant accuracy benefit for validly cued trials over invalidly cued ones, however the RT effect remained. The data nevertheless trends in the same direction, with Figure 3.1 showing that most participants still had both faster and better responses to validly cued stimuli relative to invalidly cued stimuli. Though the result fails to reach significance in this experiment, the validity effect on accuracy obtains in Experiments 2b and 3b.

Static judgment accuracy was affected by cuing (ANOVA; $F(2,38) = 4.3$, $p = 0.02$). Specifically, validly cued trials are reported more accurately than invalidly cued trials ($t(19) = 3.3$, $p = 0.01$, adj.). Dynamic judgment accuracy was not reliably affected by cuing ($F(2,38) = 1.1$, $p = 0.33$).

Static judgment RT was affected by cuing in the same direction ($F(2,38) = 20.6$, $p < 0.001$), with RT decreasing from invalidly cued trials to neutral trials, to validly cued trials ($t(19) > 3.0$, $p < 0.03$, adj., for all three comparisons). Similarly, dynamic judgment RT was affected by cuing ($F(2,38) = 20.9$, $p < 0.001$), with RT faster for validly cued trials than for neutral trials ($t(19) = 4.8$, $p < 0.001$, adj.) and invalidly cued trials ($t(19) = 7.4$, $p < .001$, adj.).

	Error (deg.)			Response time (ms)		
	Invalid	Neutral	Valid	Invalid	Neutral	Valid
Static:	9.04	8.51	8.24	825	789	762
Dynamic:	9.17	8.91	8.88	815	802	764

Table 3.1: Experiment 1: Summary of cuing effects. Shown are means of medians of individual participant performance measures. Both stimulus types and both measures show a trend toward better performance on validly cued trials.

For both kinds of judgments, there was no effect of stimulus position (left or right) on either accuracy or RT, nor any interaction with cuing ($F < 0.77$, $p > 0.39$ for all tests).

There was no interaction between cue validity and block in terms of accuracy or RT ($F(8,152) < 1.1$, $p > 0.37$ for all tests), however block affected accuracy and RT for both static and dynamic judgments ($F(4,76) > 3.5$, $p \leq 0.01$ for all tests). The pattern in Table 3.2 suggests that there may be a practice effect.

Block:	1	2	3	4	5
Error (°)	8.7	9.1	9.0	8.5	8.0
RT (ms)	945	798	778	744	710

(a) 1a - orientation

Block:	1	2	3	4	5
Error (°)	10.2	9.5	8.5	8.6	8.6
RT (ms)	906	813	763	748	742

(b) 1b - motion

Table 3.2: Experiment 1: Performance across the five experimental blocks. Entries are means of participants' median performance in each block.

The measure of accuracy here is an absolute value of the difference between judged and presented orientation. However, it is possible that participants have a consistent underlying bias, with responses shifted from the veridical, and that such bias would be affected by cuing. Here, a positive bias indicates responses consistently clockwise of the correct orientation, and a negative bias indicates a counter-clockwise overshoot. There was no reliable bias, however, for static judgments ($M = 0.24°$; $t(19) = 1.0$, $p = 0.33$) nor was there a bias for dynamic ones ($M = 0.34°$; $t(19) = 1.4$, $p = 0.18$). Note that responses are limited to a resolution of 1°. Cuing validity did not affect bias in static judgments ($F(2,38) = 0.07$, $p = 0.93$), and this interaction was not reliable for dynamic judgments ($F(2,38) = 1.9$, $p = 0.16$).

As participants moved the response dial from vertical to match the stimulus orientation, the experiment program recorded the number of times they switched the direction of the dial, if at all. For example, if the participant tilted the dial left from 90° (vertical) to 110°, and then right to 105° before ending the trial, this was recorded as a switch trial. [1]

For static judgments, cuing affected the proportion of trials in which there was a switch of response direction ($F(2,38) = 4.2$, $p = .02$). Specifically, the proportion of switch trials was larger for invalidly cued stimuli ($M = 9.0\%$) than for validly cued stimuli ($M = 7.3\%$; $t(19) = 3.6$, $p = 0.006$, adj.). Similarly for dynamic judgments, cuing affected the proportion of trials in which there was a switch of response direction ($F(2,38) = 12.3$, $p < 0.001$). A larger proportion of invalidly cued trials had switches ($M = 9.6\%$) than did neutrally cued trials ($M = 7.5\%$; $t(19) = 3.5$, $p = 0.007$, adj.) and validly cued trials ($M = 6.8\%$; $t(19) = 4.5$, $p < 0.001$, adj.).

I tested several kinds of trial-to-trial priming, seeing whether repetition of position or orientation is beneficial to performance, and whether a preceding stimulus biases the current judgment.

For static judgments, there was no interaction between positional priming and cue validity on accuracy ($F(2,38) = 0.88$, $p = 0.42$) and no main effect of positional priming ($F(1,19) = 0.03$, $p = 0.88$). However, there was an interaction between positional priming and cue validity on RT ($F(2,38) = 3.7$, $p = 0.04$) but no main effect of positional priming ($F(1,19) = 1.7$, $p = 0.21$). For dynamic judgments, there was no interaction between positional priming and cue validity on accuracy ($F(2,38) = 0.35$, $p = 0.71$) and no reliable main effect of positional priming ($F(1,19) = 2.2$, $p = 0.15$). Unlike for static judgments, there was also no interaction between positional priming and cue validity on RT ($F(2,38) = 1.6$, $p = 0.22$) and no main effect of positional priming ($F(1,19) = 0.94$, $p = 0.34$).

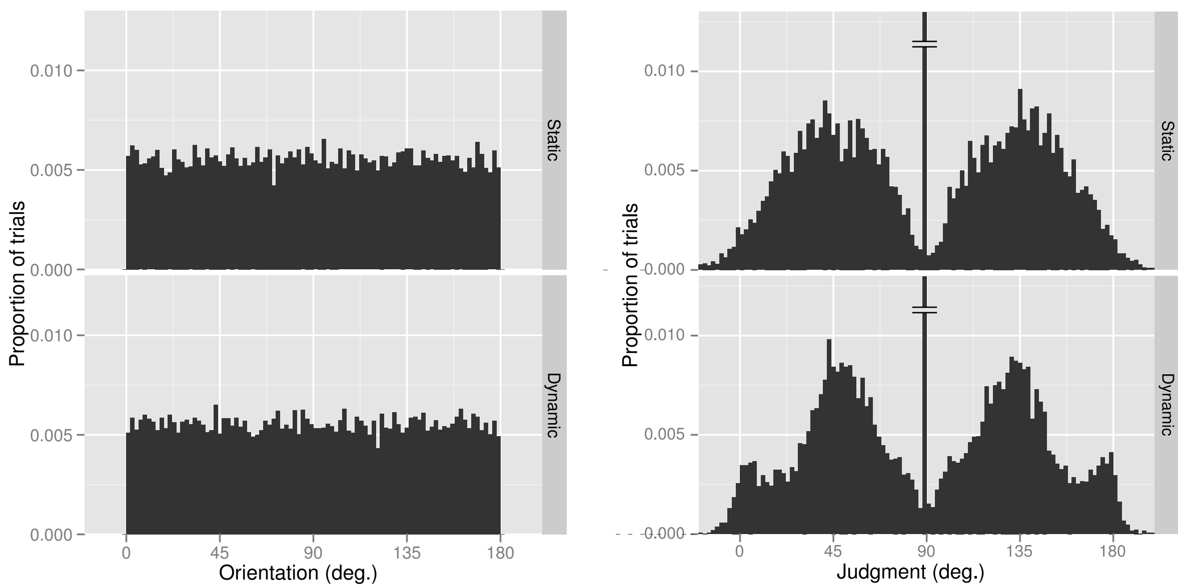
Next, I ran linear regressions on accuracy and RT as a function of orientation priming—the absolute angle difference between the current and previous trial. For static judgments, there was no effect of orientation priming on accuracy ($t(19) = 1.4$, $p = 0.16$) and none on RT ($t(19) = -0.5$, $p = 0.64$). For dynamic judgments, there was only a trend for orientation priming affecting accuracy ($t(19) = 1.8$, $p = 0.09$) and no effect on RT ($t(19) = 0.9$, $p = 0.40$).

[1] There were too few trials—less than 1% on average—with more than one switch to analyze more finely-grained data.

	Experiment 1a		Experiment 1b	
	Mean	Range	Mean	Range
Invalid:	54.0%	(43.2–61.5%)	51.8%	(46.4–57.6%)
Neutral:	52.8%	(45.2–60.3%)	50.3%	(44.0–60.2%)
Valid:	52.4%	(43.8–57.3%)	49.9%	(45.4–56.3%)

Table 3.3: Experiment 1: Sequential dependency in orientation judgments. Numbers represent the proportion of participants' trials in which responses are biased towards the immediately prior stimulus orientation or direction.

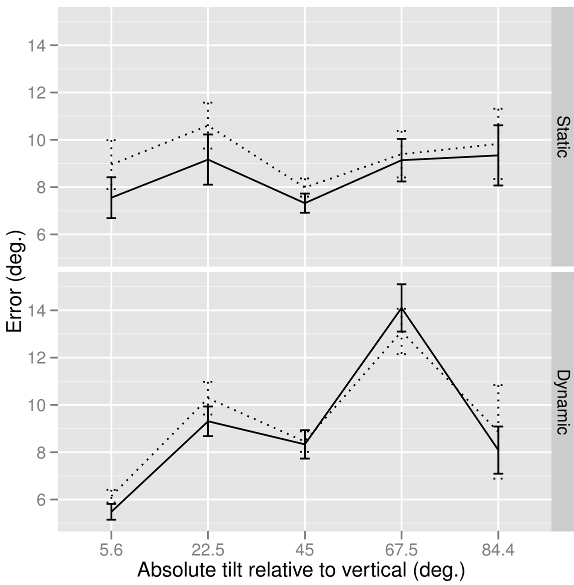
Following Fischer et al. (2011), I considered whether errors in judging the current stimulus orientation are biased towards the previous stimulus orientation. For static Gabor judgments, this turns out to be the case. The proportion of trials with judgment erring towards the previous orientation was reliably greater than half (M = 53.1%, $t(19) = 3.8$, $p = 0.001$). For motion judgments, this proportion is not reliably greater than half (M = 50.8%, $t(19) = 1.3$, $p = 0.21$). Considering both experiments together, there is not only a difference due to judgment type ($F(1,38) = 5.4$, $p = 0.03$), but interestingly there is also an effect of cuing ($F(2,76) = 4.3$, $p = 0.02$)—as seen in Table 3.3. There was no judgment type by cuing interaction ($F(2,76) = 0.05$, $p = 0.95$).



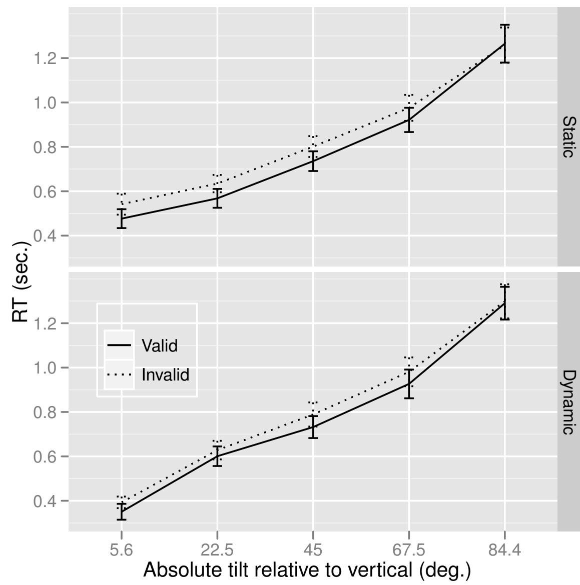
(a) Actual orientations

(b) Response judgments

Figure 3.2: Experiment 1: Distribution of stimulus orientations and participant responses. On the left are the actual orientations, which are evenly distributed. On the right is the distribution of responses. For static stimuli there is a bias to respond using the canonical oblique orientation (45° from vertical), as well as with the default vertical orientation. For dynamic stimuli the pattern is similar, except that horizontal motion judgments are not shunned as a response. Participants frequently responded with the default vertical orientation, which is the reason for the spike seen at 90°.



(a) Accuracy

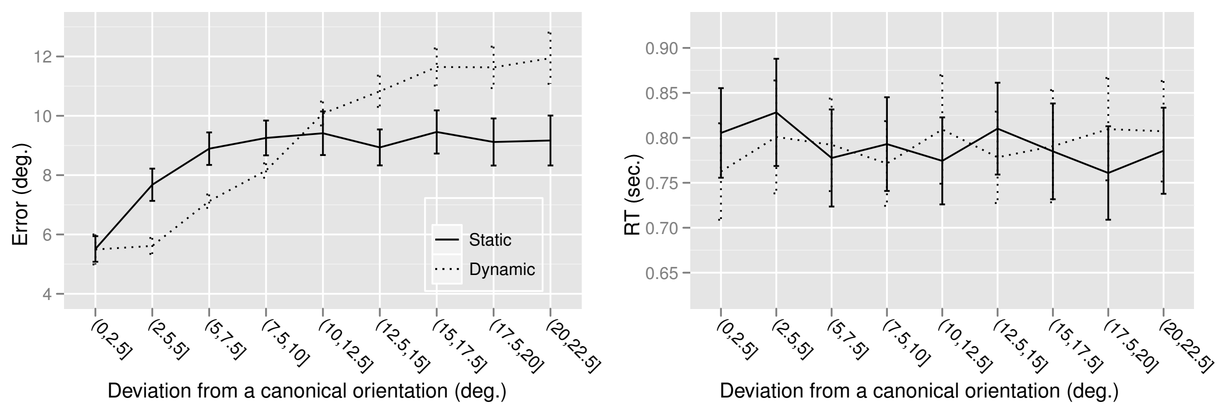


(b) RT

Figure 3.3: Experiment 1: Angular deviation from vertical—relation to performance and cue validity. Trials are binned so that alternating bins are either around canonical orientations or positioned in between them; bins are of size 22.5° except for the ones at the edges, which are half that. Accuracy shows better performance for stimuli closer to canonical orientations, as well as a larger cuing effect for stimuli closer to vertical. The cuing benefit on RT is seen in conjunction with the overall increase in RT with angle—which is due to the time taken to move the response dial, which starts out vertical.

Figure 3.3 shows a somewhat cyclical pattern of performance at and in between canonical orientations (0^o, 45^o, 90^o, etc.). It is possible to look more in depth at trials based on how close the orientation is to a canonical orientation, as is shown in Figure 3.4. The data shown in Figure 3.3 also suggest that the cuing effect is larger for stimuli oriented closer to vertical. Considering the cuing effect as the benefit to validly cued trials over invalidly cued trials, I tested this directly for both experiments together. The accuracy cuing effect was indeed affected by whether a stimulus was more vertical or more horizontal ($F(1,38) = 8.9$, $p = 0.005$), without an interaction with stimulus type ($F(1,38) = 0.03$, $p = 0.85$). No such result obtains for the RT cuing effect, with no main effect of tilt nor interaction with stimulus type ($F < 0.46$, $p > 0.50$).

I ran linear regressions on accuracy as a function of deviation from a canonical orientation. Increased distance from a canonical direction did increase error for both orientation judgments ($t(19) = 3.5$, $p = 0.002$) and motion judgments ($t(19) = 8.8$, $p < 0.001$). For static orientation judgments, participants were also *faster* to respond to stimuli that had higher deviation from a canonical orientation ($t(19)$ = -4.4, $p < 0.001$). However there was no reliable effect on RT for motion judgments ($t(19)$ = -1.1, $p = 0.28$). In direct comparison, the relation between RT and deviation from canonical is stronger for static orientation judgments than for motion judgments ($t(38)$ = -2.4, $p = 0.02$). There were no interactions with cuing on either accuracy or RT ($F(2,38) < 0.92$, $p > 0.40$ for all tests), thus data in Figure 3.4 are not broken up by validity.



(a) Accuracy **(b)** RT

Figure 3.4: Experiment 1: Relation between performance and deviation from a canonical orientation. At the left end of the scale are trials that fall right on angles of either 0^o, 45^o, 90^o, 135^o, or 180^o; at the right end are trials that maximally deviate from such angles, i.e. are exactly in between. There is a clear accuracy benefit for trials closer to a canonical orientation, but this relation is qualitatively different for static and dynamic stimuli. Note that this data is not independent of the response distribution, i.e. higher error rates for in-between orientations can be due to responses being biased towards the canonical orientations.

In the post-experiment questionnaire, participants were asked whether they perceived any stimuli better than others. Of the 20 participants for the static judgments, only seven mentioned cuing: four noted a benefit to validly cued trials, two noted a detriment, and one noted difficulty with neutral trials. In fact, the only one of these subjects to have a detriment for cued trials in their results had indicated a benefit in the questionnaire. Of the 20 participants for dynamic judgments, only four mentioned cuing, all of whom noted a benefit; two of these participants in fact had a detriment due to cuing.

3.2 Decay of iconic traces

Is the cue validity effect in Experiment 1 explained by a better initial percept or slower perceptual decay? Experiment 2 varied the delay between stimulus offset and the point at which participants could start responding. The results showed validity effects on accuracy of both orientation and motion judgments, however the delay affected only RT.

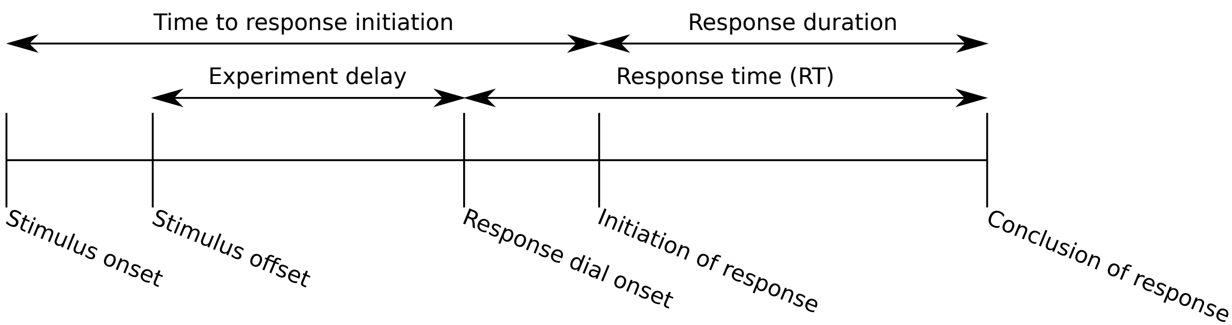


Figure 3.5: Experiment 2: Timeline of a trial.

If cuing effects are related to perceptual decay rates, delaying participants in responding tests this by lengthening the perceptual decay period prior to response. In Experiment 1, participants did not begin responding immediately when the response dial appeared. Thus, it is possible that the delay in the appearance of the response dial could have been too short to affect the actual time until participants began making their response. However, the delay manipulation did in fact slow responding. As measured from stimulus onset, participant time to begin responding was affected by the delay interval for both static judgments ($F(2,38) = 47.5$, $p < 0.001$) and dynamic judgments ($F(2,38) = 328.1$, $p < 0.001$). See Figure 3.5 and Table 3.4.

	Static			Dynamic		
Experiment delay:	200 ms	400 ms	600 ms	200 ms	400 ms	600 ms
Time to response initiation	579 ms	599 ms	685 ms	486 ms	502 ms	662 ms
Response duration	617 ms	641 ms	674 ms	700 ms	700 ms	673 ms
RT	943 ms	787 ms	743 ms	936 ms	767 ms	705 ms

Table 3.4: Experiment 2: Timing of responses varies with delay. As designed, the experimental delay does cause participants to initiate their response later, while the actual time to complete the response does not vary substantially. The RT measurement begins after the experimental delay, resulting in shorter RT when participants have more time to prepare for a response.

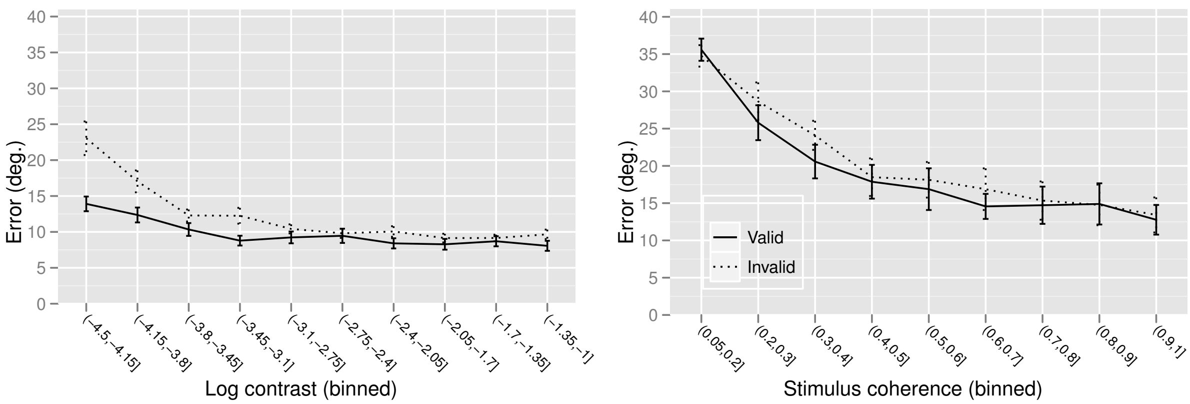
There was an effect of validity on accuracy for static judgments ($F(1,19) = 9.8$, $p = 0.006$) and for dynamic judgments ($F(1,19) = 4.7$, $p = 0.04$)—the latter test reaching significance here, even though it did not in Experiment 1b. There were no effects of delay and no interactions ($F(2,38) < 1.3$, $p \geq 0.30$ for all tests).

Validity affected RT for static ($F(1,19) = 18.9$, $p < 0.001$) and dynamic judgments ($F(1,19) = 8.9$, $p = 0.008$). There was a main effect of delay for static ($F(2,38) = 152.4$, $p < 0.001$) and dynamic judgments ($F(2,38) = 213.9$, $p < 0.001$). This effect of delay is not surprising, as the response time is only measured after the delay, which allows for greater motor preparation during longer delays. There was no interaction for static judgments ($F(2,38) = 1.0$, $p = 0.37$), but there was one for dynamic judgments ($F(2,38) = 4.3$, $p = 0.02$).

Of the 20 participants for the static judgments, 13 mentioned cuing affecting perception in the questionnaire: 11 noted a benefit, one noted a detriment, and one mentioned both. Just one participant made any mention of the timing manipulation. Of the 20 participants for dynamic judgments, 11 mentioned cuing: seven noted a benefit, two noted a detriment, and two were unsure.

3.3 Exogenous cuing and degraded stimuli

In this experiment I investigated the effect of exogenous cuing on degraded stimuli—decreased in contrast for judgments of static gratings, and decreased in coherence for judgments of dot motion. If cuing acts to effectively boost signal quality (signal gain), cuing effects should be larger for degraded stimuli. If, instead, cuing boosts response effectiveness (response gain), the effects should be seen across the range of stimulus quality.

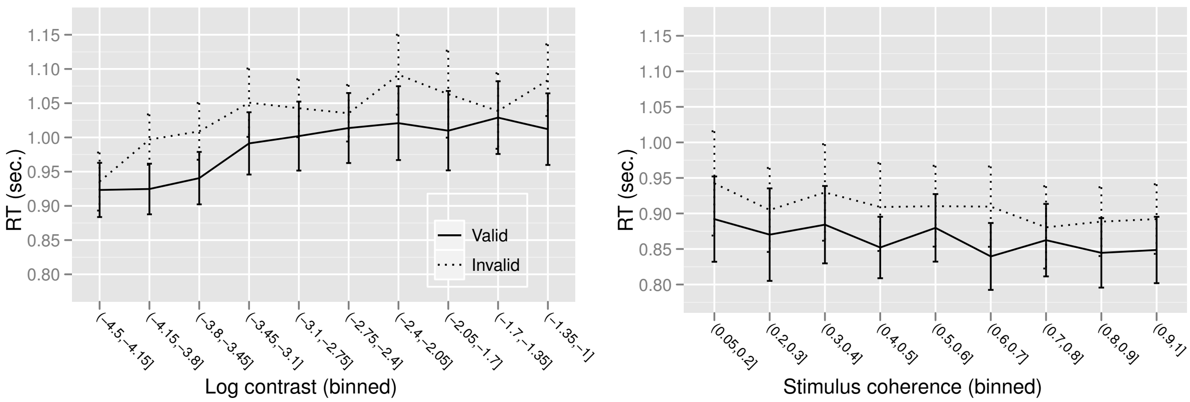


(a) Static

(b) Dynamic

Figure 3.6: Experiment 3: Accuracy for degraded stimuli. On the left is accuracy as a function of cuing and static stimulus contrast (x-axis), and on the right accuracy is a function of cuing and coherence of the dynamic moving-dot stimulus (x-axis).

For analysis purposes, static stimulus contrast was binned into 10 equal log contrast intervals, and dynamic stimulus coherence was binned into 9 bins. Static judgment accuracy was affected by cuing ($F(1,19) = 72.4$, $p < 0.001$), by contrast bin ($F(9,171) = 28.3$, $p < 0.001$), and there was an interaction ($F(9,171) = 7.7$, $p < 0.001$). Dynamic judgment accuracy was affected by cuing ($F(1,19) = 4.9$, $p = 0.04$) and by coherence bin ($F(8,152) = 62.6$, $p < 0.001$), but there was no reliable interaction ($F(8,152) = 1.2$, $p = 0.30$).



(a) Static **(b)** Dynamic

Figure 3.7: Experiment 3: RT for degraded stimuli. On the left is RT as a function of cuing and static stimulus contrast (x-axis), and on the right RT is a function of cuing and coherence of the dynamic motion stimulus (x-axis).

Response time was affected by cuing for static (F(1,19) = 16.8, $p < 0.001$) and dynamic judgments (F(1,19) = 7.5, $p = 0.01$). RT was affected by contrast bin for static judgments (F(9,171) = 4.3, $p < 0.001$) but dynamic judgment RT was not affected by coherence bin (F(8,152) = 1.1, $p = 0.38$). There was no stimulus quality by RT interaction for either static (F(9,171) = 0.8, $p = 0.65$) or dynamic stimuli (F(8,152) = 0.4, $p = 0.94$).

Of the 20 participants for the static judgments, seven mentioned cuing affecting perception in the questionnaire: six noted a benefit and one noted a detrimentl; 7 participants noted the contrast manipulation. Of the 20 participants for dynamic judgments, six mentioned cuing: three noted a benefit and three noted a detriment.

Chapter 4

Discussion

Despite the large literature of attentional effects, there is a paucity of empirical work on the relationship between attention and perception. The recent literature is contradictory on even the basic question of whether such a connection exists. I believe that appropriate methods can be used both to resolve the basic question about the existence of attentional effects on perception, and the details of how and when they occur.

In this work I have developed a basic continuous-response task for measuring visual perceptual performance in the context of noninformative exogenous cues, for static and dynamic stimuli. In Experiment 1 I considered the basic cuing effect and peripheral questions afforded by the method. Experiments 2 and 3 verified cuing effects, while investigating the impact of brief delays and degraded stimuli, respectively.

4.1 Basic cuing results

I found that noninformative luminance cues lead to quicker and more accurate orientation judgments for both static and dynamic stimuli. See Table 4.1 for a summary of effects. This section places these results in the context of earlier work on the effects of non-informative cues on attentional measures.

	Static			Dynamic		
Experiment:	1a	2a	3a	1b	2b	3b
Cuing benefit—accuracy:	0.8^o	0.7^o	1.8^o	0.3^o	0.3^o	1.3^o
Cuing benefit—RT:	63 ms	46 ms	46 ms	51 ms	36 ms	52 ms

Table 4.1: Summary of cuing effects across experiments. Figures represent the performance benefit for validly cued trials over invalid trials, computed as means of individual participant medians. All trials are considered together in each experiment, collapsed across delay (Experiment 2) and contrast/coherence (Experiment 3).

In the reported experiments a continuous-response perceptual matching task was used to test the influence of noninformative exogenous cues on orientation judgments of orientation for static and dynamic stimuli. For static Gabor patches, participant responses indicated the perceived orientation, while for dynamic moving-dot stimuli, the same response was used to indicate the direction of motion. Stimulus position was not predictable, and the cue and stimulus presentations were brief; there was neither time to make saccadic eye movements nor utility to be gained from doing so. Auditory feedback was provided to encourage accuracy.

4.1.1 Do non-informative cues affect perceptual quality?

Some previous work has investigated effects of noninformative peripheral cues on perceptual accuracy measures (Smith, Ratcliff, & Wolfgang, 2004; Pestilli & Carrasco, 2005; Prinzmetal, McCool, & Park, 2005; Prinzmetal, Park, & Garrett, 2005), but these findings don't tell a consistent story.

Smith et al. (2004) found that peripheral cues improve RTs, but that they improve Gabor orientation discrimination only for stimuli that were followed by a mask. In the present work, however, I find not only improved RTs but also improved orientation judgments for static stimuli in the absence of masking. Pestilli and Carrasco (2005) found lower contrast thresholds for cued relative to uncued stimuli using a psychophysical staircase procedure. This finding implied, but did not demonstrate, that at a fixed contrast level, cued stimuli would be judged more accurately than uncued ones.

While the above two studies differ from mine, they are in the same direction; they conclude that noninformative cues can affect perceptual quality. Arguing the opposite, Prinzmetal, McCool, and Park (2005) and Prinzmetal, Park, and Garrett (2005) report that only informative cues affect accuracy, while noninformative spatial cues do not affect perceptual representation, but only affect RT. Contrary to Prinzmetal and colleagues, I find solid evidence that noninformative cues are indeed able to improve performance on an accuracy task.

Procedurally, one of the major differences between my work and that of Prinzmetal and colleagues is my use of a continuous response measure. I suggest that this is the principal reason for the different conclusions.

4.1.2 Continuous response measures are better for demonstrating attentional effects on perceptual quality

Breaking up a continuous dimension into several discrete categories reduces precision, as responses for an entire perceptual interval are judged as equivalent. This reduces the power of the measure. And as noted by Prinzmetal in an earlier work (Prinzmetal, Nwachuku, Bodanski, Blumenfeld, & Shimizu, 1997), "The errors that result from categorizing a continuous perceptual dimension into discrete categories are pernicious." Categorization of responses makes room for response biases and other top-down effects that have little to do with the judgment of interest.

Perhaps one reason why reaction time effects—unlike those for accuracy—are robustly observed in attention experiments is that RT is a continuous response measure.

The task used in the present experiments directly asks participants to match a response line with their best estimate of the stimulus orientation. There is always a stimulus present and never distractors or comparators present, so participants always know what they are to judge. There is thus little role for a response bias.

This measure also results in a rich data set. While there are "discontinuities" of sorts with not all angles selected as judgments by participants equally often (an oblique effect), these aspects afford interesting analyses. For example, the cuing effect is particularly strong for angles closer to vertical; it remains to be seen whether this is an artifact of the particular paradigm, or represents something intrinsic to the human judgment of orientation. Findings like this raise the question as to what exactly is being affected by attentional manipulations.

4.2 Measuring attention or memory?

The judgment participants make begins several hundred milliseconds after stimulus offset. It therefore requires them to use their memory of the stimulus. While there is not always a clear division between perception and memory (Ruff, Kristjánsson, & Driver, 2007), it seems appropriate to ask how much of the observed cuing benefit is due to improvement in the abilty to retain the perceptual trace for guiding the perceptual report. One potential explanation for the improvement is that attentional benefits were conferred by slowing the decay of an iconic trace. Prior work has shown that iconic memory decays quickly (Huang & Sekuler, 2010), but those findings are on the order of several seconds, and this is much longer than the trial durations in my experiments.

If the cuing benefits are due to a more slowly degrading memory trace we should see this as a change in the cuing effect as the interval between stimulus offset and reporting lengthens. Experiment 2 tested this, achieving a delay of parcipant responses of ~110 ms (for static stimuli) or ~180 ms (dynamic stimuli). I found that the delay did not affect accuracy or change the magnitude of the cuing effect. This suggests that at the time scales in my experiment, decay of the perceptual trace is not a large factor for producing the cuing effect.

These data also demonstrate that cuing effects are occurring early in visual processing. The cuing effects may be due to differences in the quality of the initial percept or the translation from percept to motor planning of the response. My task does not allow me to further address this level of early visual processing. Experimental manipulation of the type of motor response may be a source of insight into whether the locus of the cuing effect is in motor planning.

The most straightforward account of the results is that there is an improved signal quality due to cuing.

4.3 Signal enhancement

The literature on cuing effects on accuracy measurement emphasizes two mechanisms: the exclusion of external noise (Dosher & Lu, 2000), and signal enhancement (Yeshurun & Carrasco, 1999). Noise exclusion does not explain the present results. My task has few sources of noise: there is no location uncertainty, the response line always marks the stimulus location, and there are no concurrent distractors, masks, or visual noise for four of my six experiments. However, perhaps the preceding stimulus could be considered as a source of external noise. I do note that the bias towards the preceding trial is reduced when the current trial has been validly cued. This provides some support for noise reduction as a concurrent basis for cuing effects, with signal enhancement the predominant mechanism.

4.4 Are attentional effects the same for different stimulus modalities?

If cuing effects are due to attention affecting early visual processing, stimuli requiring different kinds of processing should result in different kinds of cuing effects. While in the present experiments I found cuing to be beneficial for both orientation judgments of Gabor patches and direction judgments of dot motion, the accuracy effects were larger for the former.

Neural and psychophysical effects of attention are often modelled as a response gain or as a contrast gain (Martínez-Trujillo & Treue, 2002; Ling & Carrasco, 2006); see Figure 4.1. In Experiment 3, I considered the similar question for degraded stimuli using an accuracy measure rather than a unidirectional response function. The analogue to a response gain is a shift across the range of stimulus quality, and a contrast gain is analogous to a much larger effect for lower quality stimuli.

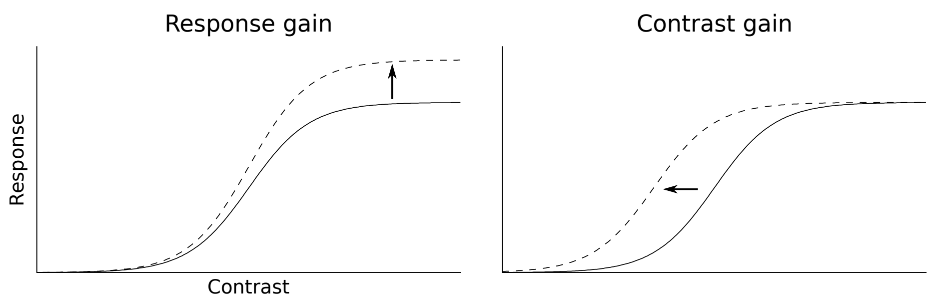


Figure 4.1: Contrast versus response gain. This figure demonstrates response gain as a multiplication of a response function and contrast gain as a leftward shift in a response function.

Experiment 3 demonstrated markedly different patterns for cue effects as stimulus quality degrades for static and dynamic stimuli. As the contrast of oriented gratings declines, the proportionate change with cuing increases, a pattern resembling "contrast gain" for static stimuli. Dynamic stimuli show a relatively uniform cuing benefit across coherence levels, a pattern that resembles a mixture of "contrast gain" and "response gain".

In the present data, it is not possible to distinguish whether the different pattern of effects is due to the dynamic nature of the stimulus or to the degradation being of stimulus coherence rather than contrast. Regardless, Experiment 3 provides behavioural evidence that suggests differences in attentional effects on different types of visual judgments.

4.5 Future directions

Natural extensions of the present work can be made to address the presence of perceptual biases due to cuing, such as the issue of contrast enhancement (Carrasco, Ling, & Read, 2004), for which the simplicity and power of the task may prove helpful. Similarly, the role of various kinds of cues can be compared, such as exogenous, endogenous, probability cues, and so on.

Combining this task with neuroimaging would allow an investigation into potential differences in the locus of static and dynamic cuing effects.

Interpretation of both the present results and earlier work would be helped through a direct comparison between continuous response measures and forced-choice measures in the same task.

Potential changes to the task could address the role of motor planning, as the time to make a response is currently confounded with the orientation. A joystick or mouse input device would perhaps shed light on the observed interaction between orientation and magnitude of cuing effect.

4.6 Conclusion

Contrary to claims that noninformative cue effects are limited to reaction time, a more powerful continuous response perceptual matching task demonstrates that such basic cues are able to affect accuracy of perceptual judgments. The cuing effects in this task provide some support for signal enhancement. Qualitative differences between cuing effects on degraded static and dynamic stimuli suggest that attentional influences differ depending on the stimulus.

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