Main Study: Summer 2000

Methods

Design

The experimental design is within-subject – each participant experiences five different trials for each of the ten levels of *Display Condition* and for each of the three levels of *Target Display Type*. This is different from the pilot study where participants experience only one level of *Target Display Type.* There are 150 observations per participant for both the overlap estimation and the intersection sketch tasks. A total of 30 participants completed the study, giving 4500 observations per task overall (three times the data points of the pilot study).

Participants

Number, age, and gender

Thirty-seven people, sixteen men and twenty-one women, are participants in the study. Subject dropout leaves fourteen men and sixteen women: a total of thirty participants. Participants range in age from 19 to 36.

Criteria for exclusion of participants

The same exclusion criteria from the pilot study are again used in main study. In addition, people familiar with the DDS display technique are asked not to participate. People who participated in the pilot study are also asked not to participate. This participant pool is meant to represent novice users of the DDS display technique.

Recruiting and inducements

Participants are recruited through fliers posted on the campus of the University of North Carolina, Chapel Hill as well as through electronic mail postings. All participants are postdoctoral, graduate or undergraduate students at the University of North Carolina, Chapel Hill. Participation is voluntary, and participants are paid ten dollars per session.

Population Sampling and Generalization

The sample of participants is meant to represent the population of students on the UNC campus in general. Of the thirty participants, twelve different majors are represented, with five majors outside the sciences.

Target and Distractor Layers

The same set of distractor layers as in the pilot study is used in this study. However, a new set of target-pairs is generated. As in the pilot, fifty target shapes are generated from a pool of seven elementary shapes: equilateral triangles, squares, circles, horizontally aligned ellipses, vertically aligned ellipses, horizontally aligned rectangles, and vertically aligned rectangles. A pair-wise combination of the seven elementary shapes creates a pool of 49 target pairs. An additional (triangle, vertical ellipse) pair makes a total of 50 target pairs. The shapes are each displaced from the center of the image with the restriction that part of the shape overlap the center, thus guaranteeing that all targets and distractors overlap.

Targets A are displaced to the left, and targets B are displaced to the right. Displacement and scale factors for each shape are random so that no two shapes were exactly the same. Table 3.25 shows the fifty pairs of target shapes see Table 3.2 from the pilot section for the distractors. Figure 3.45 presents a histogram of overlap percentages for all target pairs; the distribution is different from that of the pilot study (see Figure 3.14).

Display Condition: Counterbalancing

The target pairs are assigned to one of ten groups, which are then counterbalanced across participants and *Display Condition* levels. Counterbalancing is as in the pilot study (see Table 3.3). This counterbalancing ensures that each target pair occurs once in each level of *Display Condition*; thus no one level of *Display Condition* is unfairly affected by a particularly easy or difficult target pair.

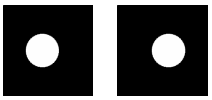
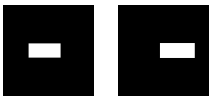
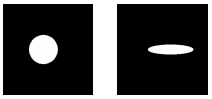
A	 **54.1%**	 **28.8%**	 **48.9%**	 **55.4%**	 **40.6%**
B	 **48.2%**	 **48.2%**	 **50.0%**	 **50.8%**	 **82.0%**
C	 **53.5%**	 **40.8%**	 **46.3%**	 **46.0%**	 **35.1%**
D	 **26.2%**	 **56.9%**	 **48.9%**	 **56.1%**	 **19.6%**
E	 **100%**	 **5.8%**	 **37.9%**	 **44.1%**	 **53.0%**
F	 **33.8%**	 **16.2%**	 **17.5%**	 **29.4%**	 **51.6%**
G	 **25.4%**	 **40.3%**	 **46.3%**	 **86.3%**	 **22.0%**
H	 **50.0%**	 **55.6%**	 **40.1%**	 **72.5%**	 **64.0%**
I	 **30.1%**	 **40.5%**	 **15.3%**	 **21.9%**	 **31.8%**
J	 **41.7%**	 **53.0%**	 **56.6%**	 **78.3%**	 **51.2%**

Table 3.25: Target pair images and correct percentage of target A that is overlapped by target B. Target pairs are randomly assigned to counterbalance group A-J (leftmost column). The five items in each counterbalance group is tested at every level of *Display Condition* and *Target Display Type.*

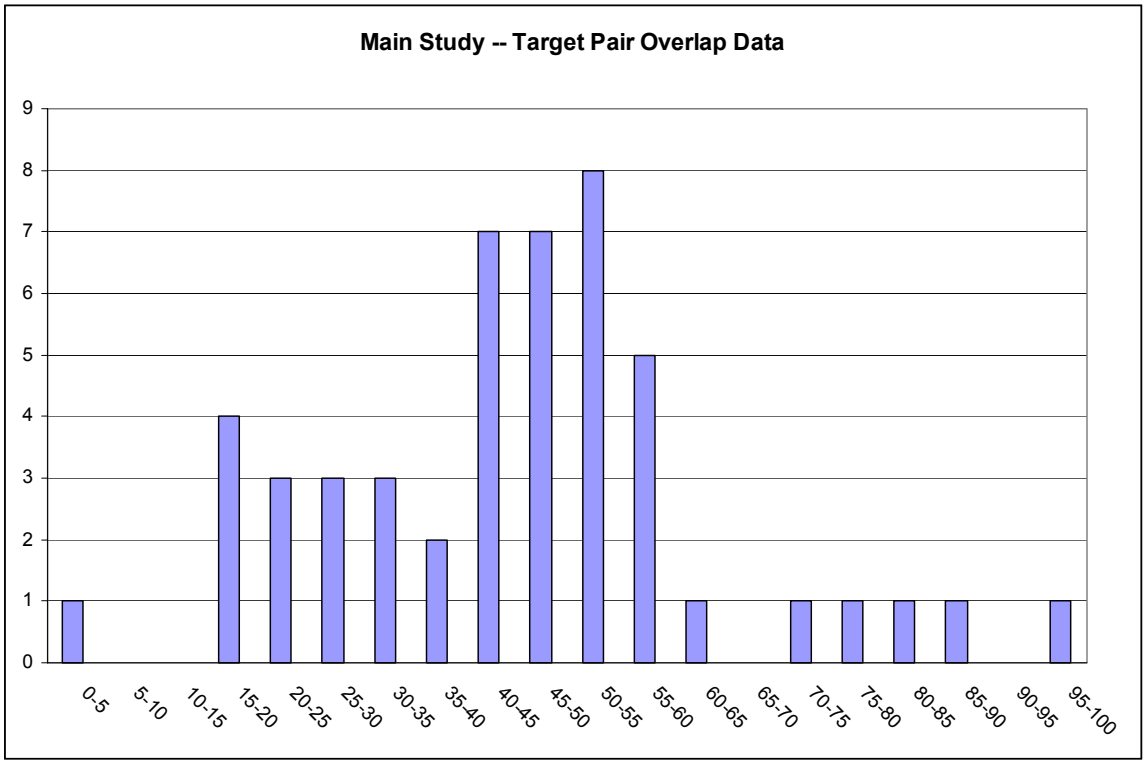


Figure 3.45: Histogram of overlap percentages.

Target Display Type: Assignment of Color and Gaussian Standard Deviation

The three levels of the independent variable *Target Display Type* are tested during three different sessions. The order of sessions is balanced across participants so that one third of the participants experience the *Color-Color* group first, one third of the participants experience the *Bump-Bump* group first, and one third of the participants experience the *Color-Bump* group first. The analysis does not show an order effect.

As in the pilot study, the spot color and standard deviations remain constant for the DDS layers at each level of *Target Display Type*. Only the instructions to the participants change; in the *Color-Color* session, target A is specified as the DDS alpha-blended layer distinguished by red hue and target B is specified as the DDS alpha-blended layer distinguished by green hue. In the *Color-Bump* condition target A is specified as the DDS alpha-blended layer with blue hue and target B is specified as the DDS bump-mapped layer of medium size. In the condition *Bump-Bump* target A is specified as the medium bump layer and target B is specified as the large bump layer. The exact parameters for all nine layers and all three levels of *Target Display Type* are given in Tables 3.29 through 3.32. The Layer Order column represents not only the order in which the layers were applied by the software, but also the perceived ordering (upper layers appear to lie on top of lower layers). Figures 3.46 through 3.48 present color swatches for each layer.

One difference between the pilot and main studies is the apparent height of the bumps. In the main study the larger bumps were made to appear taller to counteract the perceptual effect that small bumps, when overlaid on top of larger bumps, decrease the apparent height of the larger bumps.

As in the pilot study, the target layers have value 1 inside the target shape area and 0.25 outside the shape area, whereas distractor shapes have value 1 inside the shape area and value 0 outside. This is done to provide an additional cue to the participants as to which layers are targets. As such, it may weaken the perception of the boundary, hence can only strengthen the experimental results showing that such boundaries are visible despite distractors.

Materials

All 50 target pairs are tested in each of the ten levels of *Display Condition* and in each of the three levels of *Target Display Type*. For each trial the target pairs are displayed with a different number of distractors and/or different display parameters – making each trial image unique. Fifty target pairs, each tested at ten different levels of *Display Condition*, means that 500 different images were generated for each level of *Target Display Type*, and a total of 1500 different trial images were generated for the study overall.

Visual Layer Number	Layer Type	RGB Color Coordinates	HL S Color Coordinates	Relative Spot Size	Apparent height	*Color-Color*	*Color-Bump*	*Bump-Bump*
1	Large			1.0	3.0	C2	C3	target B
2	Medium			0.4	3.0	C4	target B	target A
3	Small			0.2	2.0	C6	C5	C4
4	Blue	51,51,255	170,255,153	0.83		C1	target A	C1
5	Red	255,51,51	0,255,153	1.33		target A	C1	C2
6	Green	51,255,51	85,255,153	0.5		target B	C2	C3
7	Purple	255,51,255	213,255,153	0.4		C3	C4	C5
8	Yellow	25,255,51	42,255,153	0.3		C5	C6	C6
9	Cyan	51,255,255	27,255,153	0.28		C7	C7	C7

Table 3.26: The apparent ordering, display parameters, and functions of the nine DDS layers in the main experiment. The last three columns on the right show the function of the layers in the different *Target Display Type Groups.*

Function	Layer type	Layer Order
target A	red	5
target B	green	6
C1	blue	4
C2	large bump	1
C3	purple	7
C4	medium bump	2
C5	yellow	8
C6	small bump	3
C7	cyan	9

Table 3.27: Display parameters for the targets and distractors used in the *Color-Color* session.

Function	Layer type	Layer Order
target A	blue	4
target B	medium bump	2
C1	red	5
C2	green	6
C3	large bump	1
C4	purple	7
C5	small bump	3
C6	yellow	8
C7	cyan	9

Table 3.28: Display parameters for the targets and distractors used in the *Color-Bump* session.

Function	Layer type	Layer Order
target A	medium bump	2
target B	large bump	1
C1	blue	4
C2	red	5
C3	green	6
C4	small bump	3
C5	purple	7
C6	yellow	8
C7	cyan	9

Table 3.29: Display parameters for the targets and distractors used in the *Bump-Bump* session.

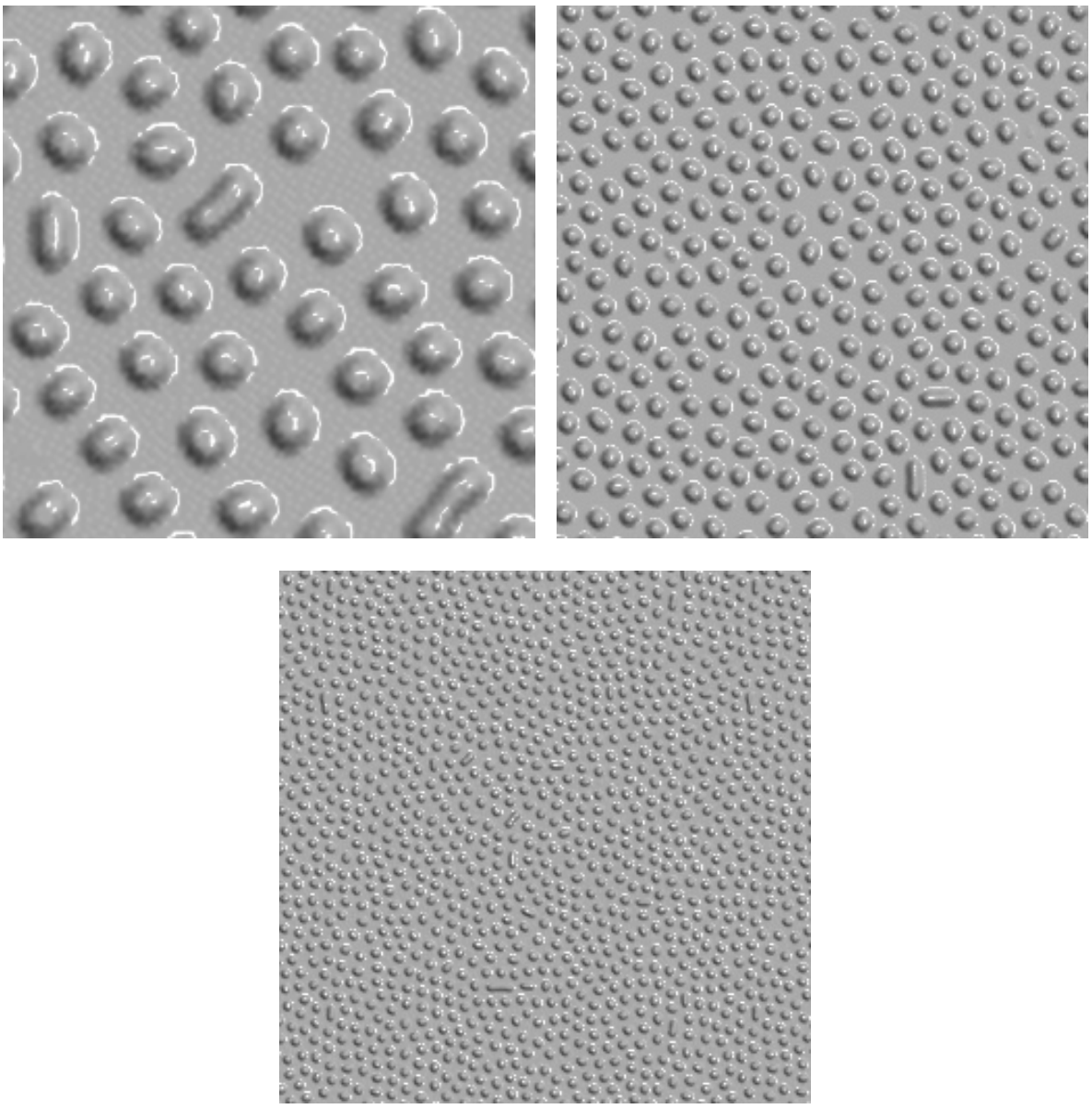


Figure 3.46: Swatches for the DDS bump-mapped layers: large, medium, and small bump sizes. The bumps are at the scale seen by the participants.

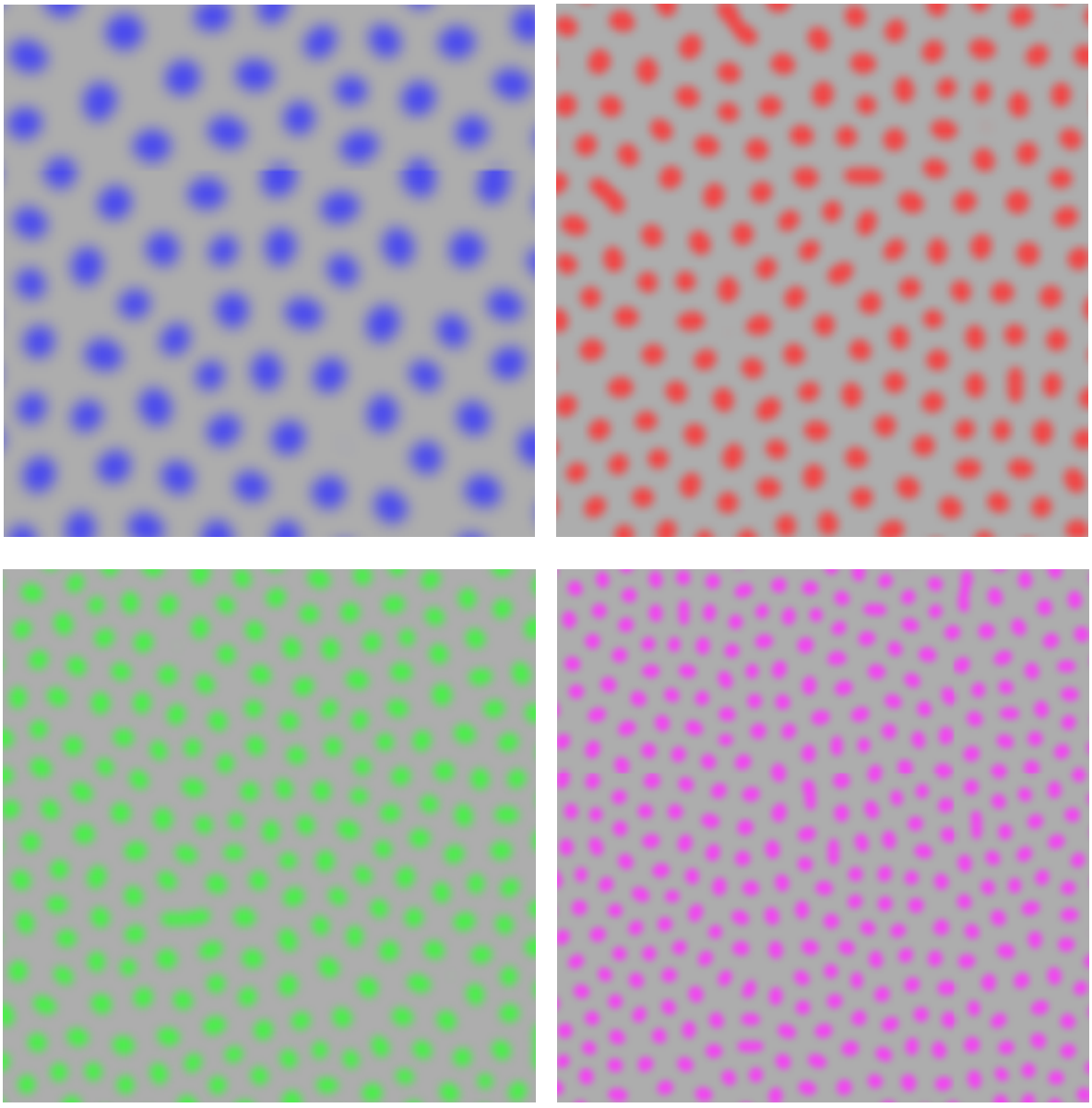


Figure 3.47: Swatches for the DDS alpha-blended layers: blue, red, green, and purple layers. The spots are at the scale seen by the participants.

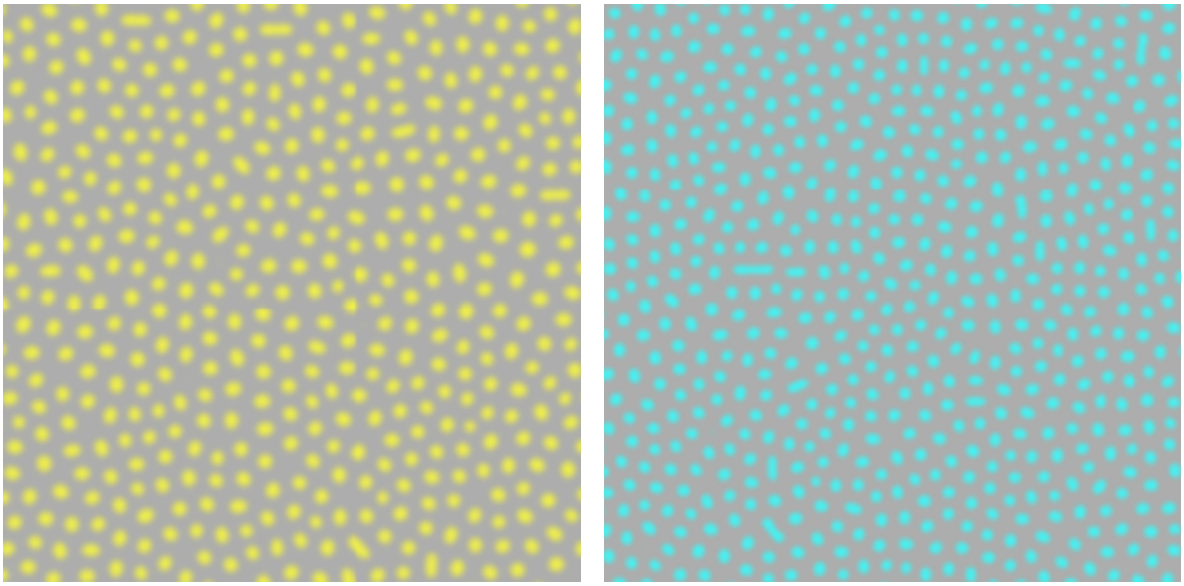


Figure 3.48: Swatches for the DDS alpha-blended layers: yellow and cyan layers. The spots are at the scale seen by the participants.

Dependent Measures

Participants are asked to complete the same tasks as in the pilot study, with the exception of the single-target sketch. The same performance measures are calculated. In this study the sketches are compared to the correct computer-derived shapes and graded on a three-point scale of wrong: -1, mostly correct: 0, exact: 1. Sketches are graded independently by two people, and the grades have a Pearson's correlation of 0.839, indicating high inter-rater reliability. The sketches are graded in opposite order by the graders, to counteract effects of grader fatigue and saturation. Sketches are judged to be correct if they matched the desired shape in form, including the correct number of vertices and edges. Exact positioning and scale of the shape relative to the image boundary is not considered. Table 3.30 shows scores by grader id; note that only 20 opposite scores in evaluation (wrong, exact) occur out of 4500 sketches. Figure 3.49 shows examples of sketches from the experiment.

Grader0	Grader1	Count
-1	-1	313
-1	0	56
-1	1	15
0	-1	134
0	0	645
0	1	315
1	-1	5
1	0	198
1	1	2819
		4500

Table 3.30: Counts of sketch scores by grader id. The Pearson's correlation between scores was 0.839, indicating high inter-rater reliability. Note that only 20 sketches were judged wrong by one grader and exact by the other, out of 4500 total sketches. Also note that sketches were judged to be exact by both graders 2819 times.

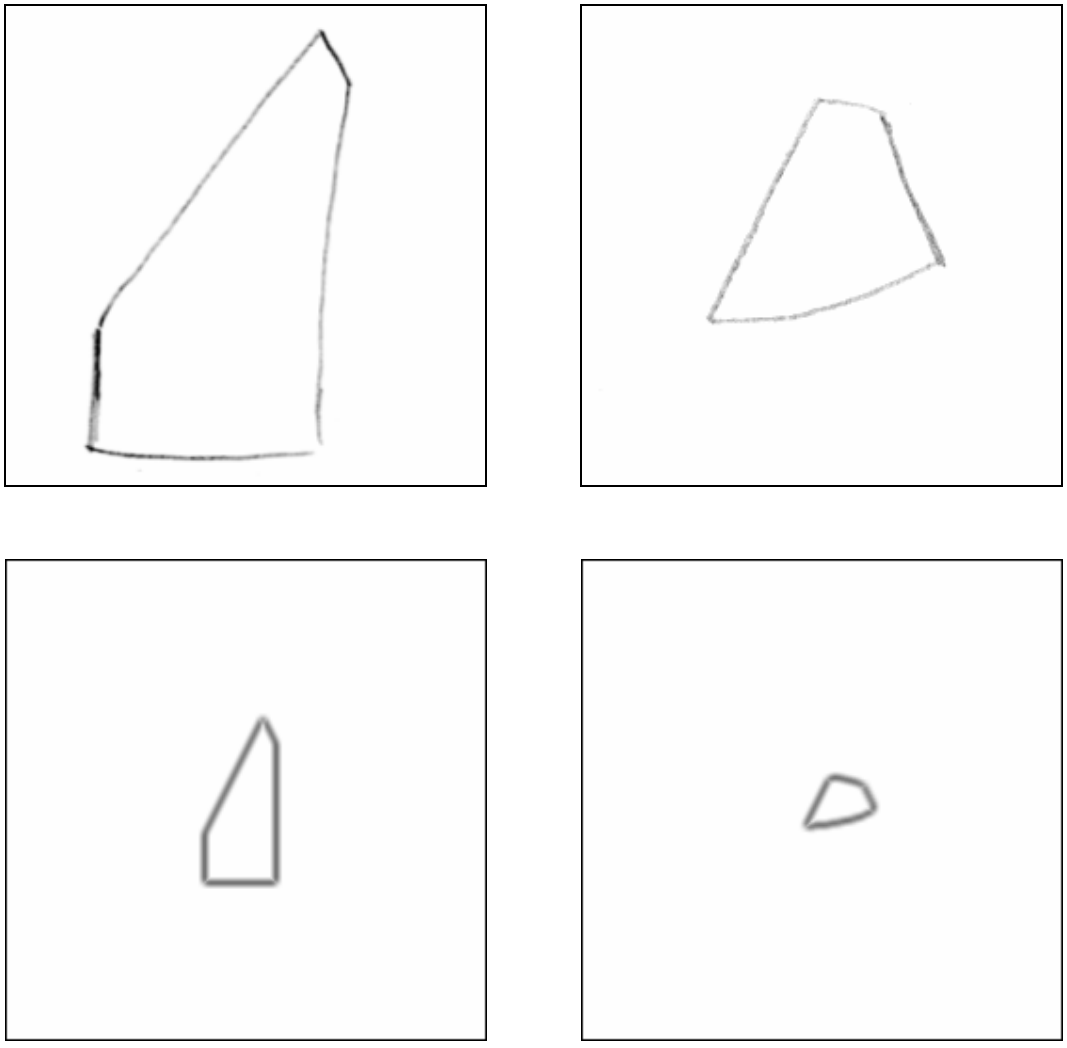


Figure 3.49: The top row shows example intersection sketches. The correct intersections are shown in the bottom row.

Procedures

Experiment schedule

Each participant visits the lab on three different days and completes one session per day. For each session the display software presents stimulus images from one of the levels of *Target Display Type*: *Color-Color, Color-Bump,* or *Bump-Bump.* Each session, including instructions, lasts approximately 45-60 minutes.

As in the pilot study, the test program presents all instructions and trials to the participant, including the instructions to read and sign a written consent form.

Apparatus

The same hardware and software display systems and image generation systems as the pilot study are used, see pages 141-142 for details.