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Perceptual Constancies and Visual Selection as Predictors of Realistic Drawing Skill

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Traditionally, two theories have been proposed to understand realistic drawing: (a) a bottom-up perspective emphasizing accurate perception achieved by suppressing perceptual constancies and other sources of misperception, and (b) a top-down view emphasizing knowledge-facilitated selection of information important for object depiction. This study compares the predictive validity of the two. Artists and nonartists completed tasks measuring the ability to suppress shape and size constancies, a limited line-tracing task measuring visual selection performance, and a freehand drawing task assessing realistic drawing ability. Evidence is reported that shows both bottom-up and top-down factors are associated with drawing accuracy. Artists outperformed nonartists on drawing and limited-line tracing accuracy and made smaller size (but not shape) constancy errors; drawing accuracy was positively correlated with limited-line tracing and negatively correlated with size-constancy errors in a depth cue condition. We propose integrating the two traditional approaches into a unified perspective emphasizing visual attention, rather than early perception, in explaining drawing accuracy.

Keywords: visual art, drawing skill, artists, visual perception, aesthetic judgment

Artists and nonartists differ profoundly in their ability to create realistic drawings. How can this disparity be explained? To what extent do various psychological processes or strategies contribute to representational drawing skill? Since the process of realistic drawing starts with acquiring visual information from the environment, artists, art historians, and psychologists have primarily focused on perceptual processing in explaining individual differences in drawing accuracy (e.g., Arnheim, 1954; Cohen & Bennett, 1997; Cohen & Jones, 2008; Fry, 1919/1981; Gombrich, 1960; Kozbelt, 2001; Kozbelt & Seeley, 2007; Mitchell, Ropar, Ackroyd, & Rajendran, 2005; Ruskin, 1857/1971; Schlewitt-Haynes, Earthman, & Burns, 2002; Thouless, 1932).

A widely accepted view of visual processing is that our perception of the world results from an interaction between "bottom-up" and "top-down" processes. In line with traditional definitions of these two concepts, bottom-up vision refers to perceptual processing that is exclusively derived from immediate sensory information processed by the retinal photoreceptors. In contrast, top-down vision is defined as perception that is influenced by additional cognitive processes that go beyond processing the raw sensory signal received by the retina. Examples of such mental processes include endogenous attention that actively selects what sensory information is to be attended to or ignored, as well as the integration of visual long-term memories into the final percept of information gathered by the senses.

By analogy, two major sets of explanations for realistic drawing ability have been advanced, differentially focusing on the importance of bottom-up versus top-down processing in explaining why some individuals are able to create highly accurate drawings and others are prone to making substantial drawing errors. In this article, our goal is to compare the extent to which measures of bottom-up versus top-down processing predict realistic drawing skill. To our knowledge, no previous empirical investigation has directly examined this question—in part because advocates of the bottom-up and top-down views have historically divided themselves into opposing camps. In the course of addressing this issue, we first outline the history and psychological nature of bottom-up and top-down accounts of skilled drawing.

Bottom-Up Accounts of Drawing Skill

The bottom-up view emphasizes artists' departure from a default mode of seeing, which is characterized by the well-established principle that everyday perception is highly influenced by unconscious inferences made by the visual system (Helmholtz, 1867/1962). Such inferences can lead to perceptual transformations of the sensory signal, such as when individuals experience perceptual "constancies," where transient sensory variation is minimized into a stable percept of an object's shape, size, color, luminance, and so forth. A bottom-up perspective of drawing

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assumes that such transformations are not only enacted on the visual information supporting conscious perceptual judgments but also enacted on the visual information supporting drawing behaviors. Following this idea, the accuracy of observational drawings is argued to be intimately tied to perceptual judgment accuracy. Cohen and Bennett (1997) promoted this notion by hypothesizing that the major contribution to drawing errors is misperception of the model being drawn. Conversely, this view posits that skilled artists are able to process visual information in such a way as to reduce drawing errors via the reduction of perceptual transformations made on the sensory input.

There is some empirical evidence that artists are less susceptible to perceptual constancies than are nonartists. Perhaps the earliest was provided by Thouless (1931, 1932), who suggested that perceptions of the size and shape of objects *regress* to the real object. Thouless (1931) found that observers systematically misperceive object size, regularly judging farther objects as larger than their retinal projection would indicate; this demonstrates the effects of a scaling mechanism that is influenced by the presence of depth cues. Presumably, the function of this mechanism is to prevent an observer from judging the physical size of an object as changing as the size of its retinal projection varies as a function of its moving closer or farther away from the observer. He observed a similar constancy for shape perception: When asked to copy a circle seen at an angle, which projects to the retina as an ellipse, participants systematically drew the shape as more circular than it appeared, again showing that perception emerges through an interaction between retinal appearance and viewpoint-invariant object representations (for similar results, see Hammad, Kennedy, Juricevic, & Rajani, 2008). Interestingly, Thouless (1932) reported that trained artists showed smaller constancy effects, though they did not completely disappear.

More recent research has corroborated many of these basic findings on perceptual constancies and, more specifically, their relation to drawing accuracy. For example, Cohen and Jones (2008) had participants view images of a window embedded in a brick wall from various perspectives and match the shape of the window to a set of parallelograms. A negative correlation between freehand drawing accuracy and the degree of shape-constancy errors was observed, suggesting that accurate drawing is related to suppressing shape-constancy processes. A similar conclusion was reached by Mitchell et al. (2005), who utilized the Shepard illusion (Shepard, 1990). When one is presented with two identically-sized parallelograms side-by-side where the vertical and horizontal lines of each differ in size, two illusory effects are commonly experienced. First, the larger sides are perceived to be longer when they are vertically oriented as opposed to when horizontally oriented, even though they are the same objective length. Second, when equated in size, the shorter sides are commonly reported to be longer when oriented vertically relative to when they are oriented horizontally. Further, the illusion that vertically oriented lines are longer than their equal-in-size horizontal counterparts is exaggerated when the parallelograms are presented as tabletops with legs attached to the corners as opposed to when they are presented as abstract geometrical shapes without any additional attachments. Mitchell, et al. (2005, Experiment 2) presented their participants with both the tabletop and non-tabletop versions of the Shepard stimuli and asked them to draw them and provide perceptual estimations of the side lengths. Misperceptions of the lengths of the figures were positively correlated with drawing inaccuracies, with a stronger effect in the table condition (see also Lee, 1989). To summarize, these studies provide support for the hypothesis that drawing accuracy is associated with the accuracy of bottom-up perceptual processing, and that drawing errors largely result from the interference of perceptual constancies and other sources of misperception of the available sensory information.

However, despite empirical support, the bottom-up view has not been universally accepted as an adequate account of skilled drawing in both the art historical and psychological research literature (Gombrich, 1960; Kozbelt & Seeley, 2007; Kozbelt, Seidel, El-Bassiouny, Mark, & Owen, 2010), and it arguably raises at least as many questions as it answers. What is the scope of situations where perceptual constancies might be overcome (or not)?[1] Does inhibiting perceptual constancies benefit all aspects of drawing or mainly, say, establishing objects' correct basic proportions? How is visual attention deployed throughout the drawing process and how does that impact accuracy? Finally, because the operationalization of the bottom-up view has focused so strongly on early perceptual processing, other stages of drawing, including the translation of a perceptual representation into a motor plan for rendering, have largely been ignored. Arguably, this has yielded an impoverished and potentially biased empirical understanding of the psychological nature of skilled drawing. All of these issues suggest deep problems with a purely bottom-up account—problems that an alternative top-down account of drawing skill directly addresses.

Top-Down Accounts of Drawing Skill

The top-down view of skilled realistic drawing argues that knowledge-driven influences can facilitate, rather than merely interfere with, perception and drawing accuracy; in its pure form, it is thus strongly opposed to the bottom-up view. The top-down position is most closely associated with art historian E. H. Gombrich (1960; see also Kozbelt & Seeley, 2007). In brief, Gombrich (1960) argued that the inverse problem in vision, whereby a retinal image can arise through an infinite number of possible configurations of real-world objects, applies to realistic drawing as well. When artists render a realistic depiction of a three-dimensional world on a two-dimensional surface, some information must be lost and other information emphasized to convey the illusion of three-dimensional form and space. In Gombrich's (1960) view, artists achieve this goal not by suppressing what they know but rather by harnessing their knowledge of the structure of appearances, in order to meet their depictive goals.

Abundant research has established that not all visual information provided by an object is equally important for efficient recognition. To cite just one key example, viewpoint-invariant "nonaccidental properties," like the vertices connecting and organizing an object's parts, are important for object identification, in contrast to, say, the midsegments of lines (Biederman, 1987). Gombrich's

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[1] Cohen and Bennett (1997) proposed that training could help overcome perceptual "delusions" resulting from reliance on object knowledge rather than object appearance but not perceptual "illusions" resulting from lower-level processes like lateral inhibition. However, a careful test of the scope of the ability to overcome various perceptual constancies, across a range of relevant stimuli, has not, to our knowledge, been undertaken.

(1960) argument implies that artists should be superior to nonartists at identifying and selecting the most relevant information to include in a depiction, to facilitate the illusion of three-dimensionality and promote object recognition. Indeed, Kozbelt (2001) suggested that artists might spontaneously emphasize such nonaccidental properties in depictions. Similarly, Kozbelt and Seeley (2007; Seeley & Kozbelt, 2008) proposed a model of artists' advantages in drawing and visual perception whereby the top-down influences of object knowledge and motor priming direct the deployment of selective visual attention to the most relevant information in a to-be-drawn object. Kozbelt and Seeley (2007) also noted that artists' use of such properties echoes that of the visual system more generally, since both need to solve versions of the inverse problem to fulfill their computational goals.

Despite the logical coherence of Gombrich's (1960) argument, until recently, little direct laboratory evidence supporting artists' superiority in visual selection in a drawing context had been found. For instance, Cohen and Bennett (1997), exploring several possible sources of drawing inaccuracies in a series of experiments, ruled out wise representational decisions as a major factor influencing drawing accuracy, instead attributing most drawing errors to misperceiving the to-be-drawn object—as in the bottom-up view. However, more recent research using a novel limited-line tracing task (Kozbelt et al., 2010, Study 1) has provided support for the importance of top-down visual selection. Specifically, artists and nonartists were asked to trace a photograph of a face using a small number of pieces of tape—not enough to trace everything, so participants had to choose which aspects of the face to include. Drawings were judged for accuracy by artists and nonartists. Artists strongly outperformed nonartists, especially when another sample of artists acted as judges. Since this tracing task controls for a host of potential methodological confounds involved in assessing visual selection, by eliminating many processes engaged when individuals make freehand drawings (such as proportion estimation, visual memory, decisions as to how many lines to include in the representation, familiarity with the drawing medium, etc.), the results strongly indicate that artists and nonartists differ in their ability to select what information is most important in realistically depicting a face. Consistent with Gombrich's (1960) view, this finding can be interpreted as demonstrating that artists' skill in realistic drawing is associated with top-down perceptual processing, where specialized knowledge guides the selection of information most diagnostic for recognition.

However, this conclusion is only speculative, in that the relationship between the accuracy of limited-line tracings and freehand drawing accuracy has not been directly assessed. Moreover, Kozbelt et al.'s (2010) use of a face as a stimulus is potentially limited in its generalizability, since faces appear to be processed differently than many other kinds of objects (e.g., Tanaka & Sengco, 1997). Therefore, it remains an open question as to the extent to which the selection process measured by a limited-line tracing task actually relates to freehand drawing accuracy—and if so, how the strength of its effect compares to widely used bottom-up indices like overcoming perceptual constancies.

The Present Study

To date, there appears to be some evidence for both bottom-up and top-down strategies influencing drawing accuracy. However, to our knowledge, no investigation has simultaneously compared their predictive power, using samples of artist and nonartist participants. In the present study, we aim to do precisely that. We rather narrowly define bottom-up processing using shape and size perceptual constancy measures and top-down processing using measurements derived from Kozbelt et al.'s (2010) limited-line tracing task—at the same time acknowledging that additional bottom-up and top-down perceptual factors and measures may contribute to drawing skill. Thus, rather than globally or exhaustively comparing bottom-up and top-down contributions to realistic drawing ability, we aim to compare the relative predictive power of previously used tasks assessing bottom-up and top-down factors, in terms of freehand drawing accuracy.

We administered a number of tasks to measure susceptibility to perceptual constancies (our defined "bottom-up" index), visual selection (our defined "top-down" index), and an ecologically valid freehand drawing task. Size- and shape-matching tasks were used to measure perceptual constancies, along the lines of earlier research (e.g., Cohen & Jones, 2008; Hammad et al., 2008; McManus, Loo, Chamberlain, Riley, & Brunswick, in press; Mitchell et al., 2005; Thouless, 1931, 1932). The size-matching task requires participants to equalize the size of two circles shown either in a perspective depth condition or in a flat nondepth condition, with the expectation that errors would be greater in the depth condition (along the lines of Thouless, 1931). Previous research using this set of stimuli has demonstrated that nonartist participants reliably judge a target perceived to be at a substantial distance from the observer to be larger in size than it actually appears in the depth cue condition (Murray, Boyaci, & Kersten, 2006). The shape-matching task requires participants to match a target trapezoid, again shown in either a perspective depth condition or in a flat nondepth condition, to one of a set of reference trapezoids, again with the expectation that errors would be greater, as well as biased toward greater rectangularity, in the depth condition relative to the nondepth condition (see Mitchell et al., 2005; McManus et al., in press). According to the bottom-up view, artists should produce smaller size- and shape-constancy errors than nonartists, especially in the depth conditions. Further, across participants, the magnitude of constancy errors should be negatively correlated with judged freehand drawing accuracy, if the experience of perceptual constancies is related to drawing accuracy.

The top-down index consisted of a limited line-tracing task, as previously described, to measure astute visual selection. Rather than a face, here an elephant was used as the tracing stimulus, to probe the generalizability of Kozbelt et al.'s (2010) findings. In line with the top-down view of Gombrich (1960) and Kozbelt and Seeley (2007), we expect that artists will produce more accurate tracings than nonartists and that tracing accuracy will be positively correlated with freehand drawing accuracy. Correlations between the perceptual constancy tasks and the limited-line tracing task are open questions. Most importantly, we will compare the relative contributions of the perceptual constancy and visual selection tasks in predicting freehand drawing accuracy in correlational and regression analyses.

Method

Participants

Forty-eight individuals participated. Fifteen (3 males, 12 females) were artists, defined as undergraduate art majors, graduate students in studio art, or professional artists, all with extensive experience in drawing; 33 (11 males, 22 females) were nonartists, all undergraduate nonart majors with no observational drawing experience, *M* (*SD*) age = 23.1 (4.3) years and 20.7 (4.3) years, for artists and nonartists, respectively. Artists were recruited by announcements in the Brooklyn College art department, by online postings, and by referrals from other participants and were each paid $20. Nonartists were recruited through the psychology department subject pool and received credit for participating.

Overview of Tasks

After receiving a brief verbal overview of the study and providing informed consent, all participants completed two perception tasks and two drawing tasks. Both perception tasks were presented on an Apple iMac computer with a 17-in monitor. The two drawing tasks used physical materials (i.e., they were not done on the computer). Task order and conditions within each of the two perception tasks were counterbalanced across participants.

Size-Matching Task

In a size-matching task (similar, though not identical, to that used in Murray et al., 2006), participants saw two circles on the computer screen. The upper circle was always the target, and participants were instructed to use arrow keys on the computer keyboard to manipulate the size of the lower circle to match the size of the target. Participants were explicitly instructed to focus on matching the actual size of the circles—that is, if they were measured on the computer screen—rather than their interpretation of their size.

Two conditions were tested. In the *depth condition* (Figure 1, upper left), the circles were shaded to suggest spherical forms and were presented against a textured, converging perspective background to give the illusion that the upper target circle was more distant than the lower circle. To the extent that viewers are unable to overcome perceptual constancies, the manipulated circle should be made larger than the target circle, to offset the perceptual interpretation that a more distant object of approximately equal retinal size should itself be physically larger.

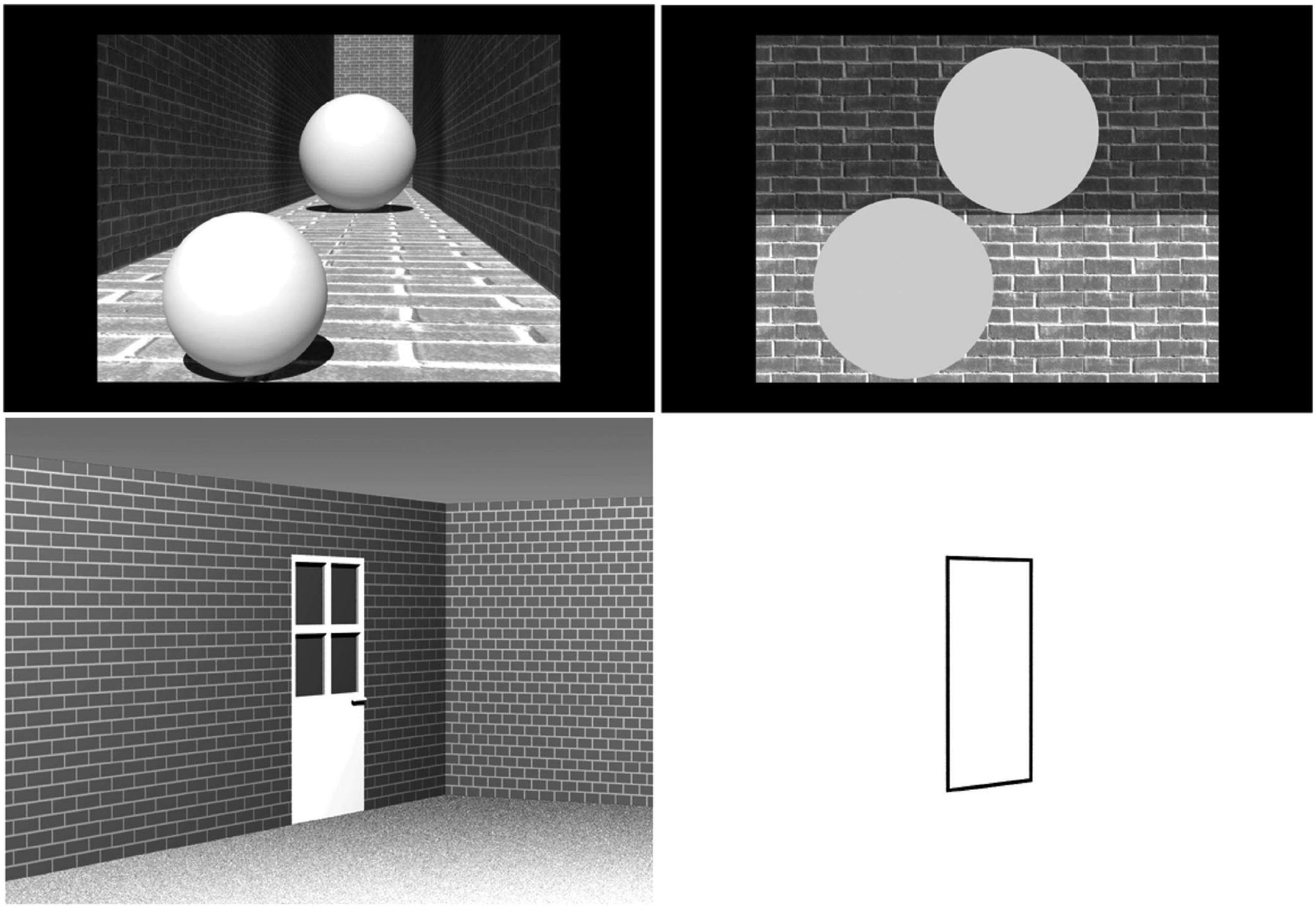

Figure 1. Example stimuli for the size-matching (top) and shape-matching (bottom) tasks. In each case, the depth condition is shown on the left and the nondepth condition on the right.

In the *nondepth condition* (Figure 1, upper right), both circles were shown in a uniform shade of gray matching the overall value of the spheres in the depth condition. The background likewise maintained the same contrast of light and dark and included a similar texture as the depth condition; however, no depth cues were present. Here, participants could conceivably cheat by simply counting bricks to match the diameters of the circles; to minimize the use of this strategy, participants were instructed at the outset of the task to only use the size of the spheres as a reference and not to use any other strategy, such as brick counting, thumb measurement, and so forth. Moreover, during the task, participants were closely monitored to make sure that their response times were faster than it would take to count and compare the bricks; participants whose response times seemed too slow were sternly reminded of the instructions.

Each condition was tested as a separate block: 50 trials in the depth condition and 25 trials in the nondepth condition, with condition order counterbalanced across participants. To facilitate analyses, in each condition, the target was always one of five standard sizes (156, 208, 260, 212, and 364 pixels in diameter—10 trials each for depth condition and 5 trials each for nondepth condition—within each block, presented in a random order). On each trial, error scores were computed based on the diameter of the two circles using the number of pixels as the unit of measure—specifically, by dividing the diameter of the manipulated circle by the diameter of the target circle (as in Murray et al., 2006). An error greater than 1 indicates a bias to see the target circle as larger; higher scores indicate larger errors in the direction predicted by the bottom-up view outlined earlier, which emphasizes perceptual constancies.

Shape-Matching Task

In a shape-matching task (derived from McManus et al., in press; cf. Cohen & Jones, 2008), participants saw a trapezoid shape on the computer screen and had to match its shape to one of 23 trapezoids shown on a printed 8.5- × 11-in reference sheet. The 23 trapezoids represented possible views of a rectangular "door" seen at 4-degree increments subtending a 90-degree quadrant: 90 degrees, 86 degrees, and so forth, to 2 degrees. Trapezoids on the reference sheet were shown in order from the most rectangular to the least rectangular across three rows; from top right to bottom left, they were numbered 1 to 23 or 23 to 1, depending on the version of the sheet.

As with the size-matching task, both depth and nondepth conditions were tested. In the *depth condition* (Figure 1, lower left), each trapezoid was presented in the guise of a door seen at an angle in one-point perspective. To the extent that viewers are unable to overcome perceptual constancies, the trapezoid interpreted as being seen in depth should be perceived as more rectangular than it veridically appears on the retina, as the result of conceptual interference of a viewer's knowledge of the usual shape of doors. In the *nondepth condition* (Figure 1, lower right), each trapezoid was shown without any perspective context, as a simple black outline against a white background, just as on the reference sheet.

Each condition consisted of five trials. As with the size-matching task, to facilitate analyses, in each condition, the targets were always one of five standard shapes, at 24, 36, 48, 60, and 72 degrees. To avoid potential repetition effects related to the reference sheet, each participant received a different version of the reference sheet across the two conditions. Condition order and reference sheet version were counterbalanced across participants. On each trial, error scores were computed based on the difference in viewing angle between the target shape and the chosen shape; an error greater than 0 indicates a bias to see a trapezoid as more rectangular. As with the size-matching task, higher scores reflect larger errors in the predicted direction.

Limited-Line Tracing Task

The limited-line tracing task, derived from Kozbelt et al. (2010), emphasized participants' ability to select the most important information to include in a depiction. The stimulus was a grayscale photograph of an elephant.[2] The photo was chosen because of its complex quality, containing numerous details of line, lighting, shading, and texture. The photo measured 6 × 7 in and was printed on a sheet of white 8.5- × 11-in paper. For the tracing task, the photo was placed inside a clear plastic folder.

Participants created depictions by tracing over the photo directly onto the folder. Participants did not use pencil or marker to create the tracings; instead, each participant was given 30 short pieces of dark brown tape with which to make a tracing. Each segment measured 2 cm × 2 mm (as in Kozbelt et al., 2010). A piece of white 8.5- × 11-in paper was available for sliding between the tracing and the photograph, so participants could see their tracing without interference from the photo underneath. The task was extensively pilot tested to determine an appropriate number of line segments to avoid both floor and ceiling effects. Thirty segments appeared to be enough to make a potentially interesting tracing and to permit a wide range of depictions, but not enough to convey all of the information in the photo. As noted above, the availability of a limited number of line segments is an important methodological control, intended to force participants to make careful choices about what aspects of the photo to include in the tracing, along the lines of Gombrich (1960). As can be seen in Figure 2, participants produced a wide variety of depictions.

Participants were instructed to use the available line segments to create a tracing that was as accurate as possible, given the constraints of the medium. Accurate realism, rather than creativity, was explicitly emphasized. Participants were required to use all 30 pieces of tape. They could bend a segment if they liked but could not tear it into smaller pieces; they could also move a piece of tape after having used it in the tracing if they decided it would go better somewhere else. A 15-min time limit was imposed.

Freehand Drawing Task

The other drawing task served as an ecologically valid of general drawing ability. In this task, each participant made a freehand pencil drawing on paper from a grayscale photograph of

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[2] An image of the photo may be found at *http://commons.wikimedia.org/wiki/File:Asian_elephant_-_melbourne_zoo.jpg*

Figure 2. Eight limited-line tracings of a photograph of an elephant. Four high-rated tracings comprise the top row; four low-rated tracings comprise the bottom row.

an octopus,[3] with a 15-min time limit. The photo was chosen for the same reasons as the photo of the elephant in the limited-line tracing task. The photo measured 6 × 7.75 in and was printed on a sheet of white 8.5- × 11-in paper. Participants were encouraged to draw as realistically as possible, using line, shading, erasures, and so on. Again, accurate realism, rather than creativity, was explicitly emphasized. As can be seen in Figure 3, participants again produced a wide variety of depictions.

Judgment Tasks

Unlike the two perception tasks, which could be scored objectively, performance in the freehand drawing and limited-line tracing tasks requires the consensual assessment of qualified outside judges (see Amabile, 1982). Previous research has demonstrated substantial differences in the results obtained by having expert artists versus nonartists assess artistic drawings, even when putatively objective "accuracy," rather than value-laden "creativity," is the criterion. Importantly, artist judges appear to be more sensitive to meaningful differences and nuances between the work of artists and nonartists (Kozbelt et al., 2010; see also Kaufman, Baer, Cole, & Sexton, 2008; Kozbelt & Serafin, 2009).[4]

In the present study, three individuals with extensive experience in observational drawing each independently rated the overall accuracy of each drawing and tracing relative to its source photograph. Ratings were made on an 8-point Likert scale, with 1 representing very low accuracy and 8 representing very high accuracy. Raters were blind to the identity and group membership of the participant who created each drawing and tracing. The drawings and tracings from each task were presented to raters in a randomized order. In both tasks, the ratings of the three judges were reliably correlated: For the limited-line tracing task, the internal consistency of the ratings, assessed by Cronbach's alpha, was .83; for the freehand drawing task, Cronbach's alpha was .93.

In separate rating sessions, two judges with extensive drawing and painting experience also coded each limited-line tracing, in terms of the numbers of four different categories of vertices: L-junctions, forks, arrows, and T-junctions (Biederman, 1987). Such vertices are essential for defining three-dimensional form in a line drawing medium—as also noted in art instruction books (e.g., Hamm, 1963)—and they are among the nonaccidental properties that facilitate the recognition of objects over a range of viewpoints. The stimulus photograph of the elephant contained ample opportunities for suggesting three-dimensionality, for instance, in terms of the articulation of the limbs relative to the torso, or the ears, tusks, and trunk relative to the head.

For each category, a count of the number of such vertices was made; coding reliability was very high, $r(46) > .90$, $p < .001$, in each case. Discrepancies were resolved by averaging scores. Moreover, among the four types of vertices, only forks and arrows were themselves reliably correlated, $r(46) = .40$, $p = .005$; no other correlations were even marginally ($p < .10$) reliable. Given the relative independence of the four categories, each was analyzed separately.

Results

Results are structured as follows. First, data from the size-matching and shape-matching tasks are analyzed, in terms of

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[3] An image of the photo may be found at *http://www.theoceanproject.org/newsletter/April_2006/9.jpg*

[4] Though it may be premature to conclude that artists' accuracy ratings are in any sense "better" than those of nonartists, since a careful comparison of each group's accuracy ratings to any objective metric of accuracy has not, to our knowledge, been performed.

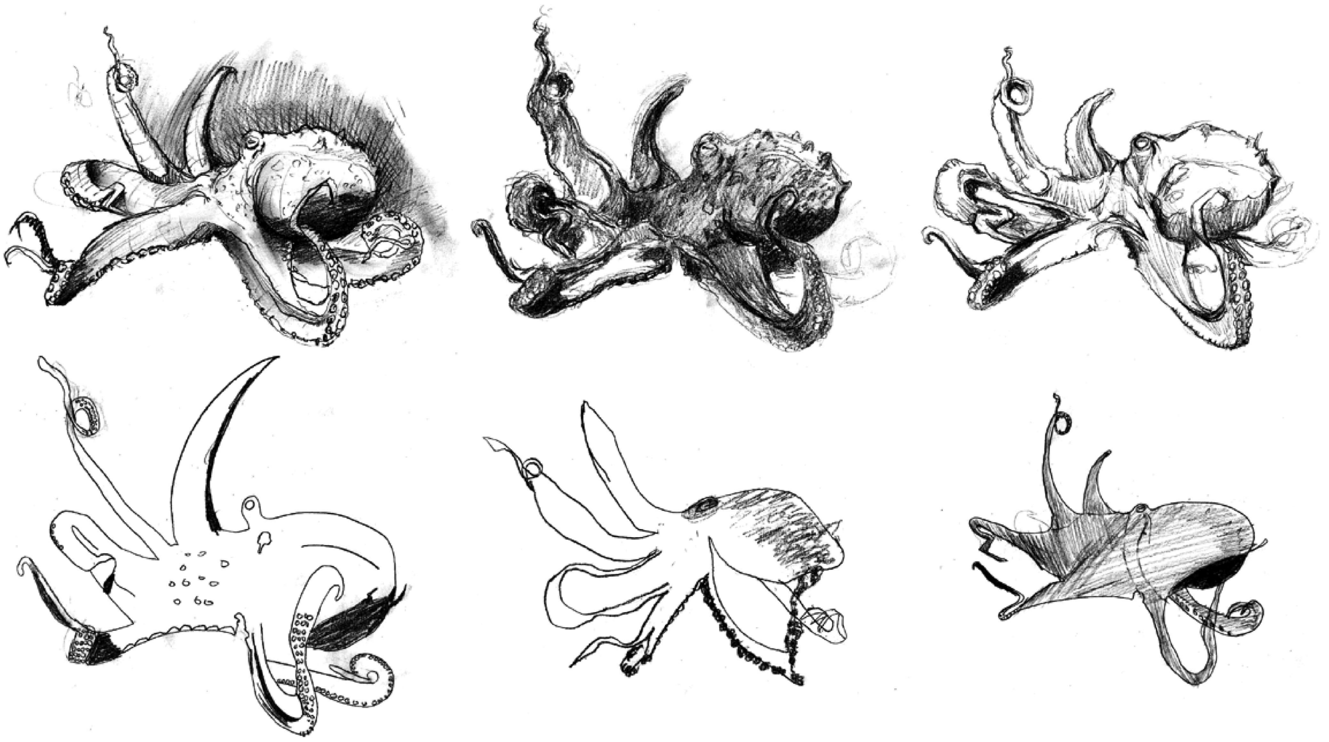

Figure 3. Six freehand drawings of a photograph of an octopus. Three high-rated drawings comprise the top row; three high-rated drawings comprise the bottom row.

differences between conditions and between artists and nonartists, as well as performance across different stimuli within each task. Next, group differences on the limited-line tracing and freehand drawing tasks are analyzed. Then, correlations among the tasks are reported, leading to a regression analysis predicting freehand drawing accuracy using the other tasks. Finally, we analyze the frequency artists' and nonartists' use of different types of vertices in the limited-line tracing task.

Size-Matching Task Performance

Data for the size-matching task were analyzed using a 2 (Group: Artist vs. Non-Artist) × 2 (Condition: Depth vs. Nondepth Cue) × 5 (Target Size: 156 vs. 208 vs. 260 vs. 312 vs. 364 pixel diameter) mixed-model ANOVA, to test for effects on size-matching errors. Cell means are represented in Figure 4. A significant main effect of group, $F(1, 47) = 12.17$, $p < .01$, partial $\eta^2 = .21$, was observed, indicating that, overall, artists produced smaller errors than nonartists. A significant main effect of condition, $F(1, 47) = 361.86$, $p < .001$, partial $\eta^2 = .89$, was also found, indicating that larger errors were produced in the depth cue condition, where participants reliably erred in judging the target sphere to be larger than it appeared compared with nondepth cue condition. Also, a main effect of target size, $F(1, 188) = 161.86$, $p < .001$, partial $\eta^2 = .78$ was observed, indicating that smaller errors were made on the trials where the target size was larger compared with small target size trials.

Significant Target × Group, $F(4, 188) = 4.06$, $p < .05$, partial $\eta^2 = .079$, Condition × Group, $F(1, 47) = 7.81$, $p < .01$, partial $\eta^2 = .14$, and Target × Condition, $F(4, 188) = 129.07$, $p < .001$, partial $\eta^2 = .73$, two-way interactions were observed. Finally, a significant Target × Condition × Group three-way interaction was found, $F(4, 188) = 3.44$, $p < .05$, partial $\eta^2 = .07$.

Follow-up 2 (Group: Artist vs. Non-Artist) × 2 (Condition: Depth vs. Nondepth Cue) quasi-*F* tests were conducted at each level of target size to explain the three-way interaction. A

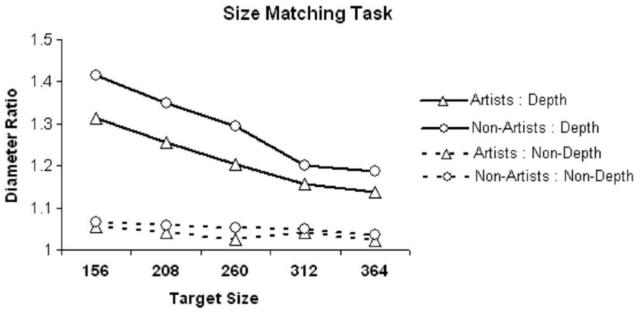

Figure 4. A comparison of artists (triangles) and nonartists (circles) in their performance on the depth (solid lines) and nondepth (dashed lines) cue conditions of the size-matching task. Participants' performance was calculated as the ratio between the sizes of the manipulated and target spheres/circles. A value of 1 indicates that the manipulated and target sizes were equal, and a value greater than 1 indicates that the manipulated sphere/circle was made larger than the target sphere/circle. This ratio is plotted as a function of the five different target sizes, measured as the diameter in pixels.

significant Group × Condition interaction was found at target size 156, $F(1, 165) = 13.23$, $p < .001$, target size 208, $F(1, 165) = 9.76$, $p < .01$, and target size 260, $F(1, 165) = 6.93$, $p < .01$. A reliable Group × Condition interaction was not observed at target size 312, $F(1, 165) = 2.21$, and target size 364, $F(1, 165) = 2.21$, both $ps > .05$. Follow-up Scheffé tests at target sizes 156, 208, and 260 indicated that artists produced reliably smaller errors than nonartists in the depth-cue condition (all $ps < .001$), but no reliable differences between the groups were observed in the nondepth cue condition (all $ps > .05$).

Shape-Matching Task Performance

An isomorphic 2 (Group: Artist vs. Non-Artist) × 2 (Condition: Depth vs. Nondepth Cue) × 5 (Target Viewing Angle: 24 vs. 36 vs. 48 vs. 60 vs. 72 degrees) mixed-model ANOVA was conducted to test for effects on shape-matching errors. Cell means are represented in Figure 5. No significant main effect of Group was observed, $F(1, 47) = 1.63$, *ns*, partial $\eta^2 = .001$, indicating that artists and nonartists did not differ in the magnitude of their shape-matching errors. A significant main effect of Condition was observed, $F(1, 47) = 68.95$, $p < .001$, partial $\eta^2 = .67$, indicating that more shape-matching errors were made in the depth cue compared to nondepth cue condition. These errors are characterized by the participants selecting shapes that were more rectangular than the target. Also, a significant main effect of Target Angle was found, $F(4, 188) = 9.14$, $p < .001$, partial $\eta^2 = .16$.

We observed a significant Condition × Target interaction, $F(4, 188) = 8.70$, $p < .001$, partial $\eta^2 = .16$, but no significant Group × Condition, $F(1, 47) = 1.38$, *ns*, partial $\eta^2 = .03$ or Group × Target interactions were found, $F(4, 188) = 1.66$, *ns*, partial $\eta^2 = .03$. Further, the Group × Condition × Target interaction was statistically reliable, $F = (4, 188) = 3.22$, $p < .05$, partial $\eta^2 = .06$.

In order to follow up on the significant Condition × Target and the 3-way interaction, follow-up Condition × Target quasi-*F* tests were conducted separately for artists and nonartists. A significant Condition × Target interaction was not observed for artists, $F(4, 189) = 0.23$, $p > .05$, but was observed for nonartists, $F(4, 189) = 2.96$, $p < .05$. Follow-up Scheffé tests comparing the shape-matching errors made in the depth and nondepth cue conditions at each target angle indicated that more shape-matching errors were made in the depth cue condition compared with the nondepth cue condition at target viewing angles 36, 48, 60, and 72 (all $p < .05$), but no difference between conditions was observed for target viewing angle 24 ($p > .05$).

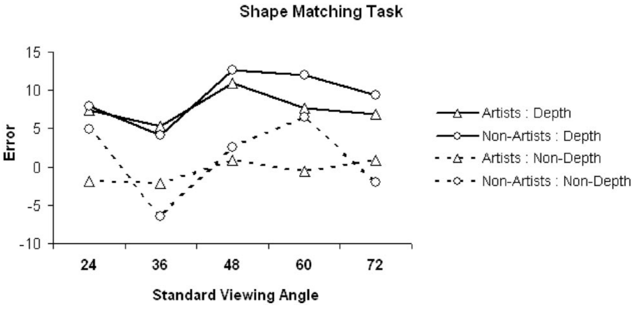

Figure 5. A comparison of artists (triangles) and nonartists' (circles) errors in the depth (solid lines) and nondepth (dashed lines) cue conditions of the shape-matching task. Participants' errors were measured as the difference in viewing angle degrees between the selected and target shapes. A value of 0 indicates a perfect match, whereas a positive value indicates that the participant selected a shape that was more rectangular than the target shape and a negative value indicates a choice more skewed than the target. Errors are plotted as a function of the viewing angle, in degrees, of the target shape.

Limited-Line Tracing and Freehand Drawing Task Performance

To assess performance differences between artists and nonartists, as well as the influence of individual raters, data from the limited-line tracing and freehand drawing tasks were analyzed as mixed-model ANOVAs, with individual raters as the repeated-measures variable and participant group (artist vs. nonartists) as the between-subjects variable. (To reduce potential error variance arising from individual differences in the harshness of judges, each judge's ratings were *z*-transformed prior to the analyses.) On both tasks, large performance differences between artists and nonartists were found. For the limited-line tracing task, a main effect for group was found, $F(1, 46) = 8.83$, $p < .01$, partial $\eta^2 = .16$, a large effect size, *M* (*SE*) *z* scores for accuracy = 0.53 (0.21) and −0.21 (0.14) for artists and nonartists, respectively; there was no main effect for rater, $F(2, 92) = 0.42$, *ns*, partial $\eta^2 = .009$, and no interaction between group and rater, $F(2, 92) = 1.38$, *ns*, partial $\eta^2 = .029$. For the freehand drawing task, a main effect for group was found, $F(1, 46) = 34.91$, $p < .001$, partial $\eta^2 = .43$, a very large effect size, *M* (*SE*) accuracy = 0.92 (0.18) and −0.39 (0.13) for artists and nonartists, respectively; there was no main effect for rater, $F(2, 92) = 0.16$, *ns*, partial $\eta^2 = .002$, and no interaction between group and rater, $F(2, 92) = 1.19$, *ns*, partial $\eta^2 = .017$. Thus, in both a tracing task emphasizing astute selection of important visual information and an ecologically valid freehand drawing task, artists showed substantial performance advantages. Since there were no reliable differences among raters on either task, we simply averaged the three ratings to provide a point estimate of the accuracy of each rendering, for use in the correlational and regression analyses described next.

Correlations Among Tasks

To assess the extent to which performance on the various tasks was associated with freehand drawing accuracy, correlations among all tasks were computed. For both perception tasks, data from the depth and nondepth conditions were kept separate. Within each condition of each task, error scores, computed as described previously, were averaged across the five target stimuli, yielding one number for each participant in each condition (depth or nondepth) of each perception task (size or shape matching), with a larger number representing a greater error. Scores in each condition were then converted to absolute values relative to a score representing perfect performance, that is, a

Table 1
Correlations Among Tasks

	1	2	3	4	5	6
1. Size matching: Depth	—	.33**	.05	.16	−.32**	−.39*
2. Size matching: Nondepth		—	−.19	−.09	−.11	−.17
3. Shape matching: Depth			—	.31**	.04	.00
4. Shape matching: Nondepth				—	−.08	−.17
5. Limited-line tracing						.39*
6. Freehand drawing						—

Note. All $df = 46$. Scores for the size-matching and shape-matching tasks are error scores; thus, a negative correlation with freehand drawing indicates an association between better perception performance and more accurate drawing.
$^{*} p < .01$. $^{**} p < .05$.

score of 1 in the size-matching task or a score of 0 in the shape-matching task.[5]

Correlations among the tasks are shown in Table 1. As can be seen, superior freehand drawing performance was associated with more accurate limited-line tracings and smaller errors in the depth condition of the size-matching task, which were themselves also positively correlated. Moderate positive correlations were also found between the depth and nondepth conditions of both the size- and shape-matching tasks, suggesting that performance on each of these tasks was relatively consistent across their depth and nondepth versions. More generally, however, even the statistically reliable correlations in Table 1 are rather moderate. This suggests that the constituent skills of realistic drawing, at least as operationalized here, do not appear to be a particularly unified set; rather, skilled drawing seems to involve a number of loosely associated component abilities. Along these lines, size matching and shape matching were statistically independent, indicating that perceptual constancies are themselves multifaceted.

Predicting Freehand Drawing Performance

The final analysis attempted to predict freehand drawing skill using performance on the other tasks as predictors. Since several variables showed zero-order correlations with freehand drawing, and those variables were themselves correlated, a stepwise regression procedure was used to identify the statistically reliable predictors in a regression context. Freehand drawing performance was the dependent variable; the remaining five measures shown in Table 1 were entered into the stepwise regression model as independent variables.

Two iterations of the stepwise procedure yielded a significant final model, $F(2, 45) = 4.72$, $p = .003$, adjusted-$R^2 = .199$. The results closely echo the correlations reported in Table 1. Performance on the limited-line tracing task was a reliable positive predictor of freehand drawing performance, *Beta* = .297, $t = 2.16$, $p = .036$; errors in the depth condition of the size-matching task showed an equally strong negative relation to freehand drawing performance, *Beta* = −.297, $t = -2.16$, $p = .036$. No other predictors were reliable.

Analyses of Vertices in the Limited-Line Tracing Task

As a postscript to the main analyses, we also explored the extent to which artists and nonartists spontaneously employed four kinds of vertices (L-junctions, forks, arrows, and T-junctions) in their depictions in the limited-line tracing task. Given violations of normality and homogeneity of variances for all but L-junctions, the data were analyzed nonparametrically, using the Mann-Whitney *U* test. The groups showed the strongest difference on T-junctions—arguably the most potent type of junction for suggesting form (see Hamm, 1963)—with artists using reliably more than nonartists, $z = -3.12$, $p = .002$, *M* (*SD*) = 1.25 (1.12) and 0.40 (0.70), for artists and nonartists, respectively. Marginally reliable results, in the same direction, were found for L-junctions, $z = -1.92$, $p = .056$, *M* (*SD*) = 5.43 (2.28) and 3.91 (2.63), and forks, $z = -1.95$, $p = .051$, *M* (*SD*) = 0.31 (0.48) and 0.09 (0.29), for artists and nonartists, respectively, in both cases. No differences were evident in arrows, $z = -1.36$, $p = .173$, *M* (*SD*) = 5.43 (2.28) and 3.91 (2.63), for artists and nonartists, respectively. (Similar results for L-junctions were found when the data were analyzed parametrically.)

Discussion

Evidence Bearing on Bottom-Up and Top-Down Approaches to Drawing Skill

To our knowledge, this investigation is the first to test the relative predictive power of the two traditional explanations of realistic drawing skill: a bottom-up mechanism whereby artists overcome perceptual transformations (Cohen & Bennett, 1997; Cohen & Earls, 2010; Cohen & Jones, 2008; Mitchell et al., 2005) and a top-down mechanism whereby artists harness their knowledge of the structure of appearances to make sound choices about important information to include in a depiction (Gombrich, 1960; Kozbelt & Seeley, 2007; Kozbelt et al., 2010). Some evidence

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[5] The particular scores thus differ somewhat from the data used in the analyses of the perception tasks reported earlier. In those analyses, the *directions* of the errors were of interest, given the predicted bias toward a larger size for the more "distant" sphere in the depth condition of the size-matching task and greater rectangularity in the depth condition of the shape-matching task. However, failure to convert the errors to absolute values distorts the meaning of the scale and, thus, interpretation of the results of correlational and regression analyses; this issue was particularly acute in the nondepth condition of the shape-matching task, where errors hovered on either side of 0 (as can be inferred from Figure 5).

consistent with each account was found. Most notably, performance in the depth condition of the size-constancy task (a bottom-up index) and the limited-line tracing task (a top-down index) showed equally strong relations with freehand drawing performance. Thus, within our narrowly defined top-down and bottom-up indices, drawing accuracy seems equally associated with size-constancy suppression and visual selection processes.

In the regression analysis, these variables accounted for about 20% of the variance in freehand drawing performance, indicating that additional processes undergird observational drawing ability. This multifaceted view of drawing skill is consistent with previous research implicating a host of factors contributing drawing accuracy, such as visual memory (e.g., Cohen & Jones, 2008; McManus et al., 2010) or the process by which a visual representation of the model is translated into the motor command by which the drawing is executed (see Kozbelt & Seeley, 2007; Seeley & Kozbelt, 2008). Future research should investigate a wider scope of cognitive processes related to drawing accuracy.

Bottom-Up Aspects

While a complete understanding of the extent to which bottom-up and top-down processes contribute to drawing skill remains elusive, our results provide some initial constraints on an answer to this fundamental question. For instance, with regard to our bottom-up measures, we found mixed evidence for the claim that early stages of visual processing, specifically the ability to accurately perceive objects without the top-down influence of viewpoint-invariant object representations, are associated with drawing accuracy. On the one hand, artists produced more accurate freehand drawings and made smaller size-constancy errors than nonartists; this suggests that the ability to suppress the contextual influence of depth cues on size perception, and thus perceive size more veridically, is associated with greater drawing skill. On the other hand, our evidence also suggests some qualifications. First, while artists made smaller size-constancy errors than nonartists, they were still unable to completely suppress its effect, since they made larger errors in the depth cue condition than in the nondepth condition (see also Thouless, 1932). Thus, it would be overstated to characterize artists' drawing advantages as a complete overcoming of perceptual transformations of size, as an extreme form of the bottom-up view would hold. Rather, a relatively lower degree of contextual influence on size constancy seems related to accurate drawing.

Second, we failed to replicate results of Cohen and Jones (2008), finding no evidence that shape constancy is related to freehand drawing accuracy. Artists and nonartists performed comparably in the depth condition of the shape-matching task (incidentally replicating a finding by Cohen & Jones, 2008, Experiment 4); both groups also showed the expected shape-constancy effect in the depth versus nondepth conditions. Considering the number of replications of the shape constancy–drawing accuracy relationship reported by Cohen and Jones (2008), our finding of a nonsignificant correlation may appear rather surprising. However, the two studies' methodologies differ in substantial ways. One is the judges used to assess drawing accuracy (nonartists vs. artists), an issue mentioned in the Introduction. Another is the freehand drawing stimulus (face vs. elephant); shape constancy may be more strongly associated with accuracy for drawings of highly familiar visual forms like faces but not with more unfamiliar forms like an octopus (for evidence bearing on qualitative distinctions in processing different visual stimuli, see Gauthier & Tarr, 2002; Tanaka & Farrah, 1993). Another is the shape-matching stimulus. Shape-constancy errors may vary across the particular stimuli used in research thus far—for instance, the photographs of Cohen and Jones (2008) versus the computer-generated images of McManus et al. (in press), which were also used in the present study. A referee noted that in the computer-generated images, the shading depth cues of the floor and ceiling appear to contradict each other, in that the darkest region of the ceiling is "closer" to the observer but the most shaded region of the floor is "farther" from the observer. Such contradictory depth cues could serve to weaken the constancy effect and mask any relationship between drawing accuracy and shape-constancy errors.[6] Yet another potential source of variation concerns the data from shape-matching task used to calculate the correlation with drawing accuracy: Cohen and Jones (2008) used only the condition that elicited the greatest shape-constancy effect, while we used the average of errors across all depth cue conditions.[7]

Although no strong a priori reason can be provided as to why any variation in the settings of these parameters should modulate the relationship between shape constancy and drawing accuracy, these differences in methods and findings raise questions as to the robustness of this relationship. Clearly, future research is needed to systematically explore the effects of shape-constancy task stimulus and parameter variation on the constancy–drawing accuracy relationship in order to better understand the inconsistencies observed across studies. In any case, our results for shape matching are at odds with the idea that freehand drawing accuracy is *robustly* related to perceptual constancy suppression. Our data suggest that both artists and nonartists show susceptibility to perceptual transformations—to a similar extent for shape constancy, and less so, among artists, for size constancy.

Notably, we found that errors in the size- and shape-constancy tasks were not reliably correlated. This would be surprising if one assumed that perceptual constancies of size and shape are generated by a common mechanism. However, there is no reason to assume this, since previous research suggests that shape and size constancy rely on independent perceptual mechanisms. Experimental manipulations of refractive error (Leibowitz, Wilcox, &

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[6] On the other hand, inconsistent vanishing points in Cohen and Jones's (2008) photographic stimuli enhance the variation across the shapes, which may act to inflate the observed relation between shape-matching errors and drawing accuracy compared with situations with more tightly controlled stimuli. We also note that, in both the photographic and computer-generated stimuli, the depth and nondepth conditions differ in many ways—perspective lines, texture gradients, shading, and so on. Unpacking such stimulus differences represents a promising line of inquiry that is necessary to fully understand the relation (if any) between shape constancy and drawing skill.

[7] However, this explanation seems unlikely: when we recalculated the correlation between drawing accuracy and shape constancy errors in the depth cue condition using only the viewing angle condition that elicited the strongest errors (48 degrees), the value of the correlation remained nonsignificant, $r(46) = -0.11$, $p > .05$. Thus, this difference between procedures cannot be the cause of our failure to replicate the previously discovered relationship between drawing accuracy and shape constancy errors.

Post, 1978), standard stimulus exposure duration (Leibowitz, Chinetti, & Sidowski, 1956), and presentation of stimuli as photographs versus physical objects (Leibowitz, Bussey, & McGuire, 1957) have been reported to lead to behavioral dissociations between shape- and size-constancy errors. Further, on theoretical grounds, size- and shape-constancy errors have been thought to arise through the processing of different types of visual information: size constancy, by an interaction of the size of the object's retinal projection and the perceived distance of the object from the observer (Epstein, Park, & Casey, 1961); shape constancy, via the integration of information about the shape of the object that projects to the retina and perceived slant of the object and the surrounding context (Epstein, Hatfield, & Muise, 1977). Thus, it is not completely surprising that we found that shape and size constancy are largely independent and differentially predict drawing accuracy.

Top-Down Aspects

Evidence bearing on our top-down measure was more straightforward than that bearing on our bottom-up measures. The limited-line tracing task was intended to measure a top-down influence on sensitivity in differentiating essential versus superfluous information in depicting an object. Our results reinforce the importance of the selection of essential visual information for skilled drawing (Kozbelt & Seeley, 2007; Kozbelt et al., 2010): Artists produced more accurate renderings than nonartists in the limited-line tracing task, and performance was correlated with freehand drawing accuracy. Our replication also extends this point to new and less familiar stimuli, and our finding that artists produced reliably more vertices—like L, T, and fork junctions—than nonartists in the limited-line tracing task underscores this point, since such information is important in facilitating object recognition (Biederman, 1987; Kozbelt & Seeley, 2007). Generally, these results implicate a strong role for top-down selection processes influencing drawing accuracy, as argued by Gombrich (1960), when one controls for a host of other perceptual and motor factors related to drawing behavior.

Integrating and Moving Beyond the Bottom-Up/Top-Down Distinction in Drawing

In this article, we attempted to test the traditional distinction between top-down and bottom-up accounts of skilled drawing, using a set of measures that tap into narrowly defined but key aspects of the two types of perceptual processing. However, this distinction is arguably artificial, especially considering that a "bottom-up" perceptual constancy measure and a "top-down" visual selection measure predicted drawing accuracy equally well. Moreover, most empirical work on this topic has focused on a single process or stage of processing at a time (e.g., Cohen, 2005; Cohen & Jones, 2008; Mitchell et al., 2005; Tchalenko, 2009). This is bound to distort our understanding, as multiple processes and stages of information processing likely dynamically interact to produce the observed degree of accuracy of a given drawing (Kozbelt & Seeley, 2007; Seeley & Kozbelt, 2008). Is there a way of integrating the two perspectives into a unified, parsimonious account of realistic drawing skill?

Kozbelt et al. (2010) outlined some ways in which bottom-up and top-down views of realistic drawing might be reconciled. Bottom-up strategies may be most effective for resolving an object's two-dimensional proportions or clarifying details, while top-down strategies likely become more important for facilitating appropriate visual selection among experienced artists. Moreover, the meaning of "top-down processing" vis-à-vis drawing varies. The bottom-up view emphasizes top-down influences as interfering with drawing accuracy, where the processing of information that is not accounted for in the retinal signal generates misperceptions, like perceptual constancies, which then leads one to perceiving, and thus drawing, information not inherent to the model to be drawn. In contrast, the top-down view argues that specialized, domain-specific knowledge leads to a biased selection for perception and action of some visual information of the model over others, and also likely includes information on how to achieve desired effects in a given artistic medium.

More generally, a richer understanding of artists' perception and cognition might be had by explicitly conceptualizing bottom-up and top-down modes of perception as *strategies* that may be flexibly implemented by artists to deal with perceptual ambiguities—rather than simply as mechanistic perceptual processes, without substantive consideration of the context in which they occur. A more bottom-up strategy might involve selecting the most characteristic lines, angles, or shapes upon which to construct the direction and movement of a form, and the capacity to realize overall spatial relationships, for instance, in "apprehending the relation of forms and color to one another, as they cohere within the object" (Fry, 1919/1981, p. 49). Top-down strategies may be useful for resolving perceptual ambiguities based on expectations of a feature at a particular location, or a decision to emphasize a diagnostic feature to enhance recognition of a depicted object (Kozbelt & Seeley, 2007). Artists' well-developed knowledge structures may also facilitate selection of viewpoint-dependent information that accurately captures the transient individuality of the appearance of a stimulus.

Along these lines, an additional way to achieve a more unified, parsimonious account of skilled drawing is to reframe the debate entirely. Virtually all writings on artists' vision and drawing emphasize *perception*; an alternative is to cast the discussion in terms of visual *attention*—specifically, the interaction between strategic shifts in attention guiding visual selection and the attentional enhancement of selected information and suppression of nonselected information (Kozbelt & Seeley, 2007; Seeley & Kozbelt, 2008). As noted earlier, a major problem in drawing is the moment-to-moment selection of what information to attend to and render. Our results on the limited-line tracing task (see also Kozbelt et al., 2010; Tchalenko, 2009) suggest that the selection process differs between experts and novices and is closely related to drawing accuracy. In sum, we propose that bottom-up and top-down strategic shifts in attention reflect the process by which a person selects what information to perceive and depict at any point in the drawing process.

However, an additional wrinkle concerns the subsequent processing of information that has *already* been selected. Consider the depth cue condition of our size-matching task. Here individuals do not have to decide which information to attend to, as the target information (circles or spheres) is clearly defined by the task itself. But if this is the case, why is it that size-constancy errors differed between artists and nonartists, and were negatively correlated with freehand drawing performance? Rather than just strategic selection processes, a more mechanistic attentional process must also be involved. Since greater size-matching errors were observed in the depth cue condition than the nondepth condition, the background information of the display, while technically irrelevant to the size-matching task, is clearly attended to and influences performance. Importantly, size-constancy errors also decreased with the increasing size of the target in the depth cue condition. An explanation for this finding is straightforward: As a target increases in size, it occludes more depth cues in the display, attenuating the distracting effect of irrelevant background information. The finding that artists make smaller size-constancy errors than nonartists could be interpreted as evidence that in practice artists are better able than nonartists to focus their attention on task-relevant information—even though it is clear to both groups what information on the display is relevant. Along these lines, we argue that artistic skill involves the ability or fundamental capacity to strongly bias attention toward enhancing the processing of target information and suppressing task-irrelevant information (see also Kozbelt & Seeley, 2007). Poor drawing can result from a weaker mechanism of this kind.

This interpretation is consistent with numerous findings, such as the fact that artists have stronger field independence than nonartists (Gaines, 1975), and, possibly, why drawing accuracy has been previously found to be inversely related to shape-constancy errors (Cohen & Jones, 2008; Matthews & Adams, 2008; Mitchell et al., 2005; Thouless, 1932)—although not in the present study. Further, Cohen (2005) offered a speculative hypothesis, similar to the one presented here, to explain his finding that increasing the frequency and speed of eye gaze shifts from model to drawing increased drawing accuracy—namely, that less time spent viewing a model to be drawn decreases the probability that nonselected information will capture attentional resources in competition with selected information. This ability to bias attentional competition between target and nontarget information seems especially pertinent to drawing accuracy, as previous research has demonstrated that attention paid to contextual nontarget information results in not only inaccuracies in perception but also motor movements. A whole line of recent research has repeatedly shown that visual illusions distort not only perceptual judgments of target information but also motor movements made toward that information (Franz, 2003; Glover & Dixon, 2001; Mendoza, Elliot, Meegan, Lyons, & Welsh, 2006). Since drawing is inherently a visuomotor activity, biasing attention toward target information and suppressing the processing of irrelevant contextual information would seem both to relate to artists' perceptual advantages and potentially to more efficient, accurate motor actions. Indeed, the role of motor priming and motor execution has been explicitly incorporated into a recent model of artists' advantages in drawing and perception (Kozbelt & Seeley, 2007; Seeley & Kozbelt, 2008), which is grounded in the deployment of selective visual attention.

To conclude, in trying to explain how strategic and mechanistic forms of attention interact with one another to impact drawing, we advocate a broad, multistage *attention-based* theory of drawing skill and accuracy. We envision the perceptual aspect of drawing as involving a continual feed-forward and feedback interaction between the strategic selection of information and the subsequent biasing of attentional resources toward enhancing the processing of selected information and suppressing the processing of nonselected information. In this sense, drawing inaccuracies can arise through multiple stages of visual processing, including inappropriate selection of information to attend to as well as an insufficient biasing of attention toward selected information and away from nonselected information. Although these ideas are speculative, and even if the specific details of this theory are inaccurate, the more general idea that drawing accuracy is best explained by considering multiple processing stages centered around attentional processing seems to be more useful than previous approaches, and thus may provide a means of resolving the seemingly competing, yet equally well-supported, historical theories of drawing accuracy in a unified, parsimonious way.

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