The Relationship Between Shape Perception Accuracy and Drawing Ability.

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Research Article

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Abstract

Accurate shape perception is critical for object perception, identification, manipulation, and recreation. Humans are capable of making judgements of both objective (physical) and projective (retinal) shape. Objective judgements benefit from a global approach by incorporating context to overcome the effects of viewing angle on an object's shape, whereas projective judgements benefit from a local approach to filter out contextual information. Realistic drawing skill requires projective judgements of 3D targets to accurately depict 3D shape on a 2D surface, thus benefiting from a local approach. The current study used a shape perception task that comprehensively tests the effects of context on shape perception, in conjunction with a drawing task and several measures of local processing bias, to show that the perceptual basis of drawing skill in neurotypical adults is not due to a local processing bias but to *perceptual flexibility*, the ability to process local or global information as needed.

Introduction

The Relationship Between Shape Perception Accuracy and Drawing Ability

The three-dimensional (3D) shape of objects and environments can be accurately determined almost instantaneously from the two-dimensional (2D) sensory information received by our retinas. This seemingly effortless capacity depends on powerful underlying neural mechanisms [1] which are the basis for shape constancy, the ability to perceive an object as having the same physical structure and shape despite a change in viewing angle [2,3]. Shape constancy is necessary for object identification [4] and facilitates action such as effortlessly grasping an item with proper hand position [5,6]. While estimating the objective (physical) shape of objects is useful for our daily interactions with the world, some people (individuals with realistic drawing skills) are also capable of accurately portraying a 3D scene or object as a 2D image, a process that seems inherently difficult to others. This difficulty stems from the fact that realistic drawing requires one to perceive and render the projective rather than objective shapes of objects and surfaces [7-9].

A principal theory of shape constancy is the shape-slant-invariance hypothesis which proposes that the accuracy of objective shape perception is dependent on accurate estimates of surface slant [10,11] (see also [12]). Much of the previous research on the estimation of shape from different viewing angles has focused on contextless estimates of isolated flat surfaces. Some of these studies have investigated projective estimates of shape [2] while others have investigated objective estimates [13]. Generally, it has been found that error in estimating shape increases with increasing slant, with projective judgements shifted in the direction of objective shapes (wider than correct estimates) while objective judgements are shifted in the direction of the projective shape (narrower than correct estimates) [for reviews, see 14-16]. Only a handful of studies have investigated the effects of context on the perception of flat shapes, demonstrating a degree of shape constancy when making objective judgements [17,18]. The only study to investigate all combinations of judgement (objective, projective) and context (present, absent) conditions demonstrated that the presence of even a small amount of 3D context facilitates objective

judgements but hinders projective judgements, whereas a lack of context has the opposite effect [19]. Sereno et al. [19] found that context facilitated shape judgements by improving estimates of surface orientation. Here we propose that it is the presence of 3D context that makes the projective judgements that are necessary for realistic drawing especially difficult.

Several studies have explicitly investigated the relationship between projective shape judgements and drawing ability [2,7,8,20,21]. One study found that errors in perception and drawing of parallelograms were greater when context was present in line drawings [8]. Another study observed that errors in projective shape judgements of parallelograms (window frames) in the presence of context (a building) were negatively correlated with drawing accuracy, suggesting that the ability to overcome normal shape constancy mechanisms responsible for the perception of objective shape is associated with greater drawing accuracy [7] (c.f., [22]). Further studies have demonstrated a relationship between drawing skill and perceptual accuracy in estimating the projective shape of angles embedded in 3D context [20,21].

Common errors in realistic drawing often reflect the artist's bias towards representing the perceived physical properties of their target [23-25]. For novice artists, this "top-down" approach [26] of utilizing additional knowledge and perspectives about the object can distort shape, size, proportion, and the presence of features. Conversely, individuals with an opposing "bottom-up" processing style are seen as possessing greater accuracy in drawing, since they render necessary line segments without the influence of additional "unseen" qualities of the object [27-29]. Individuals with Autism Spectrum Disorder (ASD) [30-32] or those who score high on measures of autistic tendencies [33,34] demonstrate a strong local processing bias associated with bottom-up processing approaches [30,32,33], and have been shown to be more accurate in their realistic drawings [32], as well as less susceptible to visual illusions that rely on context [31,34]. Previous research has proposed that a local processing bias in neurotypical adults also benefits realistic drawings abilities [28].

Other research, however, suggests that global processing is not impaired in participants with drawing skill [35] and that attention may instead be a primary factor that modulates the influence of context effects in drawing ability [35,36]. Compared to non-artists, trained artists performed better on tests of projective size (but not shape) judgements [36,37] and a limited-line tracing test, which indicated how well-placed participants' focus of attention was when depicting an object. Another study [35] showed that realistic drawing ability in adult artists and non-artists is associated with enhanced local processing as assessed by accuracy on the Group Embedded Figures task, completion times in the Block Design Task, and reduced global interference on reaction times in the Navon shape task. Since the global precedence effects in the Navon task were still extant in skilled drawers, Chamberlain et al. [35] also conclude that the local processing biases linked to drawing ability are not due to a reduction in global processing abilities but to an enhancement of local processing and the ability to filter out global information.

In the present study we develop a methodology to test disparate theories regarding the relationship between the perception of 3D shape and drawing skill. Skill in drawing relies on the ability to perceive and render projective shape irrespective of context. Perceptually, this can be accomplished if the perceiver has

a local processing bias (i.e., enhanced local processing at the expense of global processing) or a flexible processing style in which context can be ignored (e.g., when drawing) or utilized (e.g., for shape constancy) as needed. Most research on the relationship between shape perception and drawing skill has focused on testing local processing abilities and biases, including a focus on the ability to make projective shape judgements with or without 3D context [2,7,28]. To tease the local processing bias and flexible processing accounts apart, one must test shape perception more broadly, for example, by using a completely crossed design which includes all combinations of judgement (objective, projective) and context (present, absent) conditions [19]. If a local processing bias is the perceptual basis of drawing accuracy, it would be predicted that drawing accuracy will be associated with better performance on a projective-with-context shape constancy task but worse performance on an objective-with-context task, in which it is necessary to integrate context to achieve good performance. Alternatively, a perceptually flexible style would be associated with improvements in both objective and projective shape judgements viewed in a variety of circumstances (e.g., with or without context). This predicts that drawing accuracy will be associated with better performance on all shape constancy tasks. Thus, to differentiate the local processing bias and flexible processing theories, we use a shape perception task that comprehensively tests the effects of context on shape perception [19] in conjunction with a drawing task and several potential measures of local processing bias. Through this comprehensive approach, we are able to provide strong evidence regarding the perceptual style associated with skill in shape perception as it relates to drawing ability.

Results

The experiment consisted of 3 parts (see Methods) including a shape judgement task (see *Figure 1* and [19]), a drawing task (see *Figure 2*), and several questionnaires: the Autism Quotient (AQ), Systemizing Quotient-Revised (SQ), and questions regarding previous art training and participant demographics. We first analyze results from the shape judgement and drawing tasks, then perform a series of regression analyses predicting shape judgment task performance from drawing ability and questionnaire responses.

Questionnaires:

To address potential biases in processing tendencies, participants rated their agreement with 50 statements for the AQ (with possible scores ranging from 0-50) and 75 statements for the SQ (with possible scores ranging from 0-150). AQ scores ranged from 5-34 ($M=17.88$, $SD=4.89$) with two participants with scores in the range of clinically significant autism traits. SQ scores ranged from 20-125 ($M=60.66$, $SD=17.89$). Out of the 125 participants, 13% of participants ($n=16$) reported having taken at least one college level art course (which included options such as drawing, ceramics, and painting).

Shape Judgement Task:

We measured error in two ways. *Error bias* was a measure of signed magnitude (the difference between reported and correct width on each trial) where positive values indicate shape width estimates that are wider than the correct shape and negative values indicate estimates that are narrower than the correct

shape; *error magnitude* was a measure of absolute magnitude (the absolute value of the difference between reported and correct width on each trial). Both types of error were recorded in pixels but are reported here as degrees of visual angle. Scores were computed for each trial and averaged within conditions (collapsed across positive/negative rotation at each rotation angle and across all object widths) for each participant. We corrected for a small size-constancy confound in the data (see [19]), due to the probe stimulus being presented at 0° disparity, whereas the mean depth of the face of interest was in front of the 0° disparity plane, with the least rotated stimuli (+/-40°) at a farther perceived distance from the 0° disparity plane than the most rotated stimuli (+/-80°). Because of size-constancy mechanisms, estimates of width were expected to be narrower for all of the angles of rotation but with the greatest effects on the least rotated stimuli which is confirmed by our data. Error bias, collapsed over all conditions, was on average slightly negative (-0.12° of visual angle), and was also more negative for the smallest (-0.16° visual angle for +/-40° rotation) compared with the medium (-0.13° visual angle for +/-60° rotation) and largest (-0.07° visual angle for +/-80° rotation) rotations. To correct for this small artifact, we subtracted the net bias for each angle (i.e., the mean error bias) from the individual bias scores for that angle (similar to “mean centering”, see [38] for further discussion of the term), thus updating the error magnitude scores as well. Adjusted scores were then used to compute error bias and magnitude, and demonstrated similar results with or without the size-constancy correction.

Data were first cleaned by removing trials in which response times were extremely short (<500ms) or long (>30s; 4.4% of trials discarded). Using error bias as a measure, our results (*Figure 3a*) replicate our previous results [16]. Overall, performance declined as the stimulus was rotated away from a forward-facing orientation. In addition, participants performed better at the objective width-judgement task with context than without context, whereas performance was better on the projective width-judgement task with no context than with context. Since our primary interest was in the effects of context- and judgement-types on error, we collapsed across angle of rotation and performed a 2x2 ANOVA with context (present, absent) and judgement (objective, projective) as within-subjects factors. There were main effects of context ($F(1, 124)=75.48, p<0.001^*, h^2=.378$) and judgement ($F(1, 124)=74.70, p<0.001^*, h^2=.376$). Error bias was positive (wider width estimates) when context was present ($M=0.10^\circ, CI=[0.05^\circ, 0.14^\circ]$) and negative (narrower width estimates) when context was absent ($M=-0.01^\circ, CI=[-0.14^\circ, -0.06^\circ]$). Error bias was also positive for projective judgements ($M=0.15^\circ, CI=[0.10^\circ, 0.19^\circ]$) and negative for objective judgements ($M=-0.15^\circ, CI=[-0.20^\circ, -0.09^\circ]$).

Figure 3b plots the effects of rotation angle, context, and judgement-type on error magnitude. Performance declined as the stimulus was rotated away from a forward-facing orientation. In addition, performance was best for the projective/no-context and objective/context (shape constancy) conditions and worse for the objective/no context and projective/context conditions. After collapsing across angle, a 2x2 ANOVA with context (present, absent) and judgement (objective, projective) as within subjects factors revealed main effects of context ($F(1, 124)=5.34, p=.02^*, h^2=.041$) and judgement ($F(1, 124)=5.27, p=.02^*, h^2=.041$) and an interaction between context and judgement ($F(1,124)=107.66, p<0.001^*, h^2=.465$) shown in *Figure 3c*. When making objective judgements, errors were greater when

context was absent ($M=0.75^\circ$, $CI=[0.73^\circ, 0.77^\circ]$) than when context was present ($M=0.69^\circ$, $CI=[0.67^\circ, 0.71^\circ]$). Whereas, when making projective judgements, errors were smaller when context was absent ($M=0.65^\circ$, $CI=[0.63^\circ, 0.67^\circ]$) than when context was present ($M=0.75^\circ$, $CI=[0.72^\circ, 0.77^\circ]$).

Drawing Task:

Participants completed 1-minute sketches of a series of 25 photographs, 5 photographs from each of the following categories – objects (still-lives), animals, plants, buildings, and natural scenes (photographs shown in *Figure 2* and example drawings in *Figure 4*). Participant drawings were rated independently on a scale from 1-5 (low to high accuracy of the renditions) by two raters. Interrater reliability was assessed using Chronbach's alpha and was found to be adequate with an alpha of .79. Average overall drawing rating across participants was 2.16 ($SD=.46$). There was no significant difference in drawing ability ($t(123)=-.51$, $p=.61$) between those who had taken a college-level drawing course ($n=16$, $M=2.22$, $SD=.40$), and those who had not ($n=109$, $M=2.15$, $SD=.46$). Previous drawing course experience did not predict shape judgement performance ($r=.046$, $n=125$, $p=.61$), thus our measure of having taken a college-level drawing course may not be a useful indicator of drawing ability and was not included in any further analyses, though we cannot rule out that previous drawing course experiences including high school or other drawing training could have an impact on shape judgement performance.

A principle component analysis with oblique rotation (promax) was completed on participants' drawing accuracy scores to assess how the 25 image variables (i.e., photographs) clustered. The Kaiser-Meyer-Olkin measure verified the sampling adequacy for the analysis, $KMO=0.96$, which is well above the acceptable limit of 0.5. Two components were rotated, based on the criterion of eigenvalues >1 and the scree plot. The two components explained 50.74% of the variance in drawing accuracy, with the first component accounting for 46.38% of the variance, and the second component accounting for 4.36% of the variance. *Table 1* displays the items and component loadings (b -values) for the rotated components.

The first component comprised images with discrete, mostly convex objects and the second comprised scenes with complex spatial relationships between parts. The first component included all images of animals and still-life (objects), while the second included all of the natural landscape images. The plant images tended to load more heavily on the second component except for images with discrete convex shaped objects (gourds and vegetables), which loaded on both components, having some apparent similarity to the still-life images. The buildings were mixed, with two images with second component loadings (castle, skyscrapers), one with a first component loading (houses), and two with loadings on both components (buildings at the University of Oregon – Willamette Hall and Knight Law School). In general, the distinction was between discrete "objects" within a space vs. "scenes," whether natural (landscapes, plants) or constructed (buildings), which consist of a mosaic of abutting and overlapping shapes and surfaces that define or encompass the entire space.

Regression Analyses:

We first investigated the relationship between the different shape judgement tasks by examining the correlations of the error scores between the four shape perception conditions – projective judgements with context (PWC), objective judgements with context (OWC), projective judgements without context (PNC), and objective judgements without context (ONC) – by performing a two-tailed Pearson product-moment correlation analysis: PWC and PNC ($r=.63$, $n=125$, $p<.001^*$), PWC and OWC ($r=.44$, $n=125$, $p<.001^*$), PWC and ONC ($r=.43$, $n=125$, $p<.001^*$), PNC and ONC ($r=.45$, $n=125$, $p<.001^*$), PNC and OWC ($r=.45$, $n=125$, $p<.001^*$), OWC and ONC ($r=.50$, $n=125$, $p<.001^*$). The correlations are moderate, suggesting that greater accuracy in any one condition is related to greater accuracy in the others.

We next performed an analysis to answer the question of how drawing ability and local processing bias are related to shape perception accuracy. We select shape perception accuracies as outcome variables because the act of drawing drives one to perceive shape in a multitude of ways which may then influence shape perception accuracy. The presence of a local processing bias may also influence shape perception accuracy. We performed a two-step hierarchical linear regression analysis to examine the relationship between our outcome variables (shape perception accuracies) and several possible predictor variables (drawing accuracy and two measures of perceptual processing bias, the AQ and SQ). We consider each outcome variable separately – PWC, OWC, PNC, and ONC, as well as error magnitude collapsed over all judgement conditions (Average), since the different shape judgement task error scores are significantly correlated with each other. In each analysis, drawing accuracy is a predictor in model 1 and drawing accuracy as well as AQ and SQ are predictors in model 2.

The tests of *model significance* are shown in *Table 2*. Statistical significance is reported for model 1 as well as the change statistic going from model 1 to 2. Model 1 is significant for all outcome variables except OWC. None of the change statistics are significant indicating that AQ and SQ scores do not significantly explain any additional amount of variance in shape judgement error.

The tests of *predictor significance* for the 5 outcome variables are shown in *Table 3*. Statistical significance is reported for each predictor variable in models 1 and 2. Drawing accuracy is a significant predictor of error magnitude in models 1 and 2 for all shape judgements (PWC, PNC, ONC, and Average) except OWC. The AQ and SQ scores are not significant predictors of error magnitude for any of the judgement conditions. A plot of the significant correlation between the predictor variable drawing accuracy and the outcome variable average shape judgement error is shown in *Figure 5a*. The best linear fit is $\text{Shape_Judgement_Error}_{(\text{Average})} = 0.84 - 0.059 \times \text{Drawing_Accuracy}$, for which $R^2 = 0.07$.

Our final set of regression analyses investigated the relationship between local processing bias and drawing ability. Individuals with a local processing bias should score high on the AQ and SQ and also have small difference scores between conditions with and without context (OWC minus ONC, referred to as here as “DO”, and PWC minus PNC, referred to here as “DP”) because context should have little effect on their error scores. If local processing bias is a factor which underlies drawing skill, there should be a positive relationship between the AQ and SQ scores and drawing accuracy and a negative relationship between the DO and DP scores and drawing accuracy.

We first tested the construct validity of our local processing measures by performing a two-tailed Pearson product-moment correlation analysis on the four measures of local processing bias. The only significant correlation was between the difference in projective judgement task error magnitude scores with and without context (DP) and SQ ($r = -.20$, $n = 125$, $p = .03^*$) (see *Figure 5b*). The best linear fit is $DP = 0.17 - 0.0013 \times SQ$, for which $R^2 = 0.038$. As SQ scores increase in value DP scores decrease with the regression line approaching "0" (no difference between projective judgement scores whether context is present or absent). For these two measures, a local processing bias is indicated by a high SQ score and low DP score, which explains the significant negative correlation between these two variables. The correlations among the other measures of local processing bias were not significant: DP and AQ ($r = .15$, $n = 125$, $p = .10$), DO and AQ ($r = -.03$, $n = 125$, $p = .75$), DO and SQ ($r = .01$, $n = 125$, $p = .95$), DP and DO ($r = .01$, $n = 125$, $p = .93$), AQ and SQ ($r = .10$, $n = 125$, $p = .28$).

Finally, we conducted a two-tailed Pearson product-moment correlation analysis to examine the relationship between drawing ability and the four measures of local perceptual processing bias (DP, DO, AQ, SQ). None of the correlations were significant supporting the conclusion that there is no significant relationship between drawing ability and local processing bias: $r = .02$, $n = 125$, $p = .82$ for drawing accuracy and DP, $r = .05$, $n = 125$, $p = .55$ for drawing accuracy and DO, $r = .001$, $n = 125$, $p = .998$ for drawing accuracy and AQ, and $r = .06$, $n = 125$, $p = .52$ for drawing accuracy and SQ.

Discussion

Prior research on the relationship between shape perception and drawing skill has primarily focused on relating drawing skill to 1) performance on shape detection tasks (e.g., projective shape judgements) that measure the ability to overcome shape constancy mechanisms [2,7,8,20,21], and 2) measures of local processing ability (AQ and SQ questionnaires; Group Embedded Figures, Block Design, and Navon tasks) [28,35]. There have been fewer tests of the relationship between global processing abilities and drawing skill [35]. The present study contrasted two theories of the perceptual basis of drawing skill – the predominant *local processing bias theory* and the proposed *perceptual flexibility theory*. The local processing bias theory contends that skill in drawing is due to enhanced local processing (the ability to focus on local parts of an array at the expense of global processing), which has the effect of filtering out context [28]. The perceptual flexibility theory, in contrast, proposes that drawing skill can be accomplished using a flexible processing style in which context can be disregarded or utilized as needed. Such a processing style is potentially based on attentional mechanisms rather than built-in perceptual biases.

Several studies have suggested that attention may be a factor that modulates the influence of context effects in drawing ability. Examples include knowledge of which aspects of form are most important for depiction [36,37] or the use of stored schemas for depiction of familiar objects [25]. Attention as a top-down processing mechanism has been contrasted with a bottom-up view which suggests that accurate projective judgements are a result of the reduction or suppression of perceptual transformations which result in shape constancy [7]. One such bottom-up mechanism is a local processing bias which may serve to exclude contextual information, thereby making it easier to represent projective information [28].

Here, we posit a flexible processing style based on attentional mechanisms as an alternative to a bottom-up theory of the perceptual basis of shape estimation in drawing skill. That is, we propose a “top-down” attention-based account of the process of overcoming shape constancy for the purpose of estimating projective shape to accurately depict 3D shape on a 2D surface.

To distinguish between a “bottom-up” local processing theory and “top-down” perceptual flexibility theory, we measured perceptual processing of shape using interrelated tasks in which the utilization of context either helped or hindered performance (*Figure 1*). This shape judgement experiment used a fully crossed design that varied both judgement type (projective, objective) and context (present, absent). We then related performance on the different shape judgement conditions to drawing accuracy on a drawing task (*Figures 2 and 4*) and to various measures of local processing bias.

The shape judgement experiment successfully replicated and extended findings from previous research [19]. When examining error bias, participants were more accurate at judging projective shape when 3D context was absent and objective shape when 3D context was present. Conversely, bias emerges for projective shape judgements when context is present (wider than correct estimates) and for objective shape judgements when context is absent (narrower than correct estimates) (see *Figure 3a*). When examining error magnitude, error increased with angle of rotation, with the least amount of error, again, in the projective with no context and objective with context conditions (*Figure 3b,c*). These results demonstrate that the normal presence of 3D context facilitates shape constancy mechanisms (judgements of objective shape) but hinders judgements of projective shape, which are necessary for observational drawing.

For the drawing task, a principle component analysis on drawing accuracy scores assessed the clustering of the 25 image variables (25 photos from 5 categories), revealing two significant components (see *Table 1*). The first component included photos of discrete “objects” (still-lives and animals) while the second component comprised images of “scenes” (landscapes, plants, buildings). Thus, drawing accuracy scores on the “object” photos were related to each other as were the scores for the “scene” photos, with drawing accuracy for the “object” photos most indicative of participant’s overall drawing skill.

To investigate the relationship between perceptual abilities and drawing accuracy, we performed a series of regression analyses. Overall, these analyses demonstrated a negative relationship between drawing ability and shape judgement error magnitude (see *Tables 2 and 3* and *Figure 5a*). Higher drawing accuracy was associated with lower shape perception error. Drawing accuracy predicted error on all the shape judgement tasks (projective-with-context (PWC), projective-without-context (PNC), objective-without-context (ONC), and overall error (Average)) except the objective-with-context (OWC) task. These results support a flexibility theory rather than a local processing bias theory. A local processing bias theory predicts that drawing accuracy will be associated with better performance on the projective-with-context task but worse performance on the objective-with-context task, since good performance in the later task depends on the use of contextual information. Although the relationship between the OWC judgements and drawing accuracy was not significant, it trended in the direction of a negative (higher

drawing accuracy, lower OWC error) rather than a positive (higher drawing accuracy, higher OWC error) relationship as predicted by the local processing bias theory. The fact that the negative relationship with drawing accuracy was not significant is not surprising, since OWC judgements are the basis of shape constancy and epitomize normal perceptual function. Importantly, only drawing accuracy but not AQ and SQ scores, as measures of local processing bias, significantly predicted shape perception accuracy.

Additional regression analyses investigated the relationship between several measures of local processing bias – the AQ, SQ and two difference scores (DP, DO) – and drawing ability. Individuals with a local processing bias should score high on the AQ and SQ and also have small difference scores between conditions with and without context, since context should not influence their judgements. When comparing the four measures of local processing bias, the only significant correlation was between SQ and DP scores (see *Figure 5b*). As expected, as SQ scores increased in value DP scores decreased with the regression line approaching zero (no influence of context on the projective judgement scores).

Regarding the relationship between the four measures of local processing bias and drawing ability, a local processing bias account of drawing ability predicted that participants with small difference scores would have higher drawing accuracy scores resulting in a negative correlation between drawing accuracy and objective and projective difference scores, and that there should be positive correlations between drawing skill and AQ and SQ scores. None of the local processing bias measures predicted drawing accuracy, providing evidence against a local processing bias account of drawing skill.

The present study investigated the relationship between drawing ability and perception for the purpose of answering the question of whether and how individuals with varying drawing abilities perceive the world differently from each other. Our focus was on the perception of simple 3D shapes. We utilized a methodology that included a shape perception task with a completely crossed design to fully assess the effects of different contexts and judgements on perception, in conjunction with a drawing task and measures of local processing bias. Our results provide strong evidence that the perceptual basis of drawing skill in neurotypical adults is not due to a local processing bias but to *perceptual flexibility*, the ability to process local or global (i.e., contextual) information as needed. These results are supported by other investigations demonstrating that superior skill in drawing is associated with enhanced local processing due to successful filtering of global information rather than a reduction in global processing abilities [35]. Flexibility between local and global processing is required to make accurate judgements of 3D shape in contrasting conditions, such as for objective-with-context judgements (shape constancy), where utilization of context is helpful and for projective-with-context judgements (drawing tasks), where filtering out context is beneficial. In general, errors in shape judgement were significantly explained by drawing accuracy, suggesting that with improved realistic drawing abilities may come greater perceptual control between the implementation of local and global approaches to processing 3D context. Likewise, a variety of measures of local processing bias did not predict shape judgement error or drawing accuracy. Results from the current study suggest that perceptual flexibility as a processing style in perceiving 3D shape may rely on attentional mechanisms rather than built-in perceptual biases, a topic for future investigations.

Methods

Participants:

To examine the extent to which artistic ability plays a role in perception of visual shape, 125 students were recruited from the University of Oregon Psychology and Linguistics Departments' Human Subjects Pool for this study. To guarantee that our sampled population contained a more even distribution of artistic abilities, roughly half of the participants were recruited based upon their agreement with a statement in a prescreen questionnaire that read "I have an excellent ability to realistically draw things I see in the world". Participants received either class credit for their participation or were compensated monetarily for their time. All participants indicated they had normal or corrected-to-normal vision and completed the Stereo Fly SO-001 test (Stereo Optical, Inc., Chicago, IL) to verify that they also had normal depth perception. Specifically, participants were required to score an 8 or above on the Graded Circles Test to be qualified to participate in the experiment. Informed consent was acquired following protocol approved by the Institutional Review Board at the University of Oregon, and all measurements were performed in accordance with relevant guidelines and regulations for research involving human subjects as approved by this review board.

Shape Judgement Task:

Stimuli. The stimuli for the experiment consisted of 36 computer-generated red/blue anaglyphs, presented against a black background at a height of approximately 9 degrees of visual angle. The software to generate the stimuli was written in C (utilizing OpenGL) and Tcl/Tk [39]. The stimuli were systematically rotated polyhedra drawn with an orthographic projection (see *Figure 1a* for a schematic of one polyhedron). The polyhedra were first rotated downward around the x-axis by 25 degrees, then rotated by 20 degree increments around the y-axis. Orientation of these figures varied from ± 80 degrees from the frontoparallel plane, rotated around the vertical axis, including 6 different possible viewing angles (rotated ± 40 , ± 60 , or ± 80 degrees; the 0-degree stimulus was not presented). One half (18) of the stimuli were rectangular cuboid polyhedra (*Figure 1b*); the other half were isolated rectangles oriented in 3D space (*Figure 1c*). Each rectangle and visible polyhedral face was completely tessellated with 32 triangles. Participants judged the width of a rectangle (the face schematically highlighted in gray in *Figure 1a*). During blocks that displayed polyhedra, a small white arrow was used to indicate which of the faces should be attended for a subsequent matching judgement (*Figure 1b*). When facing forward (0 degrees of rotation), the depth of the polyhedra was equal to their height. The width of the polyhedra varied, with 3 different width-to-height ratios used: 0.75, 1.0 (square), and 1.25. The 36 stimuli, consisted of the combination of 6 viewing angles, 3 object widths, and 2 shapes (single rectangular face or rectangular face that is part of a polyhedron).

The response stimulus was an adjustable test shape which was a correct rendering of the face-of-interest stimulus (narrow, medium, or wide width) as a simple white outline, with its width offset by a random amount (between ± 45 pixels). For the objective judgement blocks, the test shape was the physically accurate shape, again with jitter added to the width (*Figure 1d*). For the projective judgement blocks, it

was an outline of the projective image (the shape in the picture plane) with added width jitter (*Figure 1e*). Importantly, the added width jitter and adjustments in both cases was to the actual width of the face of interest. For the projective judgements, the resultant projective shape is what is presented to participants. This is critical methodologically because it allows for the direct comparison of objective and projective error.

Procedure and Design. Participants sat approximately 15 inches from the computer screen and donned a pair of red-blue anaglyph glasses. Participants were instructed to complete a shape judgement task in which they were directed to make either a projective (2D width in the picture plane) or objective (the actual width of the stimulus if it were seen straight on) decision about the computer-generated red/blue anaglyphs presented. A tilted rectangular shape was shown with or without 3D context. Stimuli having 3D context contained the rectangular face as part of a polyhedron; stimuli without 3D context consisted of the rectangular face presented alone. Stimuli were present for 3000ms followed by a blank screen for 1000ms. After making the indicated judgement during the presentation of the stimuli, participants were instructed to recreate the dimensions of the target as accurately as possible by using the up and down arrow keys on the computer's keyboard to adjust the width of a parallelogram to match the previously presented stimulus in terms of its projective or objective shape. Participants completed four types of blocks – the two different types of judgements made in two different contexts (with or without 3D context). Each block contained 54 rectangular shape target stimuli (6 angles of rotation x 3 shapes x 3 within-block repetitions. Block order, and stimulus angle and shape within each block were randomized.

Drawing Task:

Following the shape judgement task participants completed 1-minute sketches of a series of 25 gray-scale photographs taken using a Nikon D3 digital camera and drawn from a larger set of photos from 5 categories: animals, buildings, objects (still-life), plants, and natural scenes (landscapes), with 5 photographs drawn from each category, see *Figure 2*. Photograph presentation order was randomized and participants were instructed to draw the photographs as accurately as possible and to focus on the general contours, geometry, and correct proportions over the small details, shading and/or texture in producing their sketches. The collection of drawings from each subject were rated for level of drawing accuracy (in terms of how closely the drawing resembled the photograph primarily based on accuracy in rendering the contours and proportions) by researchers on a scale ranging from 1-5 (low accuracy to high accuracy).

Questionnaires:

After the drawing task, all participants completed a multi-part questionnaire containing the Autism Quotient (AQ), Systemizing Quotient-Revised (SQ), as well as questions regarding previous art training and participant demographics. The quotients were scored based upon participants' ratings of the degree to which the statements were representative of themselves, providing a score of autistic tendencies in general [40] as well as systemizing tendencies in particular [41,42].

Declarations

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

Open Practices

Requests for the data or materials can be sent via email to the first author.

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Tables

Table 1

Image Category	Image Name	Component	
		1	2
Still-Life	1. cat toys	.865	
	2. cricket toy	.849	
	3. vases, candle, etc.	.760	
	4. cup, saucer, etc.	.663	
	5. glass, shaker, etc.	.543	
Animal	6. pigeon	.748	
	7. flamingo	.704	
	8. squirrel	.692	
	9. cat	.534	
	10. pony	.530	
Plant	11. leaves		.723
	12. lily		.547
	13. bell flower		.478
	14. vegetables	.376	.369
	15. gourds	.454	.324
Building	16. sky scrappers		.859
	17. castle		.608
	18. Knight Law School	.360	.366
	19. Willamette Hall	.376	.329
	20. houses	.487	
Landscape	21. river canyon		.831
	22. Crater Lake		.673
	23. lake canyon		.653
	24. arch		.643
	25. Horseshoe Bend		.513

Table 1: PCA results displaying the 25 image variables (photographs) and component loadings (*b*-values) for the two detected components. The 5 pre-defined image categories are also indicated. The first

component encompasses the animal and still-life photographs (discrete objects), whereas the second is comprised primarily of landscape, plant, and building photographs (scenes). Some of the building and plant photos also have loadings on component one, suggesting a mix of object and scene features.

Table 2

Outcome Variable	Model 1			Model 2		
	<i>F</i>	<i>p</i>	<i>R</i> ²	<i>DF</i>	<i>p</i>	<i>DR</i> ²
PWC	<i>F</i> (1,123)=5.78	.018*	.045	<i>DF</i> (2,121)=1.04	.358	.016
OWC	<i>F</i> (1,123)=3.19	.077	.025	<i>DF</i> (2,121)=0.63	.535	.010
PNC	<i>F</i> (1,123)=7.65	.007**	.059	<i>DF</i> (2,121)=0.91	.407	.014
ONC	<i>F</i> (1,123)=5.39	.022*	.042	<i>DF</i> (2,121)=0.76	.472	.012
Average	<i>F</i> (1,123)=9.05	.003**	.069	<i>DF</i> (2,121)=0.60	.548	.009

Table 2: Two-step hierarchical regression results testing *model significance* for 5 outcome variables based on error magnitude data for different perceptual judgements: projective judgements with context (PWC), objective judgements with context (OWC), projective judgements without context (PNC), objective judgements without context (ONC), and error magnitude collapsed over all judgement conditions (Average). In each analysis, drawing accuracy (Drawing Ability) is a predictor in model 1 and drawing accuracy as well as AQ and SQ are predictors in model 2. Statistical significance is reported for model 1 (“Model 1” columns) as well as the change statistics going from model 1 to 2 (“Model 2” columns). Significant *p*-values are indicated with an asterisk and highlighted in bold. Model 1 is significant in all conditions except OWC, which is not surprising since OWC judgements are the basis of shape constancy. None of the change statistics are significant. Note: *N* = 125; **p* < .05; ***p* < .01.

Table 3

Outcome Variable						
	Model	Predictor(s)	b	t	P	R ²
PWC	1	Drawing Ability	-.21	$t(123) = -2.40$	.018*	.045
	2	Drawing Ability	-.21	$t(121) = -2.36$	.020*	.044
		AQ	.11	$t(121) = 1.29$	.200	.014
		SQ	-.07	$t(121) = -0.76$	.488	.005
OWC	1	Drawing Ability	-.16	$t(123) = -1.79$	.077	.025
	2	Drawing Ability	-.16	$t(121) = -1.83$	.069	.027
		AQ	.04	$t(121) = 0.46$	.649	.002
		SQ	.09	$t(121) = 0.98$	.331	.008
PNC	1	Drawing Ability	-.24	$t(123) = -2.77$	.007**	.059
	2	Drawing Ability	-.25	$t(121) = -2.84$	.005**	.063
		AQ	-.03	$t(121) = -0.33$	.745	.001
		SQ	.12	$t(121) = 1.33$	.185	.014
ONC	1	Drawing Ability	-.21	$t(123) = -2.32$	.022*	.042
	2	Drawing Ability	-.21	$t(121) = -2.36$	.020*	.044
		AQ	.07	$t(121) = 0.76$	.448	.005
		SQ	.08	$t(121) = 0.89$	.377	.006
Average	1	Drawing Ability	-.26	$t(123) = -3.01$	.003**	.069
	2	Drawing Ability	-.27	$t(121) = -3.04$	.003**	.071
		AQ	.06	$t(121) = 0.72$	.472	.004
		SQ	.07	$t(121) = 0.76$	.452	.005

Table 3: Two-step hierarchical regression results testing *predictor significance* for 5 outcome variables based on error magnitude data for different perceptual judgements: projective judgements with context (PWC), objective judgements with context (OWC), projective judgements without context (PNC), objective judgements without context (ONC), and error magnitude collapsed over all judgement conditions (Average). In each analysis, drawing accuracy (Drawing Ability) is a predictor in model 1 and drawing accuracy as well as AQ and SQ are predictors in model 2. Statistical significance is reported for each predictor variable in models 1 and 2. Significant *p*-values are indicated with an asterisk and highlighted in bold. Drawing accuracy is a significant predictor of error magnitude in models 1 and 2 for all shape judgements (PWC, PNC, ONC, and Average) except OWC which is a measure of shape constancy. AQ and

SQ are not significant predictors of error magnitude for any of the judgement conditions. The significant results indicate that as drawing accuracy increases, shape judgement error decreases. Note: $N = 125$; $*p < .05$; $**p < .01$.

Figures

Figure 1

Example stimuli and response probes for the shape judgement task. (a) Schematic of stimuli which were polyhedrons rotated in different directions (rotated ± 40 , ± 60 , or ± 80 degrees; the 0-degree stimulus

was not presented); the face of interest is highlighted in gray. Example stimuli, which were computer-generated red/blue anaglyphs, are shown for context-present (b) and context-absent (c) blocks. Participants judged either the rectangle's objective (physical) width, which remained constant at varying angles of rotation, or the rectangle's projective width (the width in the picture plane). Thus, there were four block types consisting of a cross of context (present, absent) and judgement (projective, objective) types. For the context-present conditions, a white arrow (shown in b) indicated the face of interest that should be attended for the subsequent matching judgement. Example response probes are shown for objective (d) and projective (e) blocks. Participants had to adjust the width of the initial response parallelogram to match the previously seen stimulus. The initial response parallelogram was presented as a white outline. Example wider and narrower adjustments are indicated with dashed lines.

Figure 2

Photographs for the drawing task. Photographs were presented one at a time in random order and consisted of 5 categories – objects (still-life) (1-5), animals (6-10), plants (11-15), buildings (16-20), , and natural scenes (landscapes) (21-25) – with 5 photographs from each category. All 25 images were presented for one minute each and participants were instructed to focus on accurately recreating the main lines, angles, and proportions of each image to the best of their abilities.

Figure 3

Results of the Shape Judgement Task for error bias (a) and error magnitude (b,c) data. (a) Error bias, a measure of signed magnitude (the difference between reported and correct width on each trial) shown in degrees of visual angle, is plotted as a function of stimulus rotation angle (40°, 60°, 80°), context (context, no context), and judgement type (projective, objective). Positive values indicate shape width estimates that are wider than the correct shape and negative values indicate estimates that are narrower than the correct shape. (b) Error magnitude, as measured by the absolute value of the difference between reported and correct widths in terms of number of pixels and shown in degrees of visual angle, is plotted as a function of stimulus rotation angle (40°, 60°, 80°), context (context, no context), and judgement type (projective, objective). (c) Error magnitude is plotted (in terms of degrees of visual angle) as a function of context (context, no context) and judgement type (projective, objective). Error bars represent ± 1 SEM.

Figure 4

Examples of stimuli and drawings from the 5 image categories (still-life, animal, plant, buildings, and landscape). Participant renditions were rated for accuracy on a scale from 1-5. The images in column (a) show one example photo from each category. High-rated drawings (rated above the mean) for each example photo are shown in column (b) and low-rated drawings (rated below the mean) for each example photo are shown in column (c).

Figure 5

(a) Plot of the significant correlation between the predictor variable Drawing Accuracy and the outcome variable Average Shape Judgement Error. Average shape judgement error decreases as drawing accuracy increases. (b) Plot of the significant correlation between two measures of local processing bias – SQ scores and difference scores between projective shape judgement conditions with and without context (ΔP in degrees of visual angle). As SQ scores increase ΔP difference scores decrease.