Systematic Operant Bias Observed in Human Participants During Research on Choice

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In experiments involving multiple operant behaviors, it is often assumed that the operants used are equivalent and neutral for the participants prior to the experiment. Otherwise the results can be affected by systematic operant bias that is not due to the intended independent variable. During a series of three studies designed to develop a new type of operant in order to study learning history variables, persistent systematic biases were observed; these could not be eradicated through methodological changes. The operants used required human participants to draw shapes on a computer graphics tablet; the biases that emerged were associated both with the hand motions involved in executing each operant and with the operant's visual aspects. In some cases there was an interaction effect that combined the two sources of bias. Each experiment had a number of learning sessions in which participants practiced these operants different numbers of times, followed by a "test session" in which they were required to choose between them. The angle of lines drawn, the starting and ending point of each operant, the number of lines per operant, and the hand with which participants drew the lines were all varied, without elimination of operant bias; there remained persistent, classifiable preferences for certain operants over others. This type of detailed quantitative analysis of bias is potentially significant for any behavior research that assumes equivalence among operant behaviors.

Key words: response bias, operant bias, perceptual bias, kinesthetic bias, bias, human participants

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One of the methodological challenges facing any behavioral researcher is the possibility that the experimental subjects may show biases or preferences that cannot be accounted for by the study's programmed independent variables. Bias is a well-known phenomenon in behavioral studies of choice; in Baum's formulation of the generalized matching law (Baum, 1974) it is represented by a free parameter. However, it has not been a topic for systematic study in choice experiments, and outside of the literature on matching, consistent bias for one operant response over another has hardly been mentioned by experimental behavior analysts. (This type of bias will be referred to in the present paper as "operant bias" rather than "response bias" in order to avoid confusion with the common cognitive usage of the latter term, which carries a different meaning.)

Operant bias by its very nature is easy to observe but almost impossible to analyze quantitatively, let alone categorize or predict. Operant bias is not under the experimenter's control, and its existence is

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often discovered only in hindsight, after the experiment has been run and the data examined. It can have multiple causes, many of which are pre-experimental and unknown to the experimenter (Baum, 1974).

There has been some systematic work done to categorize various types of stimulus bias—the pre-existing preference for one stimulus over another. For example, in the course of their work on generalization, Schadler and Thomas (1972) found that pigeons showed an initial preference for a 90 degree line over one at any other angle. And there is an entire literature dissecting the biases that humans show for specific nonsense syllables, commonly used as stimuli in memory experiments (Jenkins, 1985). But stimulus bias is only one component of operant bias; the more complex the operant behavior, the greater the number of potential loci of bias.

The three experiments described in the present paper were conducted as part of an extensive research program on human choice, specifically how choice between complex operant behaviors is affected by the conditions under which those behaviors are learned. In order to permit valid conclusions to be drawn regarding the experimental learning history variables, it would be necessary for the operants presented as choices to be behaviorally equivalent and of neutral value to the participants at the start of the study—in other words, for them to be bias-free (at least with respect to the dependent variable of the experiment in question—unrelated bias may, of course, still exist even in experimentally-equivalent sets of operants). Prior to starting the present experiments, the experimenters had conducted numerous studies using operants consisting of non-word sequences of letters typed on the computer keyboard (Jones & Mechner, 2007; Mechner & Jones, 2001, 2011). A decision was made to attempt to replicate those results using a different type of operant. In the process we hoped to develop an entirely new operant research methodology that could be utilized in many areas of behavioral research. The apparatus chosen was a computer graphics tablet and stylus.

The present experiments were initially conceived as pilot studies; we hoped to develop a set of distinct yet equivalent operants (with each operant consisting of a different shape drawn on the graphics tablet with the stylus) that could be used to study the effect on choice of relative number of prior repetitions of an operant. Instead, we discovered that our subjects exhibited consistent and systematic operant bias. Due to the complex nature of our operants and the fact that each subject learned nine different ones representing a continuum of perceptual and kinesthetic attributes (rather than, for example, just choosing between the right and left key), these experiments provide a rare opportunity to categorize this type of operant bias in detail, and, from these results, to extrapolate some sources of operant bias in general.

Experiment 1

Method

Participants. The participants were 10 adults, recruited through flyers placed on local college campuses. They were told they could earn up to $100 for participating in two sessions, each approximately an hour in length, taking place at the same time of day on two consecutive days. The total amount of money earned would depend on their performance. They were free to withdraw from the experiment at any time, although they would receive only a token payment for their time if they did so. They signed agreements stating that they understood these terms. They pledged to keep their sleeping and eating habits and caffeine consumption consistent on both days of the experiment and to shut off cell phones or other devices during sessions. They were debriefed about the purpose of the experiment at the end of the last session.

Setting. The participants sat at chairs at one of four computer workstations arranged in a 9' by 12' room. Each workstation was separated from the others by screens, and participants faced the wall with their backs to the center of the room (and each other).

Apparatus. Four Dell 486 desktop computers were used for this experiment, each with a standard 14 inch CRT monitor with a screen resolution of 800 by 600 pixels. Each had a Wacom graphics tablet attached as an input device. Participants drew on the tablet with a stylus. The tablet was placed flat in front of them at a comfortable height on the keyboard tray of their workstation. The shapes they drew appeared on the monitor of the computer, placed at eye level in front of them. A customized software package provided the appropriate stimuli on the screen and tracked the measurable attributes of each shape they drew.

Design. The operant in Experiment 1 consisted of a straight line, drawn from a defined starting point to a defined end point. Participants started each line by placing the tip of the stylus on the graphics tablet and drew by moving the stylus along the surface of the tablet. The line ended at the point the stylus was lifted from the tablet. As they drew, each line appeared on the monitor on top of the background graphic shown in Figure 1.

Each line was drawn from left to right, starting anywhere within one of the three red dots on the left and ending anywhere within one of the three blue dots on the right—nine different lines in all. The nine different operants learned in Experiment 1 were thus A1, A2, A3, B1, B2, B3, C1, C2, and C3 (please note that the labels A, B, C, 1, 2, and 3 are for reference only and did *not* appear on the dots during the experiment). The dots were programmed to be 30 pixels in diameter, and the two rows of dots were spaced 180 pixels apart.

Figure 1. Screengrab from Experiment 1. On the monitor, the left three circles were bright red and the right three bright blue.

During the first session of the experiment, the learning session, participants were cued by the appearance of a wide gray stripe or path (25 pixels across at the widest point) between the appropriate dots to perform operants A2, B2 and C2 100 times each, operants A1, B3 and C1 200 times each, and operants A3, B1 and C3 400 times each. In order for the operant to be considered correctly-drawn (and thus registered by the experimental software), the stylus had to initially touch the drawing tablet when the cursor on screen was within the starting dot of the operant (at the left end of the gray path), and remain in contact with the tablet until the cursor was within the ending dot (at the right end of the gray path). The correct completion of each operant repetition was reinforced with the brief appearance of a large green square with the word "Good" printed inside it in the middle of the monitor screen. Operants were programmed in blocks of 25, arranged in a randomized order throughout the learning session, which consisted of a total of 2100 correctly-performed operant repetitions.

During the second session, the test session, participants were allowed to choose which line to draw from among a rotating subset of three of the nine operants. Three gray paths between dots appeared on the screen at any given time. Participants drew whichever line (or lines) they preferred of the three choices until a total of five operant attempts had been made, correctly performed or not, after which a different subset of three operants were offered as choices for another five attempts, and so on. Each choice always consisted of one operant from each of the three prior repetition levels—100, 200 and 400 repetitions; each operant was offered as a choice during the test precisely the same number of times and was paired with all possible alternatives in the other repetition levels the same number of times.

Each time one of the three operants in use at any given time was completed correctly, the participant earned 8 cents; the computer emitted a short high-pitched noise and $.08 was added to a running earnings total displayed in a corner of the screen. Each time the participant emitted an incorrect operant (not one of the three in use, or incorrectly-drawn according to the experimental software criteria) or paused for more than two seconds between operants, they lost 4 cents from their total; the computer emitted a longer, low-pitched noise and $.04 was deducted from the displayed total. The test session ended after a total of 1500 operant attempts, regardless of whether they were correctly-performed or not.

Procedure. At the beginning of the first session, after signing their participant agreements, participants were seated at a computer workstation and instructed by the experimenter to log in by entering their initials and the date. The following instructions then appeared on the monitor: "During this study you will be drawing straight lines on the graphics tablet using the stylus. Touch OK with the stylus to begin familiarizing yourself with the use of the stylus and graphics pad. Move the cursor by moving the stylus tip just above the graphics pad without touching it. Touch the stylus to the tablet at the beginning of each line and lift it at the end. Do not use the mouse. When you are able to move the cursor and draw straight lines using the stylus, touch the Done button in the lower right-hand corner to begin the session."

After the participants had finished learning how to use the tablet and stylus at their own pace, they touched "Done" and the following additional instructions appeared on the screen: "You will need to figure out how the computer wants you to draw the lines. Touch OK to start." The experimenter stayed nearby while the participants attempted to perform their first few operants, answering any questions asked—although participants very quickly realized that drawing from left to right along the gray pathway on the screen was the action required of them. After they had completed all the operant repetitions necessary during learning, the session automatically ended and they could leave for the day.

The following day, for the test session, participants sat at the same computer workstations they had used the day before and logged in using the same procedure. The following instructions were displayed on the computer screen: "You will be given a choice of lines to draw. Each time you draw a line correctly you will earn 8 cents. Each time you make a mistake or if you pause for too long between lines you will lose 4 cents. Touch OK with the stylus to begin." The test session then progressed as described until it ended automatically after the allowed number of operant attempts. Participants were then debriefed and given a check for the total amount of money earned during the session before leaving.

Results

Figure 2 shows the total number of correctly-drawn operants chosen by each participant during the test session, grouped by the level of prior repetitions: the 3 operants that were repeated 100 times, the 3 that were repeated 200 times, and the 3 that were repeated 400 times.

It is evident that the number of times each operant had been repeated (the experimenter-programmed independent variable in this experiment) is not what determined the participants' choice among operants under test conditions. Once this fact became clear, the results were reanalyzed to look for possible patterns of operant bias.

After reanalyzing the data, we found two clear systematic biases, one having to do with

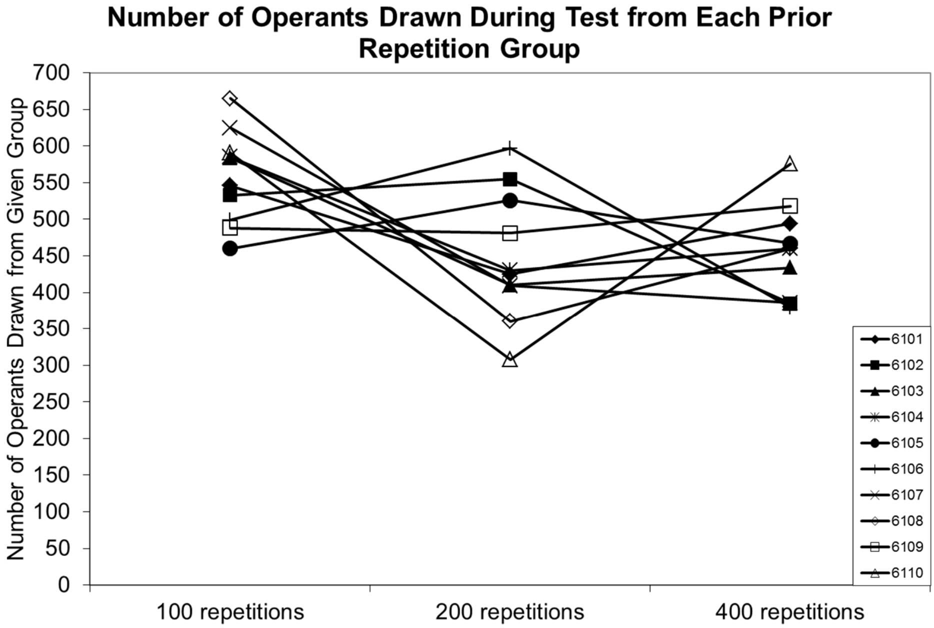

Figure 2. Results of Experiment 1, categorized by number of prior repetitions per operant chosen.

the starting point of each operant: whether they chose to draw from the starting point farthest from them on the graphics tablet (the top circle as displayed on the monitor), the one in the middle, or the one nearest to them (the bottom circle), and the other having to do with the angle of the line drawn. There are five different possible angles relative to the participant's own body at which a line could be drawn: 68° (C1), 79° (B1 and C2), 90° (A1, B2 and C3), 101° (A2 and B3), and 112° (A3). Figure 3 maps these angles onto the screengrab graphic.

All angles discussed throughout this paper are in relation to the body of the participant drawing the line; a 0 degree angle is always one drawn directly away from the body, a 90 degree angle is one drawn left to right,

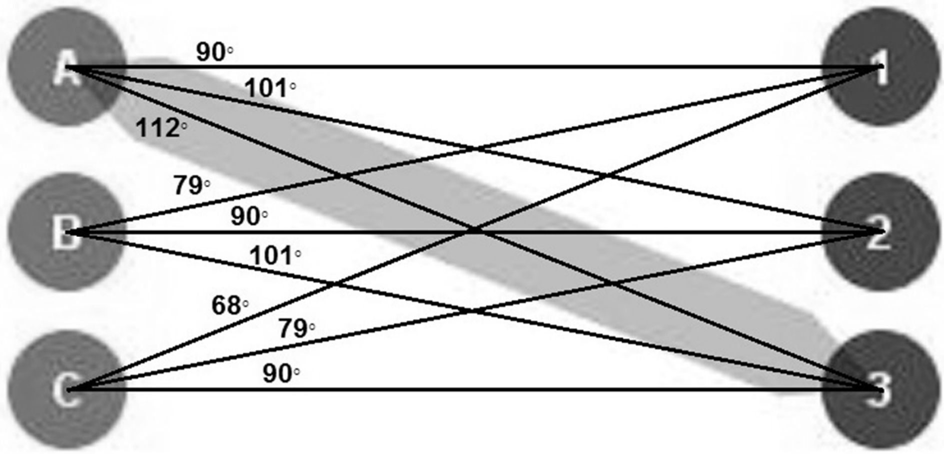

Figure 3. All nine operants learned in Experiment 1, with angle of line relative to the participant's body marked.

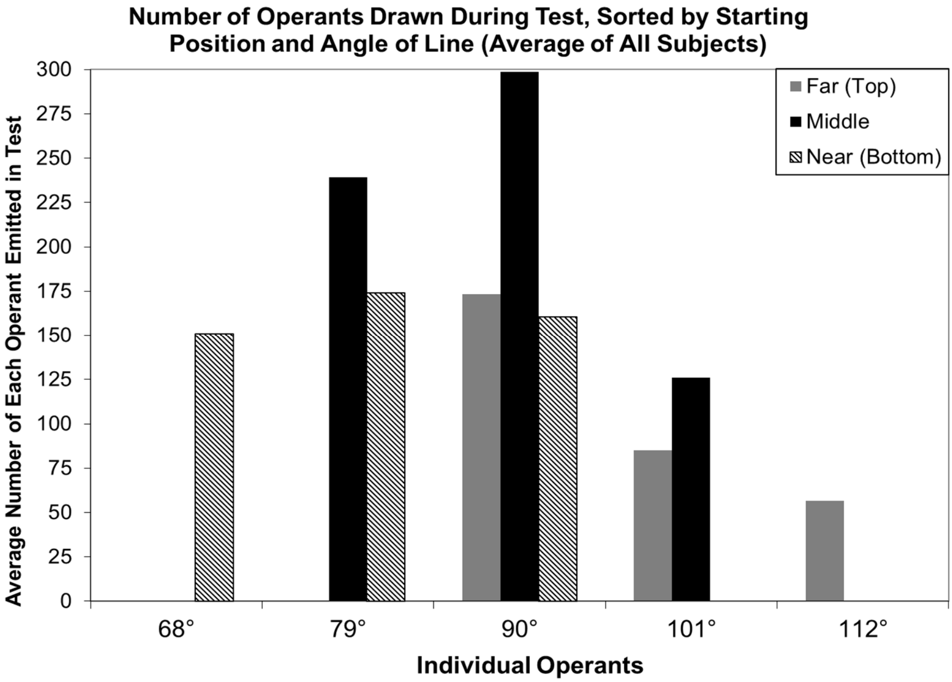

Figure 4. Results of Experiment 1, categorized by starting position of operant on the graphics tablet and angle of line relative to the participant's own body.

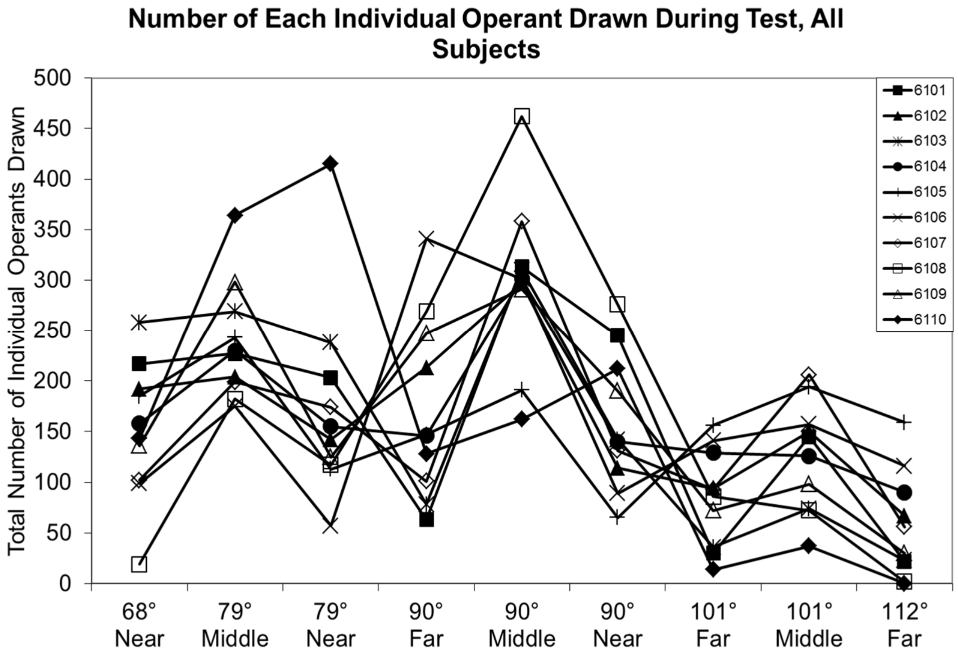

Figure 5. Individual data showing number of times each of the nine operants was chosen by each of the 10 subjects during the test session of Experiment 1.

a 180 degree angle is drawn directly toward the participant, and a 270 degree angle is drawn right to left.

Thus in addition to the independent variable programmed by the experimenters (number of prior repetitions), when the artifacts of the apparatus are examined closely, Experiment 1 is shown to have two additional, unprogrammed independent variables: starting point and angle of line, with a factorial design which explored the interaction of the two. Figure 4 shows averaged data on choice in the test session of Experiment 1, re-categorized in light of these elements.

Looking at the data in this form, there are two clear biases: 1) participants prefer to draw from the middle starting point, with the near starting point (bottom circle as displayed on the monitor) next-preferred and the farthest one (top circle) least preferred, and 2) participants prefer to draw directly left to right or angled away from their own bodies, rather than drawing a line that moves toward themselves. Furthermore, preference decreases as the angle of the line moves in either direction away from the peak at 90 degrees, forming a stepped function: drawing slightly away from oneself is preferred over drawing more sharply away, drawing slightly toward oneself is preferred over drawing more sharply toward the torso. Figure 5 shows the individual data.

There is quite a bit of variation among subjects, but the relative preference peaks for the three middle starting points, and the general bias for smaller angles over larger ones, are still clear.

Discussion

Since these operants involve visual tracking of familiar stimuli, and a relatively narrow range of specific hand and arm movements (and the biases observed are relatively systematic and consistent across our participants rather than idiosyncratic), the operant biases shown in Experiment 1 can be classified according to their interactions with the perceptual and kinesthetic coordinative structures of the human body. The bias for the center of the three starting points on the graphics tablet over the nearest, which would presumably require slightly less effort to reach, seems to be perceptual in origin, relating to the stimuli displayed on the computer monitor. Possibly relevant is Piaget's concept of "factor of centration"—the size of any stimulus in the center of the visual field is overestimated, compared with other stimuli. Perceptual researchers study this phenomenon experimentally under the name of "center bias"—the persistent fixation of the gaze at the center of the visual field (Tseng et al., 2009). As the participants in Experiment 1 kept their gaze on the computer screen in front of them, they would have focused on the center of the three starting points, which appeared more visually prominent and thus more noticeable.

A bias in favor of moving the dominant hand from left to right and from close to far in relation to the body, however, is primarily kinesthetic in origin. Normal human subjects, when asked to make a mark in the center of a horizontal line placed in front of them, consistently place the mark slightly to the left of center. This phenomenon is known as "pseudoneglect" since it resembles the neglect of one side of the visual field seen in subjects with traumatic brain lesions; it exists regardless of handedness—Jewell and McCourt (2000) provide a comprehensive review of the literature. Lourenco and Longo (2009) asked their participants to bisect lines placed at different distances away from their torsos. There was a rightward shift in bias with increasing distance (i.e. the farther participants had to reach away from their own bodies); there was also a rightward bias if participants were wearing weights attached to the wrist of their drawing arm; once again, regardless of handedness.

It is possible that the operant bias we observed for lines drawn left to right and/or away from the participant's own body has a perceptual component as well. In the visual perception literature, there are also studies showing a consistent bias toward the left when humans are asked simply to estimate the brightness of stimuli in either side of the visual field rather than reaching forward to place a mark (Nicholls & Roberts, 2002). Interestingly, this bias does not appear to be related to the subjects' history of handwriting, as one might suppose—half of Nicholls & Roberts' subjects were Israeli (Hebrew is written right to left, rather than left to right) and they still showed the effect.

Perceptually, the lower part of the visual field has a measurable advantage in reaction time when it comes to following motion and making spatial judgments (such as estimating distance), while humans working in the upper part of the visual field have a reaction-time advantage in search tasks such as picking out criterial stimuli from distracters (Thomas & Elias, 2011). Thomas and Elias also showed that the leftward bias on the horizontal line bisection task is stronger if the task is performed in the lower part of the visual field, suggesting a natural correspondence in humans between the left and lower visual fields, and between the right and upper visual fields.

Finally, one component of the observed bias for a 90 degree angle may well have been conservation of effort—due to the position of the dots which marked the starting and ending points of each operant (please refer to Figure 3 again), the three operants which were drawn directly from left to right required the subjects to move their hands the shortest possible distance of all operants learned. Operants drawn at 79° or 101° required slightly longer lines for completion, while those drawn at 68° or 112° required the most motion. This gradient of effort required matches the stepped preference function seen in the results.

In an attempt to eradicate these systematic operant biases, we redesigned the graphic operant to equalize both the starting point and the length of the line drawn, and to de-emphasize the angle of that line relative to the participant's body. This redesigned type of operant was then used in another experiment of very similar design.

Experiment 2

Method

Participants, setting and apparatus. The participants were 13 adults, recruited in the same manner used for Experiment 1. They were told they could earn up to $160 (depending on their own performance) by completing five experimental sessions, each approximately an hour in length, at the same time each day on five consecutive days. They were also free to withdraw from the experiment at any time, albeit with a token payment for time spent rather than the performance-based reward. They signed the same agreements and were debriefed in the same manner as the participants in Experiment 1. The setting and apparatus for Experiment 2 were also identical to that used in Experiment 1.

Design and procedure. The operant in this experiment was a triangle drawn on the graphics tablet with the stylus, rather than a straight line. It was hoped that if each operant required moving the dominant hand at three different angles in relation to the torso rather than only one, that there would be less or no bias toward a particular triangle. Furthermore, each operant started and ended in the exact same point in the center of the screen, removing the possibility of bias for certain starting points over others. Figure 6 shows a screengrab from Experiment 2.

Each operant was drawn starting from the center red dot, out to one of the numbered blue dots, then to a blue dot spaced 2 dots away from the first one, then finally back to the center red dot to finish, creating a triangle shape without lifting the stylus from the tablet. All dots were programmed to be 53 pixels in diameter, and each blue dot was spaced 157 pixels away from the center dot and 90 pixels away from each of its two neighbor dots. Once again, the participants

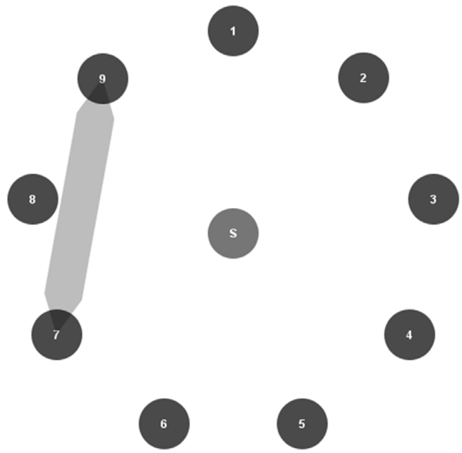

Figure 6. Screengrab from Experiment 2. On the monitor, the center circle was bright red and the nine surrounding circles bright blue.

did not see the numbers and the letter S; those are only for reference on this graphic.

To further decrease the importance of the angle of drawing, participants were allowed to draw through the two blue dots that made up a given operant in whichever order they liked. In other words, drawing through S, 1, 3, S was the same operant as drawing through S, 3, 1, S. The nine different operants learned and practiced in Experiment 2 were thus 1-3/3-1, 2-4/4-2, 3-5/5-3, 4-6/6-4, 5-7/7-5, 6-8/8-6, 7-9/9-7, 8-1/1-8, and 9-2/2-9. During the first four sessions—the learning sessions—a wide gray stripe or path appeared on the screen (40 pixels across at the widest point) between the two blue dots making up the current operant, showing the participants two points of the triangle to be drawn (with the third always being the center dot). Criteria for correct performance of an operant were very similar to Experiment 1: the stylus had to touch the drawing tablet when the cursor on screen was within the center dot and remain in contact with the tablet as the line passed through the two outer dots connected by the gray path, until the on-screen cursor was again within the center dot.

The participants were divided into two experimental groups. Seven of the 13 performed operants 2-4, 5-7 and 8-1 correctly 100 times each, operants 3-5, 6-8 and 9-2 300 times each, and operants 1-3, 4-6 and 7-9 900 times each. The remaining six participants performed operants 1-3, 4-6 and 7-9 100 times each, operants 2-4, 5-7 and 8-1 300 times each, and operants 3-5, 6-8 and 9-2 900 times each. The correct completion of each operant repetition was reinforced with the brief appearance of a large green square with the word "Good" printed inside it in the middle of the monitor screen. Operants were programmed in blocks of 25, arranged in a randomized order throughout the four learning sessions, each of which consisted of a total of 975 correctly-performed operant repetitions.

During the final test session, participants were allowed to choose which line to draw from among a rotating subset of three of the nine operants. Three gray paths between dots appeared on the screen at any given time. After five operants had been attempted, regardless of whether they were correctly performed or not, a different subset of three operants was offered (i.e. three different gray paths appeared). Each choice always consisted of one operant from each of the three repetition levels: 100, 300 and 900 repetitions. Each operant was offered as a choice during the test precisely the same number of times and was paired with all possible alternatives in the other repetition levels the same number of times.

Each time one of the three operants that were in use at any given time was completed correctly, the participant earned 20 cents; the computer emitted a short high-pitched noise and $.20 was added to a running total displayed in the corner of the screen. Each time the participant emitted an incorrect operant (not one of the three in use, or incorrectly-drawn) or paused for more than two seconds between operants, they lost 10 cents from their total; the computer emitted a longer, low-pitched noise and $.10 was deducted from the total in the corner of the screen. The test session ended after a total of 900 operant attempts, regardless of whether they were correctly-performed or not.

The procedure for Experiment 2 was identical to that for Experiment 1, with slight changes in the instructions displayed on the computer screen to reflect the equivalent changes in the experimental details.

Results

Figure 7 shows the total number of correctly-drawn operants chosen by each participant during the test session of Experiment 2, grouped by the number of prior repetitions: the 3 operants that were repeated 100 times, the 3 that were repeated 300 times, and the 3 that were repeated 900 times.

Once again, number of prior repetitions of an operant is clearly not what is controlling later choice. The uniformity of these functions is even more striking given that half of these participants were exposed to a different association of specific operants and repetition values than the other half. Again, we reanalyzed the data on choice during the test session to look for possible systematic patterns of operant bias.

And again we found two clear biases, one having to do with the angle relative to the participant's own body of the initial line of each triangle, the one drawn from the red starting point in the center of the screen, and the other having to do with the direction (either clockwise or counterclockwise around the circle) of the second line making up each operant. Figure 8 shows the nine different possible values for the angle of the initial line of each operant in Experiment 2.

The data from Experiment 2 can thus be analyzed to show the effects of these two biases, angle of initial line and direction of second line drawn. Figure 9 shows the averaged data for all participants.

Looking at the data in this format, it is clear that participants are generally biased toward operants that begin with an initial movement away from their own torsos, but the extent of that bias depends heavily on whether the movement that follows will be in the clockwise or counter-clockwise direction. There is clearly a complex interaction effect at work here, with the shape of the

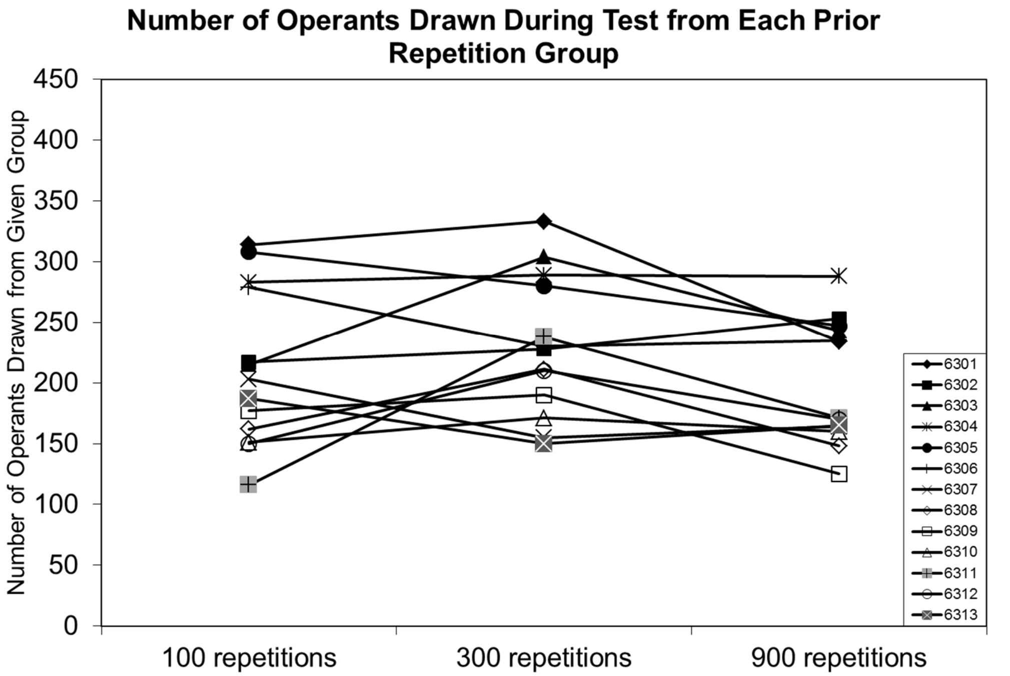

Figure 7. Results of Experiment 2, categorized by number of prior repetitions per operant chosen.

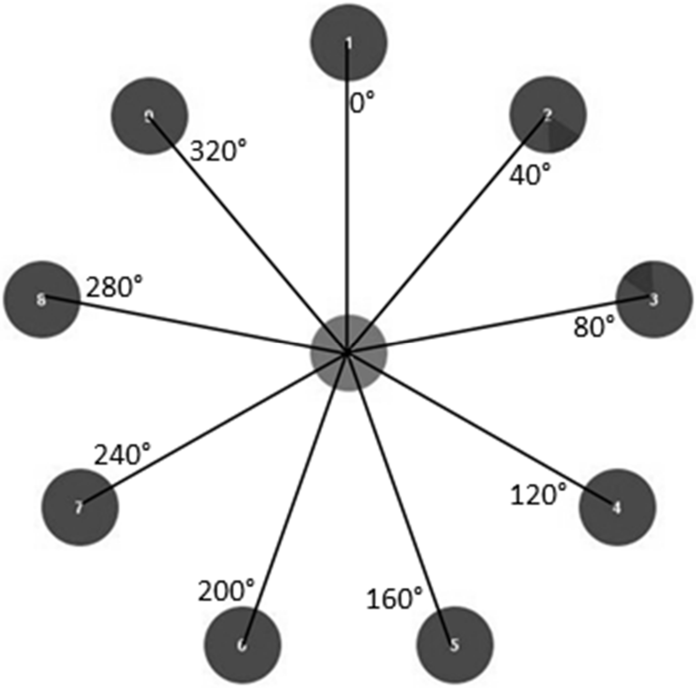

Figure 8. Initial lines of all nine operants learned in Experiment 2, with angle relative to the body indicated.

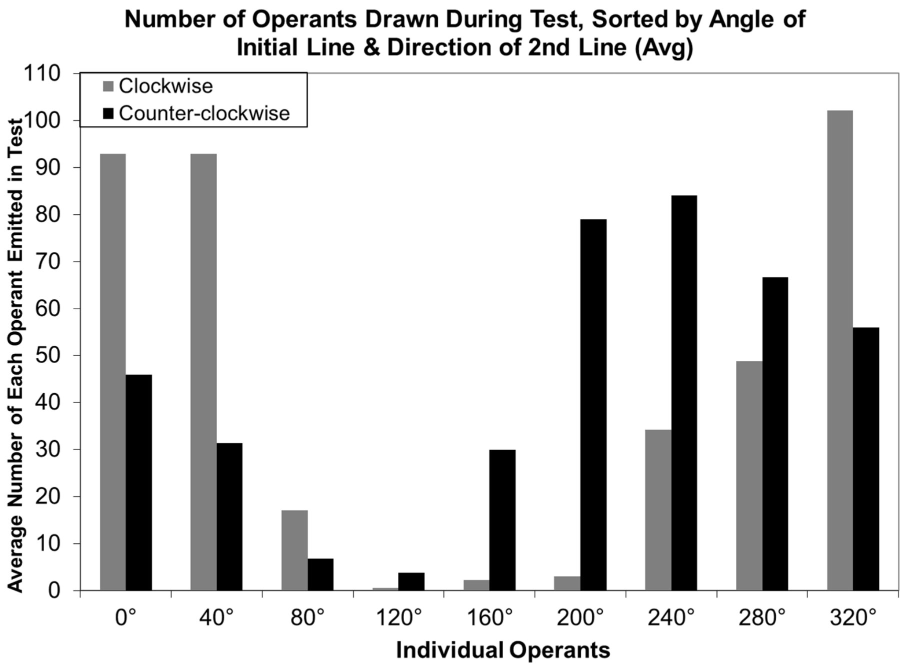

Figure 9. Results of Experiment 2, categorized by angle of initial line relative to the participant's own body and direction of second line around the circle of targets on the computer screen.

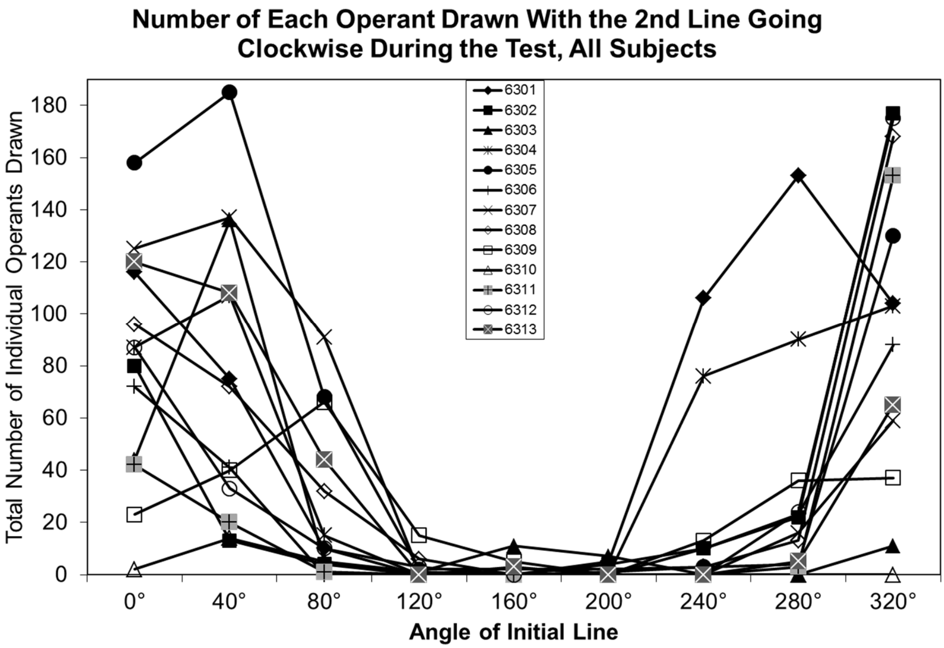

Figure 10. Individual data showing number of times each of the nine clockwise operants was chosen by each of the 13 subjects during the test session of Experiment 2.

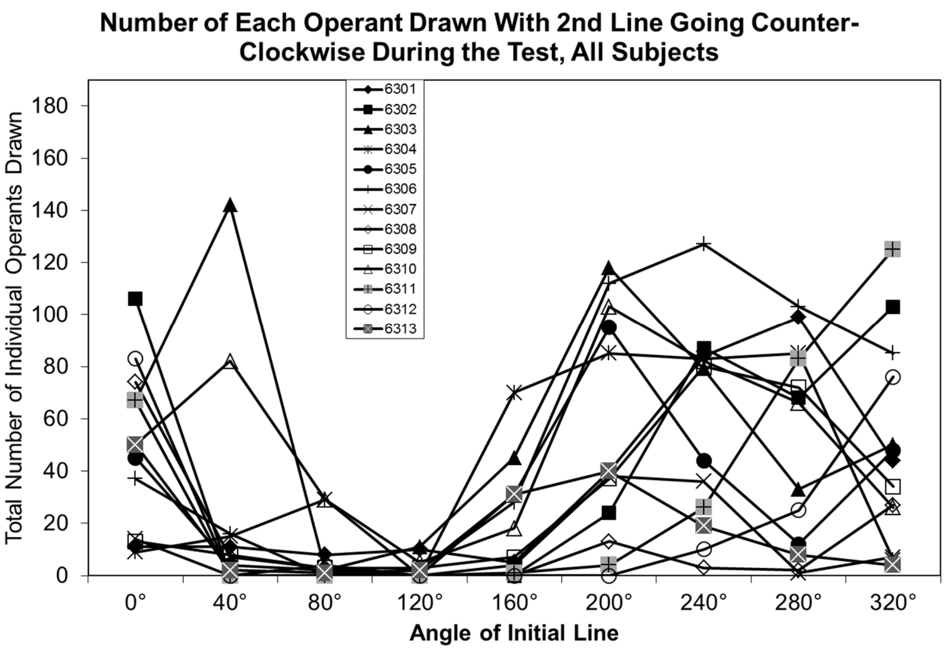

Figure 11. Individual data showing number of times each of the nine counter-clockwise operants was chosen by each of the 13 subjects during the test session of Experiment 2.

clockwise function being steeper and more oriented directly away from the participant, and the counter-clockwise function being flatter, with greater preference shown for operants that require drawing from the center toward the lower left-hand quadrant of the tablet. Figures 10 and 11 show the individual data, which are remarkably consistent in the bias against the 120, 160 and 200 degree angles in the clockwise operants, and against the 80 and 120 degree angles in the counter-clockwise ones.

Discussion

These two biases were thus observed to be interactive. Likewise, Experiment 2 provides more evidence that a combination of perceptual and kinesthetic components can cause a systematic operant bias with regard to this type of operant behavior—drawing with the dominant hand—while viewing stimuli that map to one's actions. This may be related to the phenomenon of "pseudoneglect" described in the Experiment 1 discussion section. In addition to consistently erring toward the left side when asked to bisect a horizontal line, humans also consistently err toward the top when asked to bisect a vertical line (Post et. al, 2006). The two effects combined result in neglect of the lower right quadrant, both on a kinesthetic and visual-perceptual basis. In Experiment 2 we see this combined bias effect, added to our existing observation from Experiment 1, that moving the dominant hand away from the torso is generally preferred over moving it from the starting point to a point closer to one's own body. The operants with an initial angle in the 200-280 degree range are preferred only when that initial movement toward the lower left quadrant is followed immediately by a counter-clockwise one, moving away from the body.

In our last attempt to eliminate at least some of the systematic and consistent operant bias observed, a decision was made to replicate Experiment 2 while requiring the participants to draw with their non-dominant hand.

Experiment 3

Method

The participants were 7 adults, recruited in the same manner as those in Experiments 1 and 2. They were told they could earn up to $120 by completing three sessions on three consecutive days. The setting, apparatus, design and procedure for Experiment 3 were all identical to Experiment 2, except for two changes: 1) repetition levels for the 3 groups of 3 operants were set at 100, 200 and 400 repetitions each, purely to allow the experiment to be finished more quickly (it consisted of 2 learning sessions followed by the same test session as in Experiment 2), and 2) participants were instructed to perform all operants with their non-dominant hand, whether that was the left or right.

Results

Figure 12 shows the total number of correctly-drawn operants chosen by each participant during the test session, grouped by the level of prior repetitions: the 3 operants that were repeated 100 times, the 3 that were repeated 200 times, and the 3 that were repeated 400 times.

Again, number of repetitions had no effect on choice during test conditions. When the data were re-analyzed in terms of the effect of angle of the initial line and direction of the second line of the operant, the results look very similar (with one crucial difference) to those from Experiment 2, despite the changes that must have been imposed on the participants' normal motor routines by requiring them to draw with the non-dominant hand. Figure 13 shows averaged data for all seven participants in Experiment 3.

Note that the two distributions—one for operants where the second line is drawn clockwise and one for operants with the second line drawn counter-clockwise—are much closer in shape than in Experiment 1. The general bias toward operants in which the angle of the initial line is in the 280 to 40 degree range remains quite consistent, but

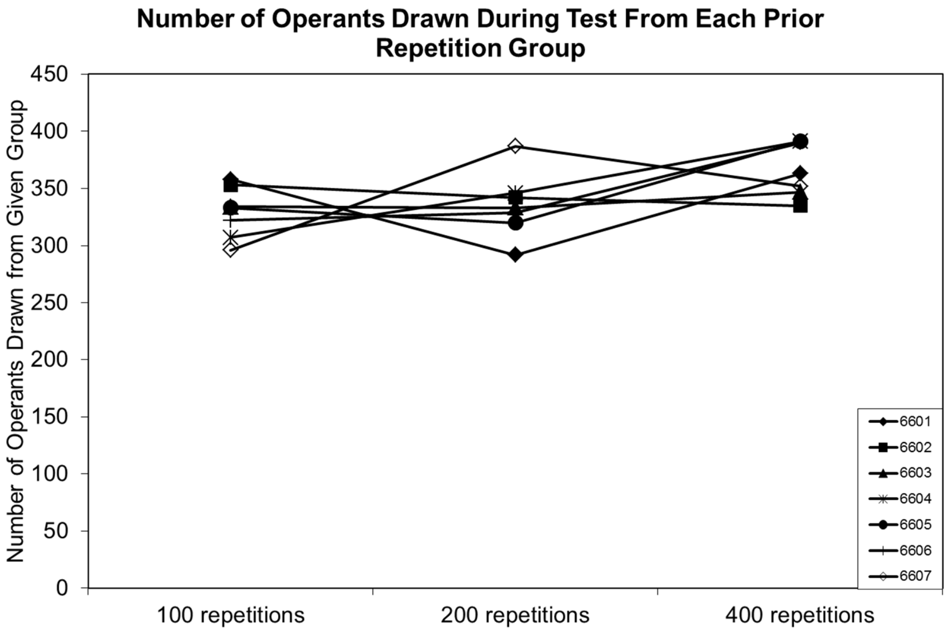

Figure 12. Results of Experiment 3, categorized by number of prior repetitions per operant chosen.

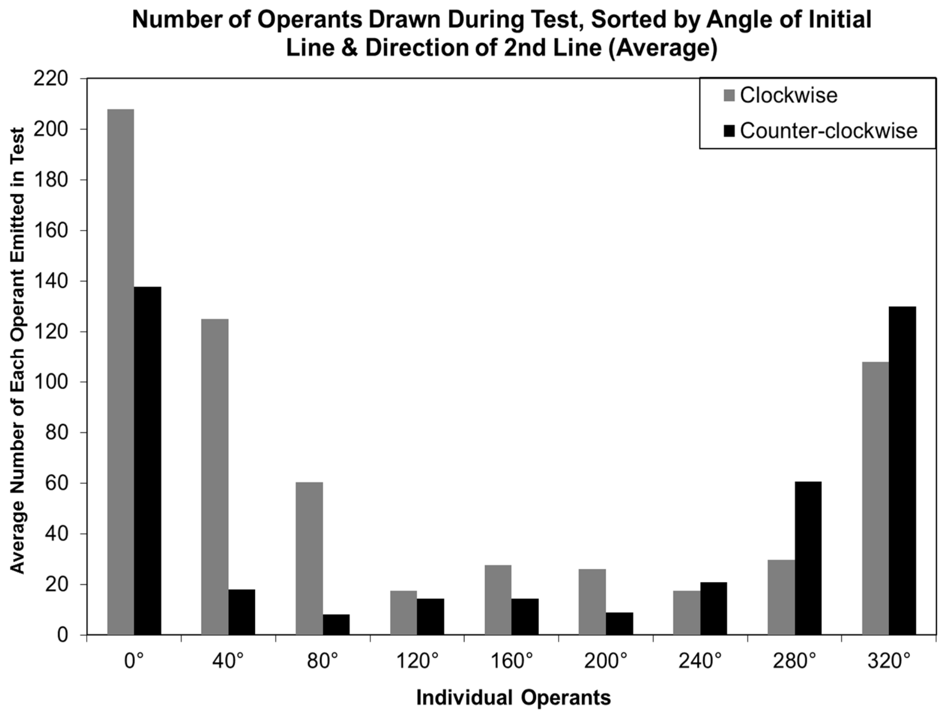

Figure 13. Results of Experiment 3, categorized by angle of initial line relative to the participant's own body and direction of second line around the circle of targets on the computer screen.

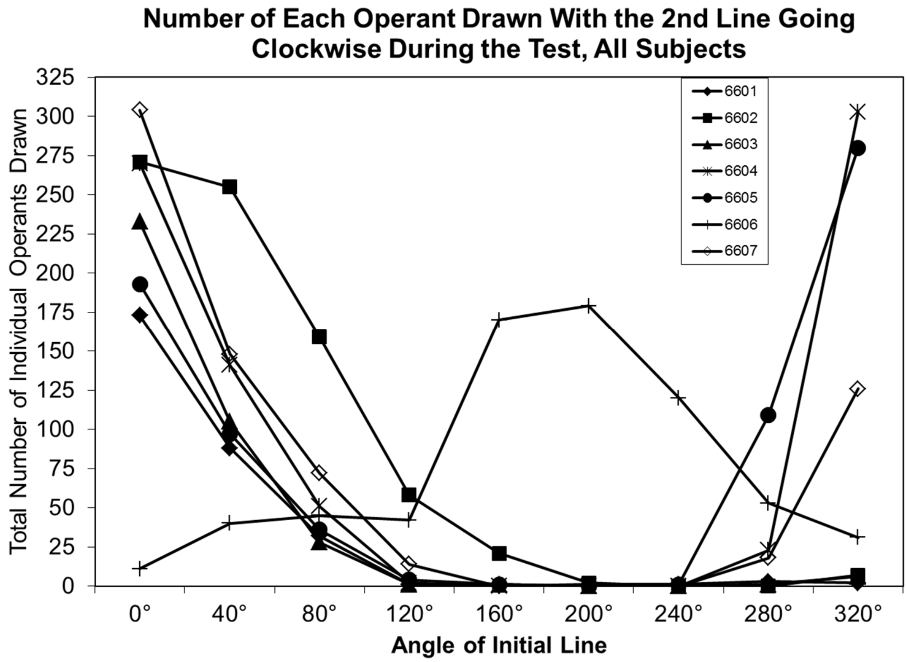

Figure 14. Individual data showing number of times each of the nine clockwise operants was chosen by each of the 7 participants during the test session of Experiment 3.

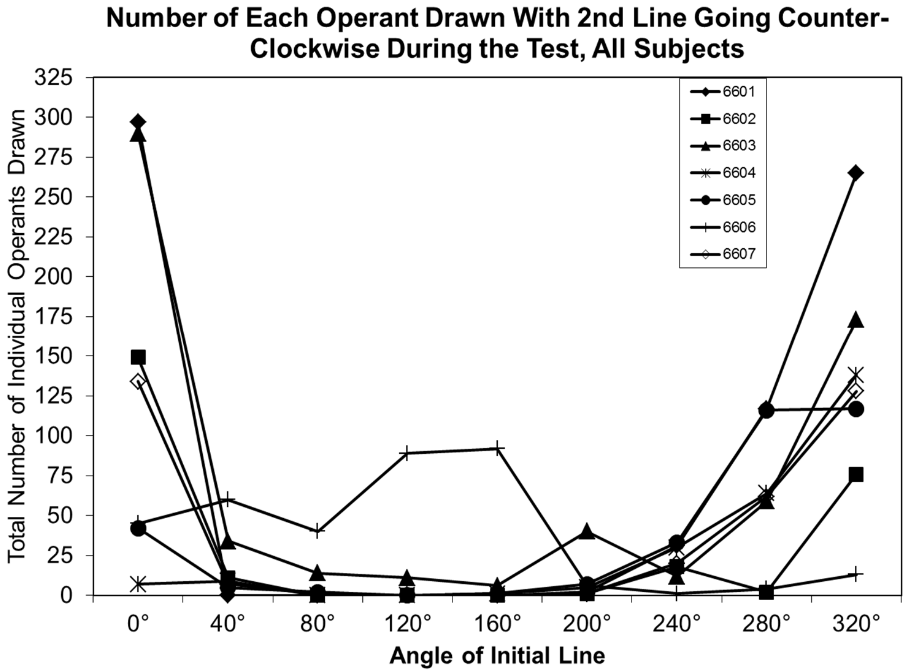

Figure 15. Individual data showing number of times each of the nine counter-clockwise operants was chosen by each of the 7 participants during the test session of Experiment 3.

the rise in the curve of the counter-clockwise function in the 160 to 240 degree range is not present in this experiment. The individual data is shown in Figures 14 and 15.

Interestingly, six of the seven participants were right-handed and thus required to draw with the left hand. One of the participants was left-handed and thus required to draw with his right hand. However the left-handed participant is *not* 6606, as one might assume, but rather participant 6607, whose operant biases appear indistinguishable from the overall data trend.

Discussion

Even when required to draw with their non-dominant hand, human participants still show the same distinct operant biases that were observed in the previous experiments in this series, based on the perceptual and kinesthetic aspects of this type of operant. In this case, however, in addition to the neglect of the lower right quadrant observed in Experiment 2, the participants in Experiment 3 demonstrate a distinct neglect of the lower left quadrant as well. Since the perceptual components of Experiment 3 were identical to those of Experiment 2, this bias must be primarily kinesthetic in origin, relating to the discomfort and unfamiliarity of being required to use the non-dominant hand for these motions.

General Discussion

Operant bias in humans is a potentially important field of study for behavior analysts. Most experimental designs in behavior analysis seek to minimize or eradicate the effects of potential bias, for example by attempting to control for it by programming more than one operant for each value of the independent variable, hoping to cancel it out by averaging the data for many subjects, or treating it as a free parameter in a mathematical equation. The present experiments, however, present extensive data on operant bias, the detailed analysis of which makes it possible to classify and understand the biases at a basic behavioral level.

The biases measured and analyzed in this paper apply only to the type of operant behavior under study in these experiments. For example, had these studies been conducted on a tablet computer laid flat in front of the subject, or on a computer with a touchscreen monitor displayed vertically before the subject (thus fusing the two distinct visual and kinesthetic planes which exist in the current studies into one), different biases might well have been observed. The current results are suggestive, however, of the types of systematic biases that may exist in other areas of behavioral research. In order to measure not only the existence of such operant bias but also to dissect and classify it into its component parts, it is necessary to use multiple (more than two) operants that have several measurable dimensions —e.g., "revealed operants" (Mechner, 1994).

It may be that for certain categories of behavior, such as choice among multiple competing alternatives, systematic pre-experimental biases that are not noticeable under other experimental conditions might be found, in both humans and animals, if the relevant dimensions of the operants were examined. For example, almost all potential human research participants have an extensive learning history with the standard circular clock face, around which the hands move in a clockwise direction. Could this be a component of the specific biases found in Experiments 2 and 3, in which participants were required to draw lines either clockwise or counterclockwise between targets arranged in a circle? Likewise, it is also possible that the consistent bias we observed against drawing toward one's own torso can be traced, at least partially, to participants' lifelong history of drawing with materials such as ink, which may smear if the drawing hand is dragged over the line. The present experiments, of course, can provide no evidence for or against either of these history-based interpretations of the data; they are offered merely as examples of possible sources of bias.

The findings reported here also have implications for the design of single-subject experiments intended to allow comparisons among different values of an independent variable. Rather than assume equivalence among stimuli or responses, or assume that possible differences among them can be "averaged out" or neglected, it may be better to accept biases as an inevitable part of the baseline features of the stimuli or operants, and use as the dependent variable the changes in these features that the experiment's intended independent variables produce.

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