The Quarterly Journal of Experimental Psychology
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/pqje20

Observational drawing biases are predicted by biases in perception: Empirical support of the misperception hypothesis of drawing accuracy with respect to two angle illusions

Justin Ostrofsky[a], Aaron Kozbelt[b] & Dale J. Cohen[c]

[a] Department of Psychology, The Richard Stockton College of New Jersey, Galloway, NJ, USA

[b] Department of Psychology, Brooklyn College of the City University of New York, Brooklyn, NY, USA

[c] Department of Psychology, University of North Carolina in Wilmington, Wilmington, NC, USA

Published online: 18 Nov 2014.

THE QUARTERLY JOURNAL OF EXPERIMENTAL PSYCHOLOGY, 2014
http://dx.doi.org/10.1080/17470218.2014.973889

Routledge
Taylor & Francis Group

Observational drawing biases are predicted by biases in perception: Empirical support of the misperception hypothesis of drawing accuracy with respect to two angle illusions

Justin Ostrofsky[1], Aaron Kozbelt[2], and Dale J. Cohen[3]

[1]Department of Psychology, The Richard Stockton College of New Jersey, Galloway, NJ, USA
[2]Department of Psychology, Brooklyn College of the City University of New York, Brooklyn, NY, USA
[3]Department of Psychology, University of North Carolina in Wilmington, Wilmington, NC, USA

We tested the misperception hypothesis of drawing errors, which states that drawing accuracy is strongly influenced by the perceptual encoding of a to-be-drawn stimulus. We used a highly controlled experimental paradigm in which nonartist participants made perceptual judgements and drawings of angles under identical stimulus exposure conditions. Experiment 1 examined the isosceles/scalene triangle angle illusion; congruent patterns of bias in the perception and drawing tasks were found for 40 and 60° angles, but not for 20 or 80° angles, providing mixed support for the misperception hypothesis. Experiment 2 examined shape constancy effects with respect to reproductions of single acute or obtuse angles; congruent patterns of bias in the perception and drawing tasks were found across a range of angles from 29 to 151°, providing strong support for the misperception hypothesis. In both experiments, perceptual and drawing biases were positively correlated. These results are largely consistent with the misperception hypothesis, suggesting that inaccurate perceptual encoding of angles is an important reason that nonartists err in drawing angles from observation.

Keywords: Drawing accuracy; Angle illusion; Misperception hypothesis.

Realistic observational drawing involves creating a depiction of an external model stimulus with the goal of achieving *visual accuracy*. A visually accurate drawing is "one that can be recognized as a particular object at a particular time and in a particular space, rendered with little addition of visual detail that cannot be seen in the object represented or with little deletion of visual detail" (Cohen & Bennett, 1997, p. 609). Years of training and practice are typically needed to achieve mastery in visual accuracy, which is evident in comparing the drawing performance of artists versus nonartists (Carson & Allard, 2013; Chamberlain, McManus, Riley, Rankin, & Brunswick, 2013; Cohen, 2005; Cohen & Earls, 2010; Kozbelt, 2001; Kozbelt, Seidel, ElBassiouny, Mark, & Owen, 2010; McManus et al., 2010; Ostrofsky, Kozbelt, & Seidel, 2012). Increasingly, experimental psychologists have sought to understand the cognitive processes related to individual variability in drawing performance. Here, we assess the influence of perceptual encoding of the stimulus being drawn on drawing accuracy, a perspective that one may term the *misperception hypothesis* of drawing errors.

Correspondence should be addressed to Justin Ostrofsky, Department of Psychology, The Richard Stockton College of New Jersey, 101 Vera King Drive, Galloway, NJ 08205, USA. E-mail: Justin.Ostrofsky@stockton.edu

The misperception hypothesis of drawing accuracy

Venerable traditions of philosophical and art historical speculation (e.g., Fry, 1919/1960; Ruskin, 1857/1971), pragmatic artistic training (e.g., Edwards, 1999), and early psychological research (e.g., Thouless, 1931, 1932) have approached the nature of drawing skill from the standpoint of the impact of perceptual processes. The modern incarnation of the misperception hypothesis, rooted in experimental psychological methods, can be traced to Cohen and Bennett (1997), who argued that drawing errors are mostly the result of misperceiving the object to be drawn.

The misperception hypothesis builds on the well-established principle that conscious visual perception is not the result of a one-to-one reproduction of the reflected patterns of light that are detected by retinal photoreceptors (Gregory, 1997; Rock, 1997). Rather, the visual system performs complex computations and transformations on visual input, which often result in nonveridical perceptual representations. Such computations aim to infer the actual structure of perceived objects and scenes, rather than merely reproducing the pattern of retinal stimulation (Purves & Howe, 2005). Clear demonstrations of this principle come from *perceptual constancies* related to size, shape, colour, and brightness perception, which are virtually universal (Day, 1972; Perdreau & Cavanagh, 2011; Todorovic, 2002, 2010).

Extending this principle, the misperception hypothesis suggests that the visual information guiding drawing behaviours is subject to the same computations as those made on the visual information supporting conscious perceptual judgements (Cohen & Earls, 2010). In other words, specific transformations that result in errors of perceptual judgement should result in similar drawing errors. For example, it is well known that the processing of depth cues can cause errors of size judgement. In the classic size constancy effect, an individual observing two objects of the same projective size, but perceived to be at different distances, will commonly report that the "farther" object appears physically larger than the "closer" object. This bias is greatly reduced, if not eliminated, when depth cues are absent from the visual array (Ostrofsky et al., 2012; Perdreau & Cavanagh, 2011). If the misperception hypothesis holds, the computation of depth cue information should result in the same pattern of size drawing errors: "Farther" objects should be drawn larger than "closer" objects, even when their projective sizes are equated, particularly in the presence of depth cues. In sum, the misperception hypothesis predicts that perceptual judgement and drawing accuracy should covary because the underlying transformations on representations of visual information impact perceptual and drawing accuracy in similar ways.

The misperception hypothesis has inspired a number of recent empirical studies. We next critically review this body of research, discussing its implications and arguing that many of the methods employed thus far have limitations that make it difficult to evaluate key aspects of the hypothesis.

Empirical evaluations of the misperception hypothesis

Numerous studies have tested predictions of the misperception hypothesis (Cohen & Earls, 2010; Cohen & Jones, 2008; McManus, Loo, Chamberlain, Riley, & Brunswick, 2011; Mitchell, Ropar, Ackroyd, & Rajendran, 2005; Ostrofsky et al., 2012). Some have found that individual differences in performance on perceptual judgement tasks are reliably associated with drawing accuracy. For instance, individuals who experience larger shape constancy errors in a perceptual matching task tended to produce observational drawings of faces that were subjectively judged to be of lower quality (Cohen & Jones, 2008; Ostrofsky, Cohen, & Kozbelt, in press; but see McManus et al., 2011; Ostrofsky et al., 2012, for failures to replicate this finding on shape constancy. Ostrofsky et al. (2012) describes potential sources of this discrepancy by discussing important methodological differences between these studies). Similar results for size constancy errors and subjectively rated accuracy of octopus and face drawings have been reported (Ostrofsky et al., in press; Ostrofsky et al., 2012). Such results suggest that the visual processes responsible for perceptual constancies also act on information guiding drawing behaviour, consistent with the misperception hypothesis. However, such studies do not directly demonstrate this point, for several reasons.

Although previous research demonstrated a relationship between perception and drawing, the influence was not well localized for two reasons. First, because judges typically are asked to make a single, holistic judgement about the accuracy of a drawing, this measure does not indicate what elements of a model were inaccurately depicted in a given drawing (e.g., line curvature, angles, proportions, and/or relative spatial positioning). Second, the perception and drawing tasks were not well matched, which weakened the ability of the research to test the prediction that specific perceptual errors would influence corresponding drawing errors.

To our knowledge, Mitchell et al. (2005) provided perhaps the strongest test of the misperception hypothesis to date. These researchers presented participants with two different versions of the well-known Shepard illusion. In one version, the stimuli were of plain parallelograms; in the other version, the parallelograms had legs attached to them, giving them the appearance of a 3D table. Previous reports suggested that when participants view these stimuli, lines are perceived to be longer when oriented vertically (versus horizontally), and that this illusion is exaggerated when the stimuli include 3D depth cues (Shepard, 1990). Mitchell et al. (2005, Experiment 2) presented subjects with Shepard illusion stimuli (either with or without the contextual cue of table legs) and asked them to draw the two models as accurately as possible. Since line length is an unambiguous property of drawing accuracy, the researchers were able to quantify drawing errors objectively by measuring the lengths of the reproduced lines. After completing the drawings, participants verbally estimated the lengths of the vertical and horizontal lines in each model, yielding an index of perceptual judgement errors. This paradigm represents a strong test of the misperception hypothesis, since the drawing stimuli were selected to allow well-defined predictions about the pattern of drawing errors, and the objective measurement of relative line-length drawing error allows this prediction to be cleanly tested.

Mitchell et al. (2005) replicated the Shepard illusion with respect to perceptual judgements using both versions of the stimulus and also found exaggerated illusion in the 3D contextual-cue condition. Analysis of line length drawing errors also showed that the signature pattern of errors associated with this illusion was only present in the 3D contextual-cue condition. Further, drawing and perceptual errors were correlated in the 3D contextual-cue condition, but not in the noncontextual-cue condition. This pattern of results supports a moderate version of the misperception hypothesis, in that drawing errors appear to have only been influenced by perceptual inaccuracies when the misperception was caused by encoding 3D depth cues.

Thus far we have argued that an ideal empirical approach to misperception hypothesis would involve examining specific predictions about drawing errors rooted in earlier perceptual research, which could be tested using identical stimuli in the perceptual judgement and drawing tasks. In the remainder of this paper, we report and discuss two experiments that test the misperception hypothesis—specifically with respect to the drawing of *angles*.

Angle drawing as a test case of the misperception hypothesis

Perhaps the most basic spatial relationships rendered in drawing involve angles, which define how two lines intersect or coterminate. Like other kinds of visual information depicted from observation, the drawing of angles is associated with individual variability in accuracy; further, this variability appears to be associated with drawing ability in general (Carson & Allard, 2013; Chamberlain, McManus, Riley, Rankin, & Brunswick, 2014; McManus et al., 2010). These findings suggest that the accurate drawing of local angles is an essential component in producing visually accurate drawings of more complex objects and scenes.

Applying the misperception hypothesis to angles yields the prediction that errors in drawing angles should be accounted for and related to errors in perceiving angles. Previous research has repeatedly demonstrated that angles are associated with systematic patterns of perceptual judgement errors (Blakemore, Carpenter, & Georgeson, 1970; Fisher, 1969; Hamad, Kennedy, Juricevic, & Rajani, 2008; Kennedy, Orbach, & Loffler, 2008; Nundy, Lotto, Coppola, Shimpi, & Purves, 2000). Thus, key predictions of the misperception hypothesis can be explored in a relatively straightforward way by using angles as a test case, by determining whether patterns of error in angle drawing are similar to the previously discovered perceptual judgement errors. The two studies reported here test the misperception hypothesis in just this way. Experiment 1 uses a previously documented angle illusion that is not supported by the processing of 3D depth cues (*the isosceles–scalene triangle angle illusion* reported by Kennedy et al., 2008). Experiment 2 uses a well-known angle illusion that is dependent on the processing of 3D depth cues (*the shape constancy effect* reported by Hammad et al., 2008). By conducting these two experiments, we are able to determine whether the relationship between perceptual and drawing biases of angles are dependent on whether or not the stimuli contain 3D depth cues (cf. Mitchell et al., 2005).

EXPERIMENT 1

Kennedy et al. (2008) originally reported an angle illusion whereby the size of a given angle is perceived to be larger when embedded in an isosceles triangle (where the two lines defining the angle are equal in length) than when the same angle is embedded in a scalene triangle (where the two lines defining the angle are unequal in length). This illusion appears quite robust: It was not influenced by the area or orientation of the triangles and was consistent across different target angles ranging from 30 to 120°. Since the stimuli consisted only of plain triangles set against a uniform grey background, and the only relevant contextual information was the length of the two lines defining the target angle of the triangle, this illusion is not caused by the processing of 3D depth cues—unlike, say, classic demonstrations of shape or size constancy, as in Cohen and Jones (2008) or Ostrofsky et al. (2012). (See Kennedy et al., 2008, for the tentative theory that the visual system's computation of the aspect ratio of the entire triangle is the causal mechanism producing this illusion).

Experiment 1 tests the misperception hypothesis with respect to this angle illusion. Participants were exposed to angles embedded in either isosceles or scalene triangles and were asked to provide perceptual judgements and drawings of target angles. The misperception hypothesis predicts that in both tasks, participants should draw a target angle as larger when embedded in an isosceles triangle than when in a scalene triangle. Critically, it also predicts that the direction and magnitude of this triangle bias should be positively correlated across the perceptual judgement and drawing tasks.

A feature of Experiment 1 (and Experiment 2) is that participants were exposed to the target angle stimuli for three seconds, after which the stimulus disappeared. Participants were instructed to begin the process of responding in the perceptual judgement and drawing tasks immediately after the stimulus exposure period ended. Thus, perceptual judgements and drawings were guided by short-term memory as opposed to direct perception of the stimulus. There are two chief reasons that we adopted this method. First, by controlling the time participants were exposed to the model before they initiated their drawing, we prevented participants from adopting different viewing strategies, which could have resulted in additional variability in performance that is not theoretically relevant to the current study. This is critical because previous research has demonstrated that the time individuals spend inspecting a model before they begin to draw affects drawing accuracy (Cohen, 2005). Second, by removing the model before participants initiated their drawing, we mimic the process that nonartists have been observed to engage in when producing observational drawings: Tchalenko (2009) observed that nonartists, while producing drawing marks, fixate on the emerging drawing as opposed to the model they are trying to reproduce. Thus, having nonartist participants reproduce the target angles from memory is arguably quite ecologically valid.

Method

Participants

Fifty individuals with no formal training in drawing [40 females, 10 males, *M* (*SD*) age = 21.9 (6.6) years] were recruited from the Brooklyn College Psychology undergraduate subject pool and participated for course credit.

Stimuli

Target angles. In both the perceptual reproduction task and drawing reproduction task, participants were presented with four target angles measuring 20, 40, 60, and 80° (see Figure 1). In each task, half of the trials depicted the target angle embedded in isosceles triangles; on the other half, it was in scalene triangles. In isosceles triangles, the two lines defining the target angle were equal in length, each measuring 111 mm on the screen. In scalene triangles, the two lines defining the target angle were unequal in length, measuring 26 mm and 148.2 mm on the screen, a ratio of 1:5.7.

Stimuli were presented to participants as they appear in Figure 1. All triangles were composed of three black lines, shown in the centre of the screen against a white background. For all stimuli, one line defining the target angle (the base line) was always presented horizontally; the second line defining the target angle (the angle line) deviated in orientation above the base line. For target angles embedded in the scalene triangles, the base line was always longer than the angle line. On each trial, a red arrow identified the target angle.

Perceptual reproduction task. In this task, participants adjusted the size of a single angle presented on the screen with the goal of matching the size of the previously presented target angle. The *adjustment angle* was composed of two black lines, each measuring 100 mm on the screen, presented on a white background. One line (the base line) remained horizontal; the second (the adjustment line) always formed an angle with the base line at their left endpoints. Participants changed the orientation of the adjustment line to adjust the size of the angle. On the screen above the adjustment angle, participants were instructed: "Adjust the size of the angle on the screen to match the size of the target angle you just saw. Click the left and right arrows on the scroll bar to adjust size. When finished, click anywhere else on the screen to move to the next trial."

The adjustment angle was created using the software program Radpix Multiple Image Capture (Version 1.0.23). This program allows one to create an image stack embedded in a Microsoft Office Powerpoint slide. The stack was composed of individual images of angles varying in size between 1° and 179° in 1° increments, displayed one at a time. Participants could change the image being displayed by using the mouse to click the left and right arrow buttons on the scrollbar near the bottom centre of the Powerpoint slide. The adjustment angle size started at 1°, with the starting position of the scrollbar set to its leftmost point. Moving the scrollbar to the right increased the size of the adjustment angle in 1° increments up to a maximum size of 179°; moving the scrollbar to the left decreased the size of the adjustment angle. Increasing the adjustment angle always moved the adjustment line in an anticlockwise direction.

Drawing reproduction task. In the drawing reproduction task, participants were shown target angles on the computer screen, just as in the perceptual reproduction task. Participants were then instructed to use a pencil to draw an angle that matched the target angle on 8.5″ × 11″ pieces of white paper in portrait orientation.

Procedure

After providing informed consent, participants were shown sample triangle stimuli on the computer and were told that they would need to pay

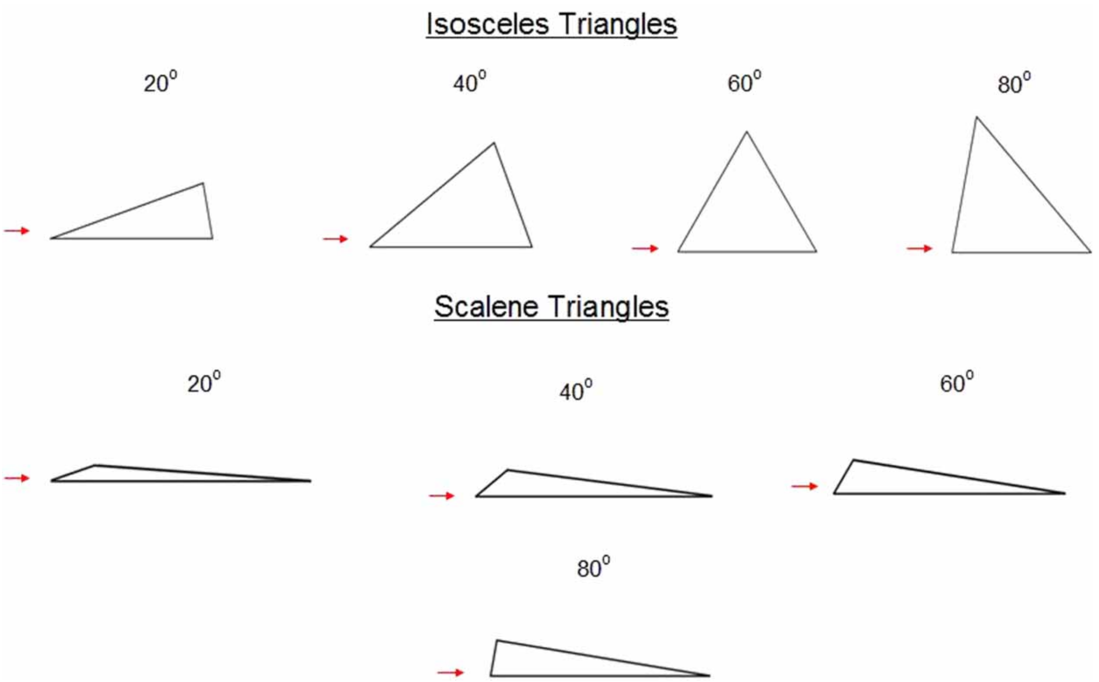

Figure 1. *Stimuli presented in Experiment 1. Participants were asked to provide perceptual judgements and drawings of the target angle (pointed to with the arrow) of the four target angles under conditions of when the target angle was embedded in isosceles and scalene triangles. To view this figure in colour, please visit the online version of this Journal.*

attention to the size of the indicated target angle and accurately reproduce it in a series of trials. After participants indicated that they understood the task, they completed the perceptual reproduction and drawing reproduction tasks. Task order was counterbalanced across participants.

Perceptual reproduction task. This task was composed of 24 trials. Each of the four target angles (20, 40, 60, and 80°) was presented six times: three times embedded in an isosceles triangle and three times embedded in a scalene triangle. Isosceles and scalene trials were intermixed; order of presentation of the stimuli was randomized for each participant, with the constraint that a given target angle could not be presented in two consecutive trials.

To ensure participants' familiarity with the task, the experimenter explained the instructions and administered a single practice trial. Participants were instructed to pay attention only to the target angle pointed to by the red arrow and were informed that they would make their response by adjusting an angle on the screen after the stimulus had disappeared. Participants were told that their goal was to reproduce the size of the target angle as best they could. After receiving instructions, participants completed the single practice trial under supervision of the experimenter. After the practice trial was completed, the task began.

Each trial began with a screen that read, "Press Spacebar to Proceed When Ready". When participants pressed the spacebar, the stimulus appeared on the screen. After three seconds, it disappeared, immediately replaced by the adjustment angle. Participants then manipulated the size of the adjustment angle until they thought it matched the target angle. When satisfied with their response, participants pressed the spacebar to move on to the next trial.

Drawing reproduction task. In terms of stimuli, presentation order, and constraints, this task was identical to the perceptual reproduction task. The experimenter first explained the instructions and administered a single practice trial. Participants were instructed to pay attention only to the target angle pointed to by the red arrow. They were explicitly instructed not to begin their drawing while the stimulus was still present on the screen, but rather to wait until the image disappeared. Participants were told that their goal was to draw the size of the target angle as best they could. They were also instructed not to draw the entire triangle. Participants were allowed to erase and modify their drawings. After these instructions were given, participants completed the single practice trial under supervision of the experimenter. Once the practice trial was over, the task began.

Each trial of the drawing reproduction task began with a screen that read, "Press Spacebar to Proceed When Ready". When participants pressed the spacebar, the stimulus appeared on the screen. After three seconds, it disappeared, immediately followed by a message reading, "Draw the Angle as Accurately as Possible to the Best of Your Ability". Participants then drew the angle as best they could, with no time limit. When the drawing was finished, participants pressed the spacebar to move on to the next trial.

Results

Reproduced angles in the perceptual reproduction task were digitally measured using the ruler tool in Adobe Photoshop CS5. Reproduced angles in the drawing reproduction task were measured by a protractor. For both tasks, the three reproductions of a given stimulus (e.g., a 20° target angle in a scalene triangle) were averaged together to generate a single *average reproduction value* for each stimulus. This resulted in 16 average reproduction values calculated per participant (eight values each for the perceptual and drawing reproduction tasks).

Contextual biases in the perceptual reproduction task

Average reproduction values from the perceptual reproduction task are represented in Figure 2a. To determine whether we replicated the previously documented triangle angle perceptual illusion (Kennedy et al., 2008), a 2 (triangle condition: isosceles vs. scalene) × 4 (target angle: 20° vs. 40° vs. 60° vs. 80°) repeated measures analysis of variance (ANOVA) was conducted, using the Huynh–Feldt method to correct degrees of freedom (Huynh & Feldt, 1976), testing for effects on the average reproduction values from the perceptual reproduction task. Not surprisingly, a reliable main effect of target angle was observed, $F(1.9, 94.1) = 537.73$, $p < .001$, $\eta_p^2 = .92$, indicating that participants were perceptually sensitive to the size differences across the four target angles.

A reliable main effect of triangle condition was also found, $F(1, 49) = 38.52$, $p < .001$, $\eta_p^2 = .44$, indicating that angles embedded in isosceles triangles were, on average, perceived to be larger than the same-sized angles embedded in scalene triangles. A reliable interaction was also observed, $F(2.8, 134.8) = 12.37$, $p < .001$, $\eta_p^2 = .20$, which was followed up using quasi-F tests comparing the effects of triangle condition separately at each target angle size. These indicated that the target angle embedded in an isosceles triangle was perceived to be larger than when embedded in a scalene triangle for 40° target angles, quasi-$F(1, 128.1) = 16.05$, $p < .001$, 60° target angles, quasi-$F(1, 128.1) = 63.37$, $p < .001$, and 80° target angles, quasi-$F(1, 128.1) = 19.08$, $p < .001$. In contrast, there was a nonreliable difference between the perceived size of the 20° angles embedded in the isosceles and scalene triangles, quasi-$F(1, 128.1) = 2.65$, $p > .05$.

In sum, except for 20° target angles, we replicated the triangle illusion. Since a perceptual transformation causes the perceived size of angles to be larger when embedded in an isosceles versus a scalene triangle, a prediction derived from the misperception hypothesis is that this systematic bias should also be observed when individuals draw angles embedded in these two forms of triangles. The next analyses test this prediction.

Contextual biases in the drawing reproduction task

Average reproduction values from the drawing reproduction task are represented in Figure 2b. A 2 (triangle condition: isosceles vs. scalene) × 4 (target angle: 20° vs. 40° vs. 60° vs. 80°) repeated

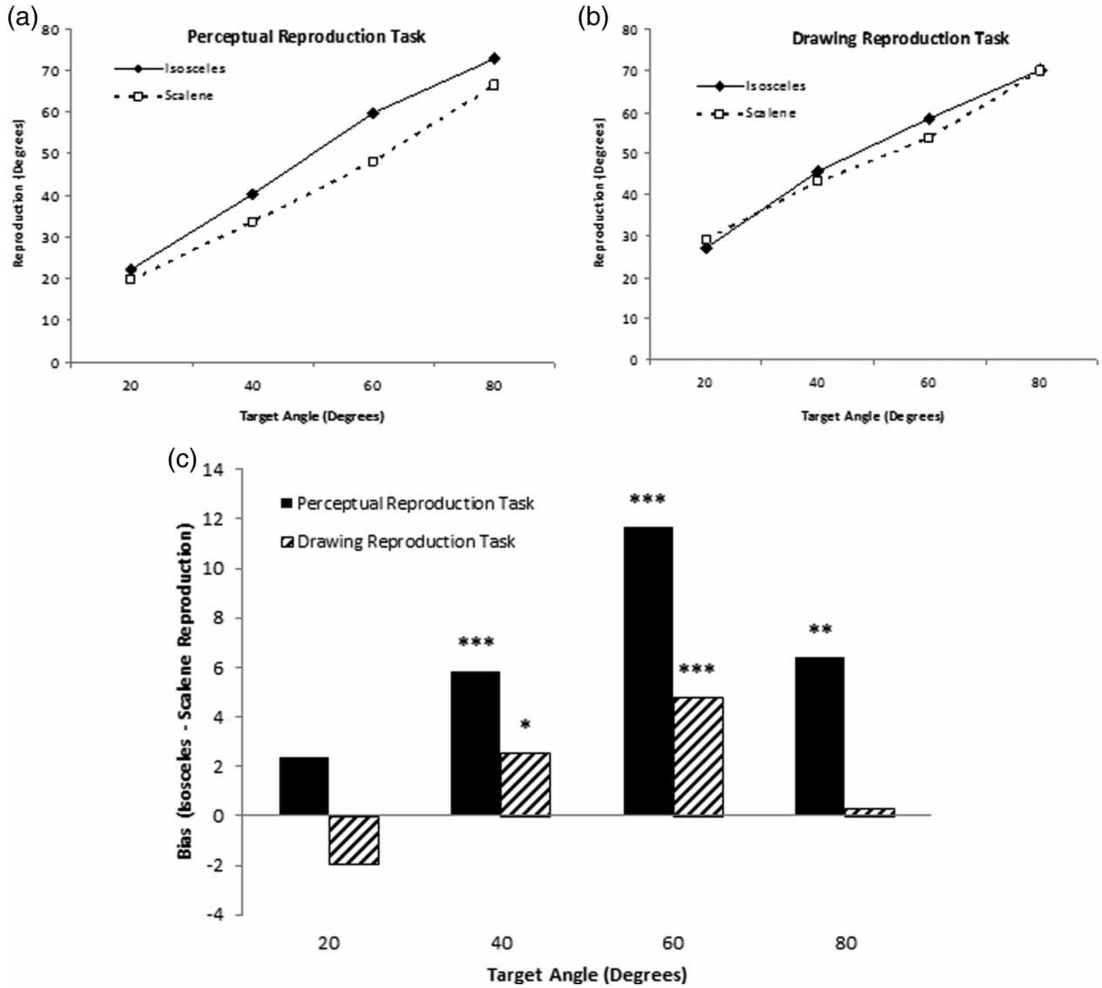

Figure 2. *Results of Experiment 1. (a) Performance in the perceptual reproduction task. Values on the* y*-axis are the mean values across participants of perceptual judgements (in degrees) of each target angle, separately for judgements made in the isosceles and scalene triangle conditions. (b) Performance in the drawing reproduction task. Values on the* y*-axis are the mean values (in degrees) across participants of the drawings of each target angle, separately for drawings made in the two triangle conditions. (c) Mean bias scores in the perceptual and drawing reproduction tasks. Bias was calculated as the difference between the reproductions made in the isosceles and scalene triangle conditions for each target angle. Positive bias scores indicate that the angle embedded in the isosceles triangle was reproduced larger than when the same-sized angle was embedded in a scalene triangle. Statistically reliable differences in the reproduced size of angles between those embedded in isosceles versus scalene triangles are indicated by asterisks:* *$p < .05$; **$p < .01$; ***$p < .001$.

measures ANOVA was conducted, using the Huynh–Feldt method to correct degrees of freedom, testing for effects on the average reproduction values from the drawing reproduction task. Again, unsurprisingly, a reliable main effect of target angle was observed, $F(2.5,\ 120.8) = 896.86$, $p < .001$, $\eta_p^2 = .95$, indicating that the size of drawn angles changed depending on the size of the target angle. Additionally, there was a reliable main effect of triangle condition, $F(1,\ 49) = 4.92$, $p < .05$, $\eta_p^2 = .09$, indicating that, on average, angles were drawn larger when embedded in isosceles triangles than when embedded in scalene triangles.

A reliable interaction was also observed, $F(3, 146.1) = 8.728$, $p < .001$, $\eta_p^2 = .15$, again followed up with quasi-*F* tests comparing the average reproduction values of angles embedded in isosceles versus scalene triangles for each target angle size. These indicated that angles were drawn larger when embedded in an isosceles triangle than when embedded in a scalene triangle when the target angle size was 40°, quasi-$F(1, 182.5) = 5.69$, $p < .05$, and 60°, quasi-$F(1, 182.5) = 20.10$, $p < .001$. However, there was no reliable difference in the size of the drawn angles for the 20° target angle, quasi-$F(1, 182.5) = 3.33$, $p > .05$, and the 80° target angle, quasi-$F(1, 182.5) = 0.09$, $p > .05$.

In sum, we obtained mixed evidence for one of the derived predictions of the misperception hypothesis. Specifically, participants on average drew the target angles as smaller when embedded in scalene than when in isosceles triangles when the target angle was 40° and 60°, just as they on average perceived the 40° and 60° target angles as smaller when embedded in scalene triangles than when in isosceles triangles. In contrast, there was no difference in the average size of drawn 80° target angles between the scalene and isosceles triangles even though 80° target angles were perceived as smaller in scalene than in isosceles triangles. Although in the 20° target angle condition there were trends in opposite directions for perception and drawing, these trends were not significant.

Relationship between perceptual and drawing reproduction contextual biases

Besides testing for congruent patterns of perception and drawing errors as described above, another major prediction of the misperception hypothesis is that perceptual and drawing reproduction task performance should be reliably correlated. To probe for such a relationship, four *bias scores* were calculated for each reproduction task per subject: For each target angle, the average reproduction of a given target angle embedded in a scalene triangle was subtracted from the average reproduction of the same target angle embedded in an isosceles triangle (mean bias scores are shown in Figure 2c). A bias score of 0 indicates no difference in the average reproduction values in isosceles versus scalene triangles. A positive score indicates a bias to perceive and/or draw the target angle larger when embedded in an isosceles triangle than in a scalene triangle. We then calculated the average of the four target angle bias scores for the perceptual and drawing reproduction tasks, resulting in one perceptual and one drawing bias score for each participant.

We then computed one Pearson *r* correlation coefficient testing for a relationship between the average bias scores between the perceptual and drawing reproduction tasks. We observed a reliable positive correlation between the perceptual and drawing reproduction bias scores, $r(48) = .33$, $p < .05$.

Discussion

Experiment 1 generated several noteworthy sets of results. First, we replicated the finding that individuals experience the isosceles–scalene triangle angle illusion (Kennedy et al., 2008), observing that participants perceptually judged the size of 40°, 60°, and 80° angles embedded in scalene triangles to be smaller than identically sized angles embedded in isosceles triangles. This perceptual effect appears to be robust over different types of perceptual judgement tasks, as it was demonstrated here for the first time using an adjustment-based perceptual reproduction task, whereas previous demonstrations of the effect have only been observed in forced-choice discrimination tasks.

For two of the four target angles used in this study (40° and 60°), we additionally found that participants' drawings showed similar reliable effects. In contrast, we found no reliable difference in the size of participants' drawings of 20° and 80° angles. Thus, in testing for congruencies in the patterns of bias induced by this specific angle illusion, we found that the misperception hypothesis made accurate predictions with respect to 40° and 60° target angles, but not 80° target angles (both perception and drawing conditions found no significant effects for 20° angles). Thus, angle-related perceptual transformations may operate most strongly and consistently on information guiding drawing performance on angles that are in an intermediate range between 0° and 90°. Finally, we found that the average extent to which participants were biased to perceive the size of a given angle differently across the two triangle conditions was reliably correlated with the extent to which participants drew the size of a given angle differently across the two triangle conditions. This suggests that transformational processes operating on the bottom-up information inherent in the stimuli similarly affected the information guiding perceptual judgements and drawing reproductions of angles. Thus, the results generated by the correlational analysis is generally consistent with the proposition of the misperception hypothesis that inaccurate perceptual encoding of angles is a major source of error in drawing angles.

One limitation of Experiment 1 relates to a confounding variable pertaining to the length of the lines of the adjustment angle that was used by participants to make their response in the perceptual reproduction task. Since the adjustment angle was composed of two lines of equal length, there was a greater similarity between the adjustment angle and the angles embedded in the isosceles triangle than those embedded in the scalene triangle. Thus, it is possible that the differences in perceptual judgement of angles embedded in the isosceles and scalene triangles were caused by differences in the similarity of target and adjustment angles as opposed to differences of the type of triangle the angles were embedded in. However, the pattern of perceptual bias we observed here (angles embedded in isosceles triangles are perceived larger than the same-sized angle embedded in a scalene triangle) has been previously observed in studies employing the psychophysical method of constant stimuli (Kennedy et al., 2008). So, we suspect that the pattern of bias observed in this experiment was caused by the contextual variable of isosceles versus scalene triangle rather than the confounding variable of similarity between the target and adjustment angles.

Another possible limitation of the drawing task (also relevant to Experiment 2) is that participants always drew one horizontal line and one oblique line. One potential critique of this method is that the drawing biases we observed could have been due to motor biases that are known to influence the drawing of oblique lines (Broderick & Laszlo, 1987). However, by assessing the difference in how an angle of a given size is drawn between when it is embedded in an isosceles versus a scalene triangle (Experiment 1), we are controlling for such motor biases. If any motor bias contributes to error in drawing the oblique line of an angle of a given size (e.g. 60°), then that motor bias should affect performance equally in the isosceles versus scalene triangle conditions. Therefore, any difference in drawing an angle of a given size across the two contextual conditions would then be assumed to be isolating influences of the perceptual processing of the different global-shapes of the stimuli on angle drawing biases.

Limitations aside, the similar perceptual and drawing reproduction biases observed in Experiment 1 were induced by the processing of 2D visual information that did not contain any available depth cues to be processed, in contrast to findings relating the perception and drawing of relative line length (Mitchell et al., 2005). The next experiment tests the robustness of the relationship between perceptual and drawing angle biases by aiming to determine whether biases in perceiving angles caused by the processing of 3D depth cue information can similarly predict the direction and magnitude of angle drawing biases.

EXPERIMENT 2

Hammad et al. (2008) demonstrated that individuals perceive the size of angles to be closer to 90° when embedded in a cube containing depth cues than when they are embedded in an abstract parallelogram devoid of depth cues. Specifically, acute angles embedded in cubes are perceived to be larger, and obtuse angles embedded in cubes are perceived to be smaller, than when these angles are embedded in parallelograms. This is an empirical demonstration of the shape constancy effect, as the perception of angles was biased by the objective shape of cubes (objects whose corners are defined by angles that are objectively 90° in size).

Experiment 2 tests the misperception hypothesis with respect to this shape constancy effect on angle drawing. Participants were shown target angles embedded in cubes and parallelograms and then provided perceptual judgements and drawings of the target angles. The misperception hypothesis predicts a greater regression to right angle effect for angles embedded in cubes than for those in flat parallelograms. Critically, it also predicts that the direction and magnitude of this bias should be positively correlated across the perceptual judgement and drawing tasks, as in Experiment 1.

Method

Participants

Twenty-four individuals with no formal training in drawing [16 females, 8 males, M (SD) age = 20.3 (3.3) years] were recruited from the Brooklyn College Psychology undergraduate subject pool and participated for course credit.

Stimuli

Target angles. In the perceptual reproduction task and drawing reproduction task, participants were presented with identical stimuli, illustrated in Figures 3 and 4. Participants were shown individual presentations of four cubes (stimuli suggesting 3D form) and four parallelograms (stimuli not suggesting 3D form), which were isolated displays of one of the faces of the cubes. The stimuli were composed of black lines and were presented in the centre of the display on a white background.

Embedded within these stimuli were eight target angles, four acute (29, 44, 57, and 83°—see Figure 3) and four obtuse (97°, 123°, 136°, and 151°—see Figure 4). Each cube or parallelogram stimulus contained one target acute angle and one target obtuse angle. Thus, one of the cube/parallelogram stimuli contained the 29° and 151° target angles, another contained the 44° and 136° target angles, another contained the 57° and 123° target angles, and the last contained the 83° and 97° target angles.

On any given trial, the target angle was either the acute or obtuse angle (but not both) and was indicated by a small red arrow. The target angle, whether acute or obtuse, was always displayed such that one of the two lines defining the angle was horizontal (*the base line*, always measuring 45 mm in length on the screen), and the other line

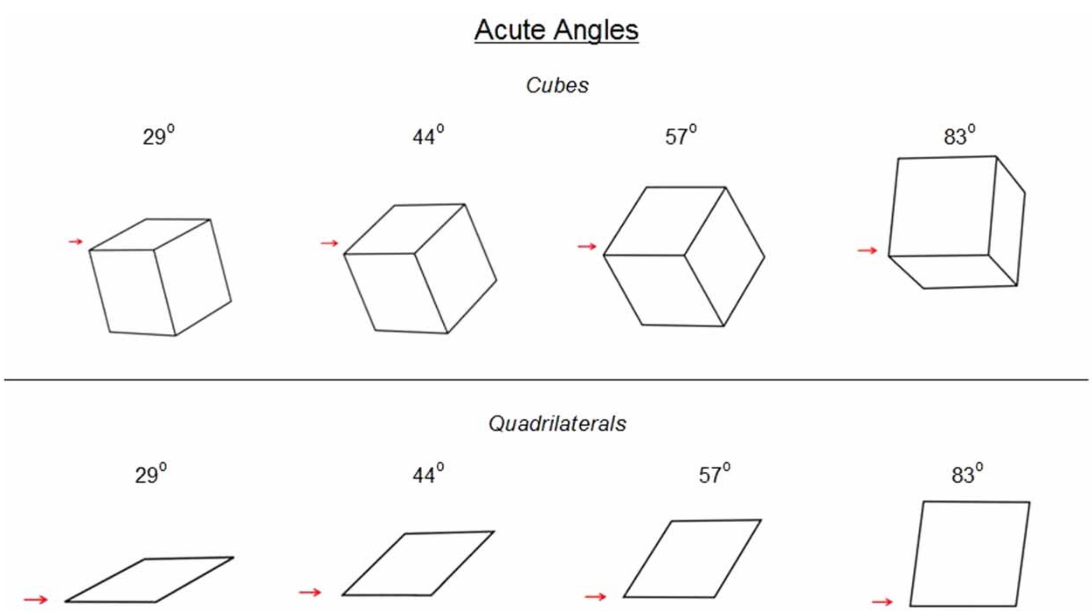

Figure 3. *Acute angle stimuli presented in Experiment 2. To view this figure in colour, please visit the online version of this Journal.*

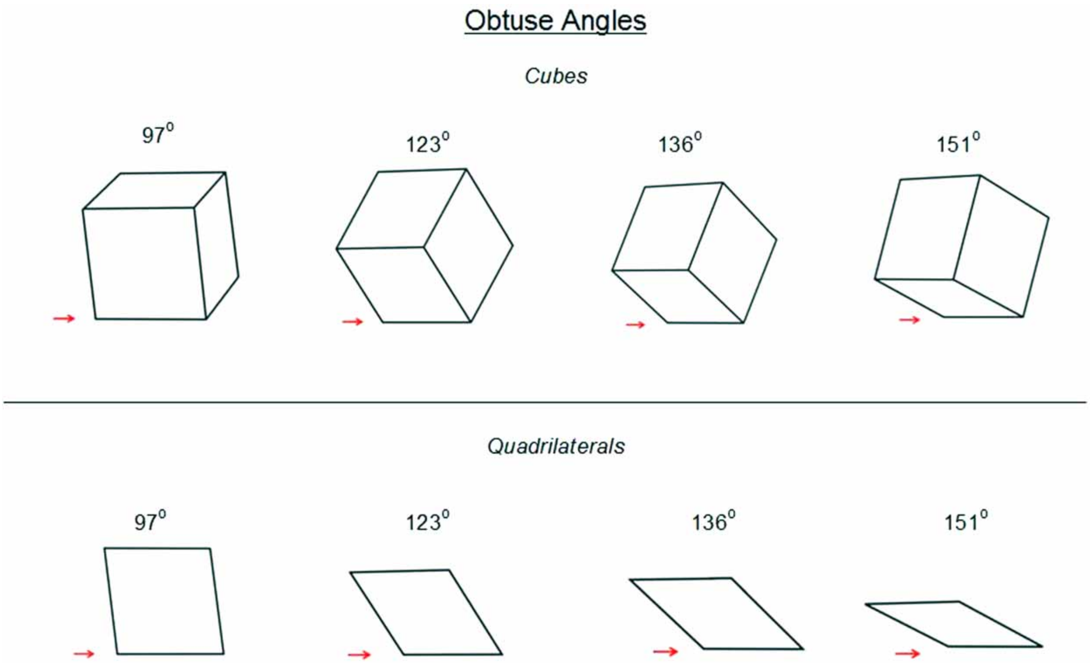

Figure 4. *Obtuse angle stimuli presented in Experiment 2. To view this figure in colour, please visit the online version of this Journal.*

(*the angle line*, also always measuring 45 mm in length on the screen) defining the angle joined the base line at their left endpoints, deviating in orientation above the baseline. This feature of stimulus presentation per target angle means that the rotation of a given cube or parallelogram stimulus differed across the acute versus obtuse target angle conditions.

Perceptual reproduction task. In this task, as in Experiment 1, participants adjusted the size of a single angle presented on the screen with the goal of matching the size of the previously presented target angle. When the target angle was acute, the response slide with the adjustment angle was identical to those used in Experiment 1. However, when the target angles were obtuse, the adjustment angle response slide was slightly different. The starting angular size of the adjustment angle was 179°, and the starting position of the scrollbar was set to the farthest left point. By moving the scrollbar to the right, the size of the adjustment angle decreased in size in one-degree increments until the minimum size of 1° was reached. By moving the scrollbar to the left, the size of the adjustment angle increased in size in one-degree increments until a maximum size of 179° was reached. All other features of the adjustment angle response slide were identical to those described in Experiment 1.

Drawing reproduction task. The materials were identical to those used in Experiment 1.

Procedure

After providing informed consent, participants were shown a single display that presented four *model images,* two cubes and two parallelograms, and were told that the images were representative of the types of images they would be viewing during the course of the experiment. Participants were told that they would need to pay attention to the size of the target angle, indicated by a small red arrow, and to accurately reproduce it in a series of trials. After participants indicated that they understood the task, they completed the perceptual reproduction and drawing reproduction tasks. Task order was counterbalanced across participants.

Perceptual reproduction task. This task was composed of 32 trials. Each target angle was presented four times each, twice while embedded in the cube stimulus and twice while embedded in the parallelogram stimulus. Cube and parallelogram stimulus trials were organized into blocks; within-block presentation order was randomized for each participant with the constraint that a given target angle could not be presented in two consecutive trials. Half of the participants completed the cube trials first, and the other half of participants completed the parallelogram trials first.

To ensure participants' familiarity with the task, the experimenter explained the instructions and administered two practice trials. Here, two cube model images, one with a 67° target angle and one with a 104 target angle, were used as the stimuli. Participants were instructed to pay attention only to the target angle pointed to by the red arrow and were given task instructions that mirrored those of Experiment 1's perceptual reproduction task. Participants then completed the two practice trials under supervision of the experimenter. After this, the participant began the task.

The procedure for an individual trial in the perceptual reproduction task was identical to that in Experiment 1 (except, of course, for the stimuli).

Drawing reproduction task. In terms of stimuli, number of trials, and presentation order and constraints, this task was identical to the perceptual reproduction task. As with that task, the experimenter first explained the instructions and administered a single practice trial. The instructions provided to participants were the same as those given to participants in Experiment 1, including the requirement that they only draw the target angle as opposed to the entire shape of the cube or parallelogram. After this, the participant began the task. The procedure for an individual trial in the drawing reproduction task was identical to that in Experiment 1 (except, of course, for the stimuli).

Results

Reproduced angles from the perceptual and drawing reproduction tasks were measured in the same way as in Experiment 1. For both tasks, the two reproductions of a given stimulus (e.g., the 44° target angle embedded in a cube) were averaged together to generate a single *average reproduction value* for each stimulus. This resulted in 32 total average reproduction values calculated per participant (16 values each for the perceptual and drawing reproduction tasks, subdivided into eight values for cube trials and eight for parallelogram trials). The structure of the results section for Experiment 2 parallels that of Experiment 1.

Contextual biases in the perceptual reproduction task

Average reproduction values from the perceptual reproduction task are represented in Figure 5a. In order to determine whether we replicated the shape constancy perceptual effect, a 2 (stimulus condition: cube vs. parallelogram) × 8 (target angle: 29° vs. 44° vs. 57° vs. 83° vs. 97° vs. 123° vs. 137° vs. 151°) repeated measures ANOVA was conducted, using the Huynh–Feldt method to correct degrees of freedom, testing for effects on the average reproduction values from the perceptual reproduction task. Unsurprisingly, a reliable main effect of target angle was observed, $F(2.4, 54.1) = 462.82$, $p < .001$, $\eta_p^2 = .95$, indicating that participants' perceptual reproductions were sensitive to changes in the size of the target angle. We did not observe a reliable main effect of stimulus condition, $F(1, 23) = 3.65$, $p > .05$, $\eta_p^2 = .14$. However, the lack of a main effect of stimulus condition is understandable when considering that we observed a reliable interaction, $F(2.8, 85.6) = 10.67$, $p < .001$, $\eta_p^2 = .32$, which generally indicated that there were opposite directions of bias between the acute and obtuse target angles, as are detailed below.

This interaction was explored by conducting quasi-F tests comparing average reproductions between the target angles embedded in the cube and parallelogram stimuli separately for each target angle size. With respect to the acute target

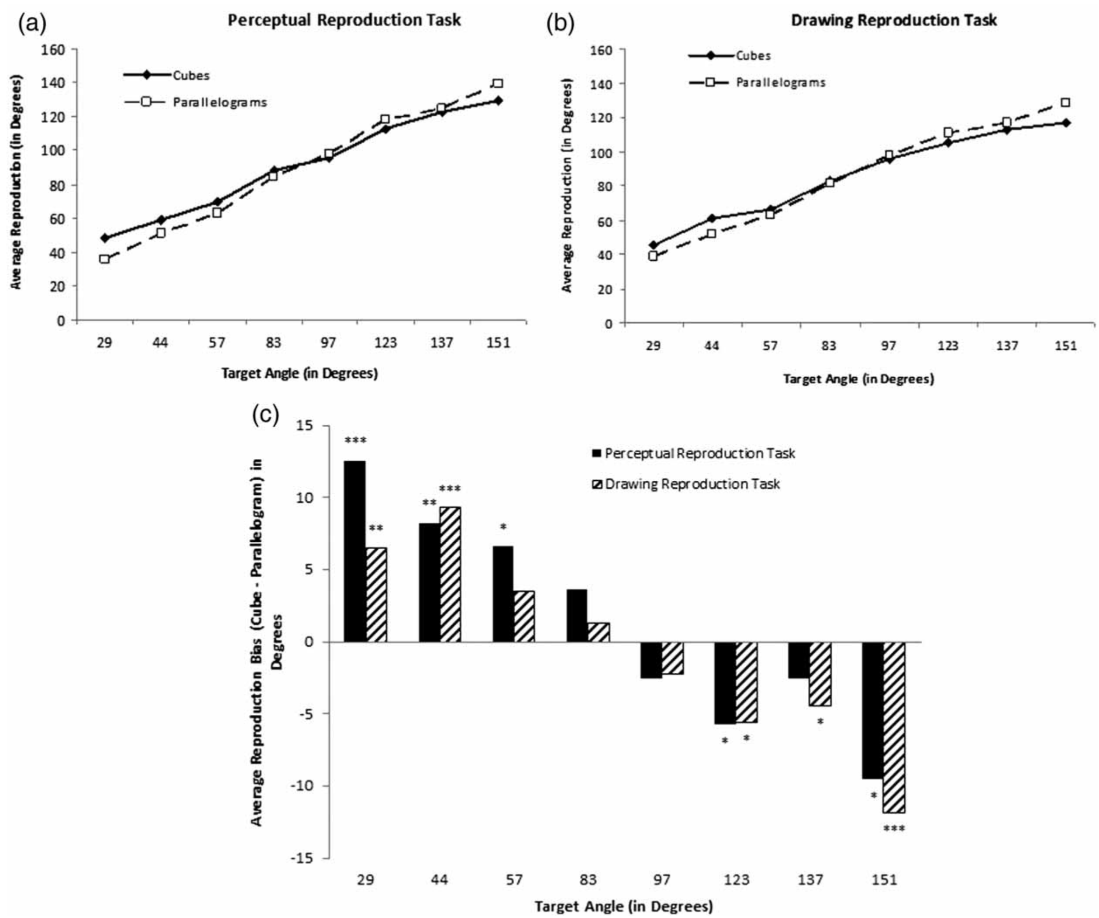

Figure 5. *Results of Experiment 2. (a) Performance in the perceptual reproduction task. Values on the* y*-axis are the mean values across participants of perceptual judgements (in degrees) of each target angle, separately for judgements made in the cube and parallelogram conditions. (b) Performance in the drawing reproduction task. Values on the* y*-axis are the mean values (in degrees) across participants of the drawings of each target angle, separately for drawings made in the cube and parallelogram conditions. (c) Mean bias scores in the perceptual and drawing reproduction tasks. Bias was calculated as the difference between the reproductions made in the cube and parallelogram conditions for each target angle. Positive bias scores indicate that the angle embedded in a cube was reproduced larger than when the same-sized angle was embedded in a parallelogram. Statistically reliable differences in the reproduced size of angles between those embedded in cubes versus parallelograms are indicated by asterisks:* *p < .05; **p < .01; ***p < .001.

angles, the target angles were perceptually reproduced as larger when embedded in cubes than when embedded in a parallelogram for the 29° target angle, $F(1, 99.9) = 17.83$, $p < .001$, for the 44° target angle, $F(1, 99.9) = 7.65$, $p < .01$, and for the 57° target angle, $F(1, 99.9) = 4.90$, $p < .05$. We did not observe a reliable difference on this comparison for the 83° target angle, $F(1, 99.9) = 1.45$, $p > .05$. With respect to the obtuse target angles, participants perceptually reproduced the target angle as reliably smaller when embedded in a cube than when in a parallelogram for the 123° target angle, $F(1, 99.9) = 3.71$, $p = .05$, and the 151° target angle, $F(1, 99.9) = 10.33$, $p < .01$. We did not observe a reliable difference on this comparison for the 97° target angle, $F = (1, 99.9) = 0.75$, $p > .05$, or the 137° target angle, $F(1, 99.9) = 0.73$, $p > .05$.

Overall, these results replicate the previously documented shape constancy effect. Since angles embedded in cubes are perceptually transformed to be closer to 90° than when embedded in parallelograms, this leads to a prediction derived from the misperception hypothesis that the drawings of angles embedded in cubes should also be closer to 90° than those embedded in parallelograms. The next analysis tests this prediction.

Contextual biases in the drawing reproduction task

Average reproduction values from the drawing reproduction task are represented in Figure 5b. In order to determine whether there is a shape constancy effect with respect to the drawing of angles, a 2 (stimulus condition: cube vs. parallelogram) × 8 (target angle: 29° vs. 44° vs. 57° vs. 83° vs. 97° vs. 123° vs. 137° vs. 151°) repeated measures ANOVA was conducted, using the Huynh–Feldt method to correct degrees of freedom, testing for effects on the average reproduction values from the drawing reproduction task. A reliable main effect of target angle was observed, $F(2.3, 51.7) = 416.34$, $p < .001$, $\eta_p^2 = .95$, indicating that the size of participants' drawings was sensitive to the changes in size of the target angles. We did not observe a reliable main effect of stimulus condition, $F(1, 23) = 0.40$, $p > .05$, $\eta_p^2 = .02$, but we did observe a reliable interaction, $F(3.5, 81.5) = 16.41$, $p < .001$, $\eta_p^2 = .42$, indicating opposite directions of drawing bias between acute and obtuse angles.

This interaction was explored by conducting quasi-*F* tests comparing the drawing reproduction values of angles embedded in cubes relative to when embedded in parallelograms separately for each target angle size. With respect to the acute target angles, participants reliably drew the target angles larger when embedded in cubes versus in parallelograms for the 29° target angle, $F(1, 102.2) = 7.86$, $p < .01$, and the 44° target angle, $F(1, 102.2) = 15.99$, $p < .001$. We did not observe reliable differences for the 57° target angle, $F(1, 102.2) = 2.27$, $p > .05$, or the 83° target angle, $F(1, 102.2) = 0.31$, $p > .05$. With respect to the obtuse target angles, the size of participants' drawings of target angles were reliably smaller when embedded in cubes than when embedded in parallelograms for the 123° target angle, $F(1, 102.2) = 5.80$, $p < .05$, the 137° target angle, $F(1, 102.2) = 3.63$, $p = .05$, and the 151° target angle, $F(1, 102.2) = 26.14$, $p < .001$. We did not observe a reliable difference in the size of the drawn 97° target angles embedded in a cube versus a parallelogram, $F(1, 102.2) = 0.94$, $p > .05$.

Relationship between perceptual and drawing reproduction contextual biases

Finally, we tested the prediction that individual variability in shape constancy should be correlated across the perceptual and drawing reproduction tasks. To do so, eight *bias scores* were calculated for each reproduction task per participant. Bias scores were defined as the difference between the average reproduction value of the target angle when it was embedded in a cube and the average reproduction value of the same target angle when it was embedded in a parallelogram (the mean bias scores are represented in Figure 5c). The resulting value is interpreted as follows. A bias score of 0 indicates no difference in the average reproduction values in cubes versus parallelogram stimuli. A positive score indicates a bias to perceive and/or draw the target angle larger when embedded in a cube than in a parallelogram.

As one can see in Figure 5c, the average bias scores are negatively related to the size of the target angle, reflecting that acute target angles were, on average, associated with positive bias scores and that obtuse angles were, on average, associated with negative bias scores. In order to determine whether there was a covarying relationship between the perceptual and drawing shape constancy biases, we calculated the slope of the best fitting regression line for each participant's bias scores across the eight target angle sizes separately for the perceptual ($M_{slope} = -2.98$, $SD = 3.56$) and drawing ($M_{slope} = -2.71$, $SD = 2.26$) reproduction tasks. Then, we calculated the Pearson *r* correlation coefficient that quantified the relationship between the slopes of the best fitting lines of the perceptual and drawing reproduction task bias scores as a function of target angle, observing a reliable positive correlation,

$r(22) = .46$, $p < .05$. Therefore, the individual variability in how shape constancy biases vary across different target angle sizes are related between perceptual judgements and drawings of angles embedded in cubes versus parallelograms.

Discussion

The results of Experiment 2 were largely consistent with the misperception hypothesis of drawing accuracy. We observed a strong congruency in bias across the perceptual and drawing reproduction tasks using stimuli eliciting a perceptual illusion due to processing 3D depth cue information. Specifically, the typical pattern of regression to a right angle was evident both when participants made perceptual judgements and when they made drawings of the size of angles. Further, we observed a covarying relationship between the shape constancy biases that were observed in the participants' perceptual judgements and drawings of angles that were embedded in cubes versus parallelograms.

GENERAL DISCUSSION

The results of both experiments largely support the misperception hypothesis of drawing accuracy: Angle drawing biases were related to inaccurate perceptual encoding of the visual information inherent in a stimulus representing an angle. Despite our making strong efforts to have the participants selectively attend only to the size of the single target angle and to ignore the surrounding contextual information, participants' perceptual judgements and drawings were still affected to varying degrees by the task-irrelevant global properties of the stimuli. Thus, the presence of such contextual cues causes the visual system to perform transformations on the bottom-up visual input that results in the perceived size of angles to systematically deviate from the veridical size of angles. In addition to the visual systems' transformations of bottom-up visual information guiding and influencing perceptual judgements of angles, such transformations also guide and influence the drawing of such angles.

Relating our findings to previous research, we observed some effects that are somewhat inconsistent with those reported by Mitchell et al. (2005). Here, perceptual biases induced by the processing of both 2D and 3D visual cues predicted the direction and magnitude of drawing biases. Whereas not all perceptual transformations predict specific drawing errors, the distinction between which transformations do or do not affect drawing may not be rooted in whether the perceptual transformations are induced by the processing of 2D versus 3D visual cues. Perhaps only sufficiently strong perceptual illusions exert a measurable influence on drawing performance. For instance, Mitchell et al. (2005) observed that the 2D version of the Shepard illusion exerted a relatively weak effect on participants' perceptual judgements: Vertically oriented lines were judged to be on average 8% longer than horizontally oriented lines of equal size in the 2D version compared to an average 22% difference in the 3D version. Since Mitchell et al. (2005) reported that drawing biases were generally weaker than perceptual biases for both the 2D and 3D versions of the Shepard illusion, it may simply be the case that the 2D version of the Shepard illusion may not induce a sufficiently strong perceptual illusion to appreciably influence drawing performance. In future empirical evaluations of the misperception hypothesis, a potentially fruitful direction may be to test the extent to which the strength of perceptual transformation processes determines whether drawings will be affected by inaccurate perceptual encoding of a model stimulus.

Another issue that should be addressed by future research pertains to whether the natural transformation processes that cause perceptual biases, such as those observed in this study, can be overcome by individuals with expertise in drawing. A popular topic of psychological research relates to identifying differences in cognitive processing ability between experts and novices in a given domain (e.g., Abernethy, Neal, & Kroning, 1994; Green & Bavelier, 2003; Jentzsch, Mkrtchian, & Kansal, 2014). The logic of such research is that by identifying what cognitive advantages experts have relative to nonartists, one could potentially identify the component cognitive processes that support skill in that domain. This methodological approach has employed to understand drawing skill, with some studies demonstrating cognitive and perceptual advantages experienced by skilled artists relative to nonartists (Chamberlain et al., 2013; Kozbelt, 2001; Ostrofsky et al., 2012; Zhou, Cheng, Zhang, & Wong, 2012) and other studies failing to find such differences (Ostrofsky, Kozbelt, & Kurylo, 2013; Perdreau & Cavanagh, 2011).

It remains open to question whether individuals who are drawing experts experience the same angle-based perceptual biases that nonartists were observed to experience in this study. Although greater skill in drawing (assessed by both subjective accuracy ratings of drawings of complex images and objective measurements of drawn angles) appears to be associated with perceptual judgement accuracy of the size of angles (Chamberlain et al., 2014, but see Carson & Allard, 2013, for a lack of difference between artists and nonartists with respect to accuracy of verbal estimates of angle sizes), those studies analysed errors in the absolute judgements of the perceived size of a plain angle (e.g., the degree to which individuals misperceive the size of a plain 60° angle). It remains unclear whether expertise in drawing is related to the degree of contextual biases in angle perception that are caused by task-irrelevant global properties of the object the angle is embedded (e.g., the degree to which individuals differ in their perceptual judgements of a 60° angle embedded in a cube versus a parallelogram or an isosceles versus a scalene triangle). Such information may further clarify why expert artists and nonartists differ in angle-drawing accuracy (Carson & Allard, 2013) and, more generally, identify the degree to which the transformational processes of visual input that determine our perceptual awareness of the environment can be inhibited.

In any case, the current study has demonstrated the considerable benefits of exploring the misperception hypothesis via tests of specific predictions about perceptual judgement errors rooted in earlier research, using identical perceptual judgement and drawing tasks, with objectively quantified drawing errors. This approach revealed evidence largely, although not perfectly, consistent with the misperception hypothesis: congruent and correlated patterns of bias in the perceptual judgement and drawing tasks. This suggests that perceptually mediated transformations of bottom-up visual stimuli affect the processing of information guiding drawing performance, with stronger perceptual transformations being associated with larger drawing errors. We believe that future research testing the misperception hypothesis would greatly benefit from adopting this methodological strategy in assessing the relationship between perception and drawing for other dimensions of visual stimuli relevant to drawing, such as relative size or brightness. Doing so will facilitate determining how robustly perceptual processes impact drawing performance.

Original manuscript received 24 March 2014
Accepted revision received 24 July 2014

REFERENCES

Abernethy, B., Neal, R. J., & Kroning, P. (1994). Visual-perceptual and cognitive differences between expert, intermediate and novice snooker players. *Applied Cognitive Psychology*, *8*, 185–211.

Blakemore, C., Carpenter, R. H. S., & Georgeson, M. A. (1970). Lateral inhibition between orientation detectors in the human visual system. *Nature*, *228*, 37–39.

Broderick, P., & Laszlo, J. I. (1987). The drawing of squares and diamonds: A perceptual-motor task analysis. *Journal of Experimental Child Psychology*, *43*, 44–61.

Carson, L., & Allard, F. (2013). Angle-drawing accuracy as an objective performance-based measure of drawing expertise. *Psychology of Aesthetics, Creativity and the Arts*, *7*, 119–129.

Chamberlain, R., McManus, I. C., Riley, H., Rankin, Q., & Brunswick, N. (2013). Local processing enhancements associated with superior observational drawing are due to enhanced perceptual functioning, not weak central coherence. *The Quarterly Journal of Experimental Psychology*, *66*, 1448–1466.

Chamberlain, R., McManus, I. C., Riley, H., Rankin, Q., & Brunswick, N. (2014). Cain's house task revisited and revived: Extending theory and methodology for quantifying drawing accuracy. *Psychology of Aesthetics, Creativity and the Arts*. Advance online publication. http://dx.doi.org/10.1037/a0035635

Cohen, D. J. (2005). Look little, look often: The influence of gaze frequency on drawing accuracy. *Perception and Psychophysics*, *67*, 997–1009.

Cohen, D. J., & Bennett, S. (1997). Why can't most people draw what they see? *Journal of Experimental Psychology: Human Perception and Performance*, *23*, 609–621.

Cohen, D. J., & Earls, H. (2010). Inverting an image does not improve drawing accuracy. *Psychology of Aesthetics, Creativity, and the Arts*, *4*, 168–172.

Cohen, D. J., & Jones, H. E. (2008). How shape constancy relates to drawing accuracy. *Psychology of Aesthetics, Creativity, and the Arts*, *2*, 8–19.

Day, R. H. (1972). The basis of perceptual constancy and perceptual illusion. *Investigative Ophthalmology*, *11*, 525–532.

Edwards, B. (1999). *Drawing on the right side of the brain* (2nd rev. ed.). New York: Penguin Putnam, Tarcher.

Fisher, G. H. (1969). An experimental study of angular subtension. *Quarterly Journal of Experimental Psychology*, *21*, 356–366.

Fry, R. (1919/1960). *Vision and design*. NY: Meridian Books.

Green, C. S., & Bavelier, D. (2003). Action video games modifies visual selective attention. *Nature*, *423*, 534–537.

Gregory, R. L. (1997). *Eye and brain: The psychology of seeing*. 5th edition. Princeton: Princeton University Press.

Hammad, S., Kennedy, J. M., Juricevic, I., & Rajani, S. (2008). Angle illusion on a picture's surface. *Spatial Vision*, *21*, 451–462.

Huynh, H., & Feldt, L. S. (1976). Estimation of the Box correction for degrees of freedom from sample data in randomised block and split-plot designs. *Journal of Educational Statistics*, *1*, 69–82.

Jentzsch, I., Mkrtchian, A., & Kansal, N. (2014). Improved effectiveness of performance monitoring in amateur instrumental musicians. *Neuropsychologica*, *52*, 117–124.

Kennedy, G. J., Orbach, H. S., & Loffler, G. (2008). Global shape versus local feature: An angle illusion. *Vision Research*, *48*, 1281–1289.

Kozbelt, A. (2001). Artists as experts in visual cognition. *Visual Cognition*, *8*, 705–723.

Kozbelt, A., Seidel, A., ElBassiouny, A., Mark, Y., & Owen, D. R. (2010). Visual selection contributes to artists' advantages in realistic drawing. *Psychology of Aesthetics, Creativity, and the Arts*, *4*, 93–102.

McManus, I. C., Chamberlain, R. C., Loo, P.-W., Rankin, Q., Riley, H., & Brunswick, N. (2010). Art students who cannot draw: Exploring the relations between drawing ability, visual memory, accuracy of copying and dyslexia. *Psychology of Aesthetics, Creativity, and the Arts*, *4*, 18–30.

McManus, I. C., Loo, P.-W., Chamberlain, R. C., Riley, H., & Brunswick, N. (2011). Does shape constancy relate to drawing ability? *Two failures to replicate. Empirical Studies of the Arts*, *29*, 191–208.

Mitchell, P., Ropar, D., Ackroyd, K., & Rajendran, G. (2005). How perception impacts on drawings. *Journal of Experimental Psychology: Human Perception and Performance*, *31*, 996–1003.

Nundy, S., Lotto, B., Coppola, D., Shimpi, A., & Purves, D. (2000). Why are angles misperceived? *Proceedings of the National Academy of Sciences*, *97*, 5592–5597.

Ostrofsky, J., Cohen, D. J., & Kozbelt, A. (in press). Objective versus subjective measures of face-drawing accuracy and their relations with perceptual constancies. *Psychology of Aesthetics, Creativity and the Arts*. doi:10.1037/a0037558

Ostrofsky, J., Kozbelt, A., & Kurylo, D. D. (2013). Perceptual grouping in artists and non-artists: A psychophysical comparison. *Empirical Studies of the Arts*, *31*(2), 131–143.

Ostrofsky, J., Kozbelt, A., & Seidel, A. (2012). Perceptual constancies and visual selection as predictors of realistic drawing skill. *Psychology of Aesthetics, Creativity and the Arts*, *6*(2), 124–136.

Perdreau, F., & Cavanagh, P. (2011). Do artists see their retinas? *Frontiers in Human Neuroscience*, *5*(171). doi:10.3389/fnhum.2011.00171

Purves, D., & Howe, C. Q. (2005). *Perceiving geometry: Geometrical illusions explained by natural scene statistics*. New York: Springer.

Rock, I. (1997). *Indirect perception*. Cambridge: MIT Press.

Ruskin, J. (1857/1971). *The elements of drawing*. Mineola, NY: Dover.

Shepard, R. (1990). *Mind sights: Original visual illusions, ambiguities, and other anomalies*. San Francisco: W.H. Freeman.

Thouless, R. H. (1931). Phenomenal regression to the real object. Part I. *British Journal of Psychology*, *21*, 339–359.

Thouless R. H. (1932). Individual differences in phenomenal regression. *British Journal of Psychology*, *22*, 216–241.
Todorovic, D. (2002). Constancies and illusions in visual perception. *Psihologija*, *35*, 125–207.
Todorovic, D. (2010). Context effects in visual perception and their explanations. *Review of Psychology*, *17*, 17–32.
Tchalenko, J. (2009). Segmentation and accuracy in copying and drawing: experts and beginners. *Vision Research*, *49*, 791–800.
Zhou, G., Cheng, Z., Zhang, X., & Wong, A. C. N. (2012). Smaller holistic processing of faces associated with face drawing experience. *Psychonomic Bulletin and Review*, *19*, 157–162.