Artists as experts in visual cognition: An update

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Abstract

The question of whether and how visual artists see the world differently than non-artists has long engaged researchers and scholars in the arts, sciences, and humanities. Yet as evidence regarding this issue accumulates, it has become clear that the answers to these questions are by no means straightforward. With a view to advancing ongoing debate in this field, the current study aimed to replicate and extend previous research by exploring the differences in visual-spatial ability between art students (*n* = 42) and non-art students (*n* = 37), using a comprehensive battery of visual-spatial and drawing tasks. Art students outperformed non-art students on drawing measures and some (but not all) visual-spatial tasks. This nuanced pattern of results broadly supports the notion that art students differ from non-art students in their ability to exert top-down control over attentional processing, but not in the phenomenology of low-level visual processing. Implications for theories of artistic expertise are discussed.

Keywords: artists, spatial skills, visual perception, expertise

Artists as experts in visual cognition: An update

The question of whether and how visual artists see the world differently than non-artists has long engaged researchers and scholars in the arts, sciences, and humanities (e.g., Fry, 1919; Gombrich, 1960; Kozbelt & Seeley, 2007). Given the complexity of both visual perception and art, various aspects of perception and cognition may undergird artists' supposed perceptual advantages. In principle, such differences could span multiple levels of analysis and stages of information processing. These may range from very low-level visual processes like acuity or contrast sensitivity, to explicit high-order representations useful for depicting particular categories of stimuli in specific media.

Over the last twenty or so years, psychological researchers have made significant efforts to understand how artists and non-artists may differ in their perception, and how this is related to drawing skill (Chamberlain & Wagemans, 2016; Drake & Winner, 2011; Glazek, 2012; Kozbelt & Seeley, 2007; Seeley & Kozbelt, 2008; Tchalenko, Nam, Ladanga, & Miall, 2014). No one doubts that artists draw better than non-artists, a point empirically confirmed numerous times (Chamberlain, McManus, Riley, Rankin, & Brunswick, 2013; Chamberlain & Wagemans, 2015; Kozbelt, 2001; Perdreau & Cavanagh, 2013, 2015). However, understanding how perceptual processing contributes to individual differences in depictive ability is more complex. To date, empirical work on this issue has adopted a range of methodologies. This has included group-based comparisons of the performance of artists and non-artists on various perception and drawing tasks (Chamberlain & Wagemans, 2015; Kozbelt, 2001; Perdreau & Cavanagh, 2011), correlational analyses exploiting within-group variability (Cohen & Jones, 2008; Drake & Winner, 2011; McManus et al., 2010; Ostrofsky, Kozbelt, & Seidel, 2012) and case studies of individual expert artists or drawing prodigies (Drake & Winner, 2012; Miall, Gowen, & Tchalenko, 2009; Ruthsatz, Ruthsatz, & Stephens, 2014; Selfe, 1977). Paradigms that use neuroimaging (Chamberlain et al., 2014; Miall, Nam, & Tchalenko, 2014; Schlegel et al., 2015; Solso, 2001) and eye-movement (Tchalenko, 2007, 2009) analyses have also been employed to explore underlying mechanisms of depictive skill. These studies have yielded a substantial range of findings, some more convincing and well-supported than others. To give a sense of these results and to contextualize our own approach, we now highlight some key discoveries in this literature.

Empirical Research on Artists and Perception

After a lengthy prehistory in which artists' perception was mainly discussed by artists, art critics, art historians, and psychological theorists (Arnheim, 1965; Edwards, 1989; Fry, 1919; Goldwater & Treves, 1974; Gombrich, 1960; Nicolaides, 1941; Petherbridge, 2010; Ruskin, 1856; van Sommers, 1989), an empirical focus has recently taken the fore. While some empirical work dates farther back[1] it is striking how recent much of the research literature is. A parallel line of recent theoretical work complements this empirical focus by arguing that artists use expert practical knowledge about the visual system to create convincing artworks. By studying how artists do this, researchers can make more general discoveries about the human visual system (Cavanagh, 2005; Kozbelt & Ostrofsky, in press; Melcher & Cavanagh, 2011; Sayim & Cavanagh, 2011).

A representative example of research in this area is an early study by Kozbelt (2001), who gave artists and non-artists a variety of drawing tasks (mostly copying line drawings, which were then judged on accuracy) and perceptual tasks requiring visual analysis but which did not involve drawing *per se* (e.g., mental rotation, locating simple target shapes embedded in more complex displays, and identifying the subject of blurry photos or fragmented images). Artists outperformed non-artists on both kinds of tasks, providing empirical support

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[1] Studies by Thouless (1932) on phenomenal regression in shape constancy, Gaines (1975) on field independence, and Winner and Casey (1992) on mental imagery.

for the idea that artists indeed perceive the world differently than non-artists. Moreover, performance on the two sets of tasks was positively correlated. Statistically controlling for one or the other kind of task revealed that artists' perceptual advantages are best viewed as a subset of their drawing skills. In other words, artists' perceptual advantages appear to be developed largely to the extent that they are useful in drawing. The roles of domain-knowledge and perceptual-motor integration (Gowen & Miall, 2006) suggested by these initial findings were elaborated in a later theoretical treatment (Kozbelt & Seeley, 2007), which emphasized top-down aspects of processing as central to artists' advantages in drawing and perception (Gombrich, 1960; Kozbelt, Seidel, ElBassiouny, Mark, & Owen, 2010). This has been corroborated by studies linking mental representations of target objects with drawings of those objects (Matthews & Adams, 2008; Ostrofsky, Kozbelt, & Cohen, 2015; Ostrofsky, Kozbelt, Tumminia, & Cipriano, 2016).

In contrast to this focus on the top-down influence of stored schemas for depiction, other early work, by Cohen and colleagues (e.g. Cohen, 2005; Cohen & Bennett, 1997; Cohen & Jones, 2008), took a different theoretical position. These authors emphasized initial perceptual encoding as the primary determinant of drawing accuracy. This hypothesis has been supported by several other studies assessing how accurately individuals perceive and draw identical stimuli. For example, Mitchell, Ropar, Ackroyd, and Rajendran (2005) found a positive association between degree of perceptual distortion in the Shepard illusion and drawing errors. Ostrofsky, Kozbelt, and Cohen's (2015, Experiment 2) study of angle sizes in a shape constancy illusion demonstrated that individuals perceive the same angle to be closer to 90 degrees when embedded in a three-dimensional object like a cube than in a two-dimensional pattern. Thus, at least in some cases, the degree to which one misperceives a feature of an object appears to predict the degree to which one errs in drawing it.

Other studies have found artist advantages in other aspects of perceptual processing. These include the ability to overcome shape constancy (Cohen & Jones, 2008) and size constancy (Ostrofsky, Kozbelt, & Seidel, 2012), enhanced local processing of visual details (Chamberlain et al., 2013), field independence (Gaines, 1975), visual memory (Winner & Casey, 1992), and reduced attentional cost in switching between global and local aspects of visual displays (Chamberlain & Wagemans, 2015). Artists' perceptual advantages thus appear to span a range of quite different types of visual processing. These different visual processes may be differentially useful in specific rendering situations. For instance, the ability to overcome shape or size constancy may help an artist establish the proper proportions of a to-be-drawn object or scene. Sensitivity to the most important form-defining details may help an artist maximize viewers' ability to recognize a depicted object. Being able to conceptualize the key elements of a perspective space may help an artist establish the setting and relations among objects in a scene (Ostrofsky et al., 2012). Each of these skills is important in realistic drawing, though the perceptual processing demands are quite different in each case.

Notably, however, artists' advantages do not necessarily extend to all aspects of visual processing. Several studies (McManus, Loo, Chamberlain, Riley, & Brunswick, 2011; Ostrofsky et al., 2012) have failed to replicate earlier findings that artists performed better on shape constancy tasks than non-artists. Chamberlain and Wagemans (2015) found no difference in artists' and non-artists' experience on a variety of visual illusions and Ostrofsky, Kozbelt, and Kurylo (2013) found no differences between artists and non-artists in the ability to perceptually group different sets of elements in a noisy visual display. Perdreau and Cavanagh (2011) similarly failed to find evidence for artists' advantages on tests of size constancy, lightness constancy, and amodal completion. They convincingly argued that artists' perceptual advantages arise from robust representations of object structure in memory, which they can use to efficiently encode and depict the most important aspects of objects (see also Kozbelt, 2001; Kozbelt et al., 2010; Ostrofsky et al., 2012).

Artists and Perception: Where Things Stand

Broadly speaking, the tasks typically used in the artist versus non-artist perception literature form a curious mixture, representing both well-established and brand-new measures. The well-established instruments, like indices of mental rotation ability (Hunt, Davidson, & Lansman, 1981) or global versus local processing (Navon, 1977), have typically been inherited from studies addressing broader issues in perceptual processing. Others have been co-opted from fields of study that are tangential to the study of artists, such as case studies of child prodigies (Drake & Winner, 2012) or individuals with autism spectrum disorder (e.g., Drake, 2013). In contrast, newly-created tasks or stimuli typically aim at assessing specific aspects of perception that are theoretically relevant to artists. Such novel tasks have the benefit of a tighter theoretical focus. However, because they have not been subject to extensive vetting or replication, they are potentially idiosyncratic and confound-laden, limiting their utility. Indeed, in some cases, researchers using putatively identical tasks but different stimuli have found highly discrepant patterns of results: for instance, some studies (e.g. Cohen & Jones, 2008; Ostrofsky, Cohen, & Kozbelt, 2014) have shown negative correlations between general drawing skill and the degree to which individuals experience shape constancy, while others (e.g., McManus et al., 2011; Ostrofsky et al., 2012) have not. Exacerbating these limitations is the fact that most studies tend to administer a small number of perception tasks to any given sample; thus, even basic questions about the correlations among these tasks remain largely unanswered.

Lest the piecemeal approach to artists' perceptual advantages deter other researchers from examining this literature more closely, we hasten to argue that despite these issues of methodology, some significant progress has indeed been made. Research on artist versus non-artist differences in perception has gathered momentum in the last decade (Chamberlain & Wagemans, 2016; Kozbelt & Ostrofsky, in press). Some key findings, such as an association between drawing skill and local visual processing, have replicated repeatedly (Chamberlain et al., 2013; Chamberlain & Wagemans, 2015; Drake & Winner, 2011). Even in cases where attempted replication has been slow or unsuccessful, an optimistic appraisal would emphasize the usefulness of exploring the conditions under which a particular result trends one way or the other. This is particularly the case with the growing number of studies on the relationship between perceptual constancy and drawing skill (Cohen & Jones, 2008; McManus et al., 2011; Ostrofsky et al., 2014, 2012). We believe that the current situation of discrepant empirical results is an ideal (though hopefully temporary) state of affairs for a nascent area of inquiry. That is, there is now enough data to suggest some likely initial constraints, but there remain many unanswered questions and fruitful avenues for research.

The Current Study

The goal of the current study is to attempt to build productively on this state of affairs. The work we report here is part of a larger longitudinal project examining artists, drawing, and perception. In this paper, we report on the perceptual and drawing performance of a cohort of first-year college art and design students at the start of the academic year. We compare them to a non-artist undergraduate sample. As Kozbelt (2001) reported differences between first-year art majors and non-art majors, we expect that visual-spatial advantages will be present in the art students, even before their rigorous training in drawing as part of their first-year curriculum begins. The data will also serve as a baseline for a longitudinal analysis of perception and drawing performance changes throughout the academic year (to be reported later). From this we can assess whether domains in which art students already outperform non-art students are also those that are further developed as a result of training.

We aim to use the best-developed empirical methods, administering a wider variety of perception and drawing tasks taken from the research literature to artists and non-artists than in any other study known to us. In some sense, this may be regarded as an attempt to replicate and extend some aspects of Kozbelt's (2001) study, though with a larger sample and more diverse battery of perceptual tasks – and with the benefit of the empirical and theoretical work done in the interim. A major addition is that here we include an assessment of non-verbal IQ as a possible covariate, to explore the influence of intelligence on visual thinking in the arts, following the approach of some previous research (Chamberlain et al., 2013; Drake, Redash, Coleman, Haimson, & Winner, 2010).

A wider aim of this research project is to assess the value of drawing instruction in art and design education. Undoubtedly drawing underpins a great many activities within, but not confined to, the visual arts. However, it is especially pertinent for art students to develop their drawing skills in the service of a wider range of skills, which potentially include creative and analogical reasoning, the understanding of three-dimensional space, and perceptual and mental imagery ability. Therefore, in the current study we focus specifically on observational and creative drawing in relation to perceptual ability, while acknowledging that this by no means exhausts the range of skills artists possess. The drawing tasks in our study include freehand observational drawing and limited-line tracing, both of which largely assess technical skill, as well as a measure of creative drawing.

This approach allows us to address how artists and non-artists differ on a range of perceptual and drawing tasks and to examine correlations among those tasks in both groups, which should inform where artists' perceptual advantages may lie. This should go some way to addressing the inconsistencies in previous research. In addition, we will be able to specifically address the issue of whether artists' advantages are predominantly a product of top-down (Kozbelt & Seeley, 2007) or bottom-up (Cohen & Bennett, 1997) influences on visual perception.

We hypothesized that art students will report substantially more experience in drawing and will substantially outperform the non-art students on any measure involving making drawings, as is often found (e.g., Chamberlain, McManus, Riley, Rankin, & Brunswick, 2013; Chamberlain & Wagemans, 2015; Kozbelt, 2001; Ostrofsky et al., 2012; Perdreau & Cavanagh, 2013, 2015). Based on earlier studies (e.g., Kozbelt, 2001; Chamberlain & Wagemans, 2015), we also expect some perceptual advantages among art students for tasks involving higher-order perceptual processes involving the deliberate deployment of visual attention (disembedding figures from a complex display), manipulation of visual information (mental rotation), and higher-order visual processing (recognizing the content of degraded images). Finally, we expect that visual-spatial tasks involving lower-level processes (the ability to overcome visual illusions) will not evince artist advantages (e.g., Chamberlain & Wagemans, 2015; Perdreau & Cavanagh, 2011). Given the multifarious nature of visual processing, we expect correlations among many of the visual-spatial tasks to be fairly weak; we expect correlations among the drawing tasks to be somewhat stronger, and we expect those visual-spatial tasks that are associated with advantages among artists to be moderately correlated with drawing performance. Finally, in line with Kozbelt's (2001) findings that artists' perceptual skills are best viewed as a subset of their drawing skills, we expect that partial correlational analyses of the two sets of tasks will yield similar results.

Method

Participants. The art student group consisted of 42 first-year students enrolled at the Pratt Institute of Art and Design in Brooklyn, New York who were each taking a foundation art and design course (37 female; M_{age} = 18.6; *SD* = 1.0). The non-art student group consisted of 37 psychology students enrolled at Brooklyn College (27 female; M_{age} =21.6; *SD* = 6.8).

The art students were tested within the first two weeks of their foundation course and the non-art students were tested throughout the fall semester.

The foundation year course at Pratt includes courses in Drawing, Light, Color and Design, Material and Three-dimensional Form, Stills to Motion, and Shaping Time. The drawing training component of the course constitutes eight hours of instruction per week, with additional homework assignments, and is organized into three distinct teaching sections. These are aimed at developing: 1) spatial and structural awareness and investigation; 2) structural analysis of form and space, visualizing in three dimensions; seeing through and into objects, mental rotation of volumes in space, understanding points of view; and 3) synthesis, complex structures, invention and agency. Art students were registered for a wide range of artistic majors: animation (*n* = 8), graphic design (*n* = 7), fine arts (*n* = 6), illustration (*n* = 5), industrial design (*n* = 4), interior and fashion design (*n* = 3), photography and film (*n* = 3), advertising (*n* = 4) and art therapy (*n* = 1). The majority of the art students reported practicing drawing every day or a few times a week for the past two years, both inside and outside of class (see Table 1). Very few of the non-art students reported practicing drawing with any frequency comparable to the art students, as can be seen in Table 1.

TABLE 1 HERE

Materials and Procedure

All participants were tested within a 1.5-hour testing session at their respective institutions in a quiet room. Tasks were administered in a standardized order, the same order in which tasks are described below. Participants completed a questionnaire and then a series of computer-based visual-spatial tasks and non-computer-based drawing tasks. All computer tasks were performed on a 13” liquid crystal computer screen with a 60 Hz refresh rate. Stimulus presentation was controlled using the Psychopy package (Peirce, 2007). Art students received $40 for participating while non-art students received research credit as part of a course requirement.

Questionnaire Measures. Participants completed a questionnaire on their date of birth, gender, ethnicity, handedness, and academic major. Several other trait-based questionnaires were administered as part of separate study; those results are not reported here.

Shortened Form of Raven's Advanced Progressive Matrices. A shortened form of Raven's Advanced Progressive Matrices (RAPM) was administered. This form has been validated and normalized (Arthur, Tubre, Paul, & Sanchez-Ku, 1999) and represents a valid predictor of non-verbal IQ. Participants were given one practice item from Set I of the RAPM. They were then given 12 items from Set II of the longer 36-item RAPM to complete in 15 min.

Mental Rotation Task (MRT). A Mental Rotation Task (Hunt, Davidson, & Lansman, 1981) was used to test individual differences in visual imagery. Pairs of 2D drawings rendering 3D block constructions were presented to participants. The stimuli were presented as black drawings on a white background. There were 10 practice trials followed by 16 experimental trials, presented in a randomized order. In each trial, participants had to indicate via key press whether the drawings presented depicted the same object from two different angles (key = S) or two different objects (key = D). There was no per trial time limit but participants had a time limit of 3 min to complete as many of the 16 trials as they could. Accuracy and reaction times were recorded.

Out-of-Focus Pictures Task. To test for global processing skills, we administered an Out-of-Focus Pictures Task similar to that used by Kozbelt (2001). We selected 125 photographs from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 1999) because of their easily recognizable subject matter. In Photoshop, each image was resized to 4 inches at 100 pixels per inch and converted to grayscale. We then modified each image into four progressively blurrier versions based on a Gaussian blur of 100 pixels at 2, 4, 6, and 8 radii. Thus, each image had five versions (the original and the four levels of blurriness).

A pilot test on the images was conducted with 100 participants using Amazon's Mechanical Turk. We created five sets of images with no image duplicated within the set and randomly assigned participants to view one of the sets. For each image, participants were asked to indicate the scene or object depicted. Based on the pilot data, 45 of the 125 images were selected for inclusion in the main study; these elicited good variation in performance, without floor or ceiling effects.

In the main task, participants were instructed that they would be shown a series of 15 blurred pictures for up to 15s each and that they should try to identify what was in each picture by typing a free response after the image was shown. Participants were given unlimited time to type their response before proceeding to the next trial. Participants first completed two practice trials (with feedback) and then completed 15 test trials. Free-responses were coded for accuracy by two independent raters (inter-rater reliability r = 0.96). Responses that named an exemplar or the class of the object (e.g., tulip or flower) were counted as correct. Summed accuracy scores were then calculated for each participant.

Embedded Figures Task (EFT). Individual differences in disembedding performance were examined using a modified version of the Embedded Figures Test (Witkin, 1950) which has been developed for the L-POST (Leuven Perceptual Organization Screening Test; Torfs, Vancleef, Lafosse, Wagemans, & de-Wit, 2014; Vancleef et al., 2014) and has been used in previous research (Chamberlain, Van der Hallen, Huygelier, Van de Cruys, & Wagemans, in press; Chamberlain & Wagemans, 2015). Stimuli were presented as black patterns on a white background. Participants were presented with complex 2D or 3D patterns presented below a 2D target shape. Participants were asked to search for the upper target shape in the lower complex pattern and report whether the target was present (key = J) or absent (key = F) within 12s. Participants were given six practice trials with feedback before completing the experimental trials. There were 40 experimental trials containing an equal number of target present and absent trials. The order of trials was randomized for each participant. Accuracy and reaction times were recorded for each trial.

Navon Hierarchical Shape Task. Individual differences in local and global visual processing were assessed in a selective attention Navon shape task, similar to that used in Caparos, Linnell, Bremner, de Fockert, and Davidoff (2013). On each trial, a large shape made up of smaller white shapes on a black background was presented. On some trials, many small shapes comprised the larger shape; on other trials, the shapes that made up the larger shape were fewer and larger (Figure 1). This created trials in which the local level (small shapes) was more salient and trials in which the global level (large shape) was more salient.

Participants were instructed to focus on either the large shape or the smaller shapes in blocks of 16 trials. There were 32 practice trials (two blocks) followed by 128 experimental trials (eight blocks). In each trial participants were instructed to respond to the identity of the shape (square =F key, triangle = J key) at the allocated level of attention (local/global). The stimulus shape was presented onscreen for 300ms and participants were given up to 2s to respond. The inter-trial interval was 1s. Participants were given positive or negative feedback with a colored fixation cross after all trials.

FIGURE 1 HERE

Visual Illusion Task. Individual differences in the strength of visual illusions were investigated with three illusions: the Ebbinghaus, Muller-Lyer, and Rod-Frame illusions. The method of continuous adjustment was used to measure participants’ responses. Illusions were presented as black shapes on a white background. For each trial, an illusory stimulus was presented on one half of the screen while a test shape was presented on the other half (the locations of the illusory stimulus and the match stimulus were randomized). Participants were required to match the test shape (a line or a circle) to the illusory stimulus on the screen, adjusting the relevant parameters (line angle or length/circle radius) using the up and down arrow keys. When they were satisfied with their match, they could continue to the next trial. There was no time limit. Participants matched stimuli in two illusion trials and two control trials per illusion.

Bistable Figure Task. The Bistable Figure Task measured participants' ability to manipulate their internal perceptual representations. Participants viewed a structure-from-motion (SFM) rotating cylinder consisting of two transparent planes of random white dots (6 pixels in diameter) moving in opposite directions on a black background, along a vertical axis. There were 400 dots on screen at any time moving at a speed of 0.20 full cycles per second. The global percept of motion of the stimulus can be perceived as going from left to right or from right to left (that is, as counter-clockwise or clockwise rotation, if one imagines viewing the cylinder from the top). Participants were shown a practice stimulus and instructed how to access each percept. Only when participants had reported that they could experience each percept were they allowed to proceed to the experimental trials.

Three trials were presented to each participant, each lasting 120s. In each trial participants were asked to gently fixate on a red point in the centre of the visual stimulus. As they viewed the stimulus they were asked to indicate which of two competing percepts they were currently experiencing. They did this by holding down one of two keys (F or J) on the keyboard for as long as they experienced that direction. If they saw a mixture of the two percepts or no one percept dominated they were asked to refrain from pressing either of the response keys. Participants completed three trials one of each of the following conditions, presented in a fixed order:

1. Passive fixation: participants were instructed to focus on the stimulus but not to try to control which percept they saw at any given time.
2. Hold fixation: Participants were asked to hold one percept in mind for as long as possible.
3. Switch fixation: Participants were asked to switch between percepts as quickly as possible.

Participants were encouraged to take breaks between trials to avoid fatigue. Rates of reversal and percept duration were measured by recording the length of time the key corresponding to each percept was pressed as well as the number of times the participant changed keys during each trial.

Limited-Line Tracing Task. The Limited-Line Tracing Task, developed by Kozbelt et al. (2010), emphasized participants’ ability to select the most important information to include in a depiction. The stimulus was a grayscale photograph of an elephant on a white piece of 9” x 11” letter paper (as in Ostrofsky et al., 2012). For the tracing task, the photo was placed inside a clear plastic folder. Participants were instructed to create depictions of the elephant by tracing over the photo directly onto the folder using 40 short pieces of tape (2cm × 2mm). A white piece of paper was available for sliding between the tracing and the photograph, so participants could see their tracing without interference from the photo underneath. Participants were instructed to use the available line segments to create a tracing that was as accurate as possible, given the constraints of the medium. Participants were instructed to use all 40 pieces of tape and could bend segments but could not tear them into smaller pieces; they could also move a piece of tape after having used it in the tracing if they decided it would go better somewhere else. Participants had 10 min to complete the task.

Observational Still-Life Drawing Task. To assess drawing skill, participants were given a still-life set-up consisting of common objects including a cup, bowl, fork, and bag

(Figure 2). Participants were asked to draw the arrangement as accurately and completely as possible in 10 min; if they had time, they were permitted to add shading and detail. Participants were instructed not to move the objects while drawing. Figure 2 presents a drawing by an art student and a non-art student.

FIGURE 2 HERE

Creative Drawing Task. One form (A: figural) of the Abbreviated Torrance Test of Creative Thinking (ATTA; Goff, 2002) was used to measure creativity. The task consisted of two subtests, both timed at 3 min. The first required participants to create a drawing from their imagination based on a simple shape provided on a sheet of paper. In the second, participants were required to make a series of drawings based on a simple repeated shape of triangles. After completing each subtest, participants were asked to provide titles for their drawings. Participants were encouraged to create drawings that were as novel and as interesting as possible.

Ethics

The study was approved by the Institutional Review Board at Brooklyn College.

Results

Because of the large number of tasks and analyses, our findings are organized into several sub-sections. We begin with preliminary analyses examining group differences in non-verbal IQ and an overview of correlations among some of the main visual-spatial task measures, with an eye to later covariate or multivariate analyses. We then examine performance differences between art students and non-art students on each task, beginning with the perception tasks and ending with the drawing tasks. In the comparative analyses, we control for non-verbal IQ by adding total Raven’s Progressive Matrices scores as a covariate in each model. We then explore correlations among the drawing tasks and between the perception tasks and drawing tasks, concluding with a partial correlational analysis to determine the overall relation between perception and drawing (cf. Kozbelt, 2001). In all analyses, the data are collapsed across participant handedness and gender, due to low rates of left-handers and males in the sample.

Preliminary Analysis of Non-verbal IQ

We first examined whether art and non-art students differed in non-verbal IQ and age. We found that art students (M = 6.95, SD = 2.54) had higher non-verbal IQ than non-art students, (M = 5.14, SD = 2.41), t (76) = 3.23, p = .002, d = 0.73, 95% CI of difference [0.70, 2.93]; moreover, art students were younger than non-art students, t (76) = -2.80, p = .007, d = -0.63, 95% CI of difference [0.86, 5.11]. While there were fewer males in the art-student group, this difference was not statistically significant, $\chi2$ (1) = 1.88, p = .17, ϕ = 0.16. Given the group differences in non-verbal IQ, in all analyses of group differences with respect to the visual-spatial task battery we controlled for non-verbal IQ.

Inter-task Correlations

To assess whether the experimental tasks measured similar or independent underlying visual-spatial constructs, a correlational analysis was conducted among representative measures from the visual-spatial tasks as well as the drawing tasks (Table 2; a full correlation matrix of a larger set of experimental variables is included in the Supplementary Analysis). The correlations were performed on participants who provided data points for all tasks (n = 71 out of 79). Inter-task correlations were not strong, and few survived correction for multiple correlations, suggesting that our visual-spatial tasks were largely independent of one another. However, there were a few notable exceptions, including a moderate correlation between performance on the MRT and EFT. Also, non-verbal IQ correlated strongly with accuracy on the MRT and EFT; non-verbal IQ correlated weakly with illusory strength in the Muller-Lyer illusion, number of reversals in the passive condition of the Bistable Figure Task, and interference of incongruence on reaction time in the Navon Task. There were also modest correlations between MRT accuracy and Muller-Lyer illusory strength and between the EFT and the strength of the Muller-Lyer illusion.

TABLE 2 HERE

Comparison of Art Students' versus Non-art Students' Performance on the Visual-Spatial Tasks

Mental Rotation Task (MRT) and Embedded Figures Test (EFT). Since the MRT and the EFT were significantly correlated (Table 2), the analysis of these tasks is presented together.

Participants' accuracy and reaction times were averaged across the 16 experimental trials of the MRT. Reaction times for the MRT were positively skewed and were therefore submitted to natural logarithmic transformation before further analysis. There was a weak but significant correlation between accuracy and log-transformed reaction time, r (76) = .27, p = .02, 95% CI of correlation [.05, .47] suggesting some degree of speed-accuracy trade-off; however, as the correlation was rather low, between-groups differences for accuracy and speed were each investigated. Similarly to the MRT, there was a weak but significant correlation between mean accuracy and reaction time across the 40 experimental trials on the EFT, r (75) = .24, p = .04, 95% CI of correlation [.02, .44], again suggesting some degree of speed-accuracy trade-off; however, as the correlation was again rather low, between-groups differences were again investigated for both accuracy and speed.

Since accuracy scores in the MRT and EFT, as well as non-verbal IQ, were all positively inter-correlated (Table 2), we performed a MANCOVA to examine group differences on the MRT and EFT accuracy scores while controlling for non-verbal IQ. Art students outperformed non-art students on accuracy for the EFT, F (1, 75) = 6.338, p = .014, $\eta_p^2 = 0.078$ but not the MRT, F (1, 75) = 2.025, p = .159, $\eta_p^2 = 0.026$. We also ran a MANCOVA on RT for the MRT and EFT. There were no group differences for RT on the

MRT, *F* (1, 75) = 0.014, *p* = .908, η_p^2 = 0.0 or the EFT, *F* (1, 75) = 0.225, *p* = .636, η_p^2 = 0.003.

Out-of-Focus Pictures Task. A one-way ANCOVA on summed accuracy scores controlling for non-verbal IQ, revealed no difference in performance between art (*M* = 5.50, *SD* = 2.26) and non-art students. (*M* = 5.14, *SD* = 2.04), *F* (1, 75) = 0.19, *p* = .67, η_p^2 = 0.002.

Navon Hierarchical Shape Task. Accuracy averaged across all experimental trials was high (*M* = 0.91, *SD* = 0.09). Since reaction times were positively skewed, a natural logarithmic transformation was performed on the dependent variables. Trials were split into global salient and local salient trials and congruent and incongruent trials, and mean reaction times were calculated for each of the nested within-subjects conditions (global/local salience; global/local attention).

FIGURE 3 HERE

From initial inspection of the data (Figure 3), there did not appear to be consistent differences in RT between the two student groups across the various conditions of the Navon Task, although in a one-way ANOVA, RTs were reliably faster for consistent (untransformed *M* = 0.63, *SD* = 0.13) than for inconsistent trials (untransformed *M* = 0.66, *SD* = 0.13), *F* (1, 76) = 38.98, *p* < .001, η_p^2 = 0.34. To analyze potential group differences in interference on RT, we calculated difference scores between consistent and inconsistent trials in each condition and tested whether these interference effects differed between art students and non-art students. A mixed-model ANCOVA (2 × 2 × 2) was performed with group as the between-subjects variable, attentional level (local/global), and level salience (local/global) as the within-subjects variables, non-verbal IQ as a covariate, and difference in reaction time between consistent and inconsistent trials as the dependent variable. There were no effects of group, *F* (1, 74) = 0.02, *p* = .88, η_p^2 < 0.01, attentional level, *F* (1, 75) = 0.02, *p* = .88, η_p^2 < .01, or salience, *F* (1, 74) = 1.76, *p* = .19, η_p^2 = 0.02. Additionally, there was no interaction between group and attentional level, *F* (1, 74) = 0.53, $p = .47$, $\eta_p^2 < 0.01$, or group and salience level, *F* (1, 74) = 0.63, $p = .43$, $\eta_p^2 < 0.01$. There was a two-way interaction between attentional level and salience, *F* (1, 74) = 25.16, $p < .001$, $\eta_p^2 = 0.25$; interference was larger when salience and attentional level were contrasted.

To further test this, we compared interference in trials in which salience and attentional level matched (global/global; local/local) with interference when salience and attentional level were contrasted (local/global; global/local), including non-verbal IQ as a covariate. The ANCOVA revealed that interference was indeed higher for matched trials in comparison to non-matched trials, *F* (1, 75) = 23.80, $p < .001$, $\eta_p^2 = 0.24$. In addition, there was a trending three-way interaction between group, attentional level, and salience, *F* (1, 74) = 2.96, $p = .09$, $\eta_p^2 = 0.04$. On inspection of the graph, interference appears similar between the two groups for local attention trials across both salience levels. However, in global attention trials, non-art students show a reversed interference effect when the global level was salient: they responded faster to incongruent trials when attending globally in globally salient trials. In these trials art students showed a modest interference effect. In summary, there were very few differences in attentional performance between the two groups on the Navon Hierarchical Shape Task.

Visual Illusions Task. The average effect of each visual illusion was calculated by subtracting the absolute illusory response from the absolute baseline response for each illusion. All average illusory effects were reliably different from zero, indicating that the stimuli were successful in inducing illusory percepts, with the Muller-Lyer being the strongest and the Ebbinghaus being the weakest (one-sample *t* tests: Muller-Lyer: *t* (76) = 11.51, $p < .001$, $d = 1.31$; Ebbinghaus: *t* (76) =3.97, $p < .001$, $d = 0.45$; Rod-frame: *t* (76) =7.71, $p < .001$, $d = 0.88$). To determine whether illusion strength differed by group, we performed an ANCOVA controlling for non-verbal IQ. There were no differences between the two groups on the Muller-Lyer: F (1, 74) = 0.01, p = .91, $\eta_p^2 < 0.001$, Ebbinghaus: F (1, 74) = 1.34, p = .25, $\eta_p^2 = 0.02$ or Rod-frame: F (1, 74) = 0.52, p = .47, $\eta_p^2 = 0.01$ illusions. These results suggest that art students were as susceptible to visual illusions as non-art students were, though it should be noted that the responses of the non-art students in the Muller-Lyer task were more varied than those of the art students (Levene's test: Muller-Lyer: F (1, 75) = 5.81, p = .02; Ebbinghaus: F (1, 75) = 2.01, p = .16; Rod-Frame: F (1, 75) = 1.75, p = .19), and the art students consistently showed numerically smaller illusory effects than the non-art students (Table 3).

TABLE 3 HERE

Bistable Figure Task. Eight participants were excluded from the analysis due to incorrect percept reporting (e.g., not holding down a response key for the duration of each percept or pressing an inappropriate response key). Due to the positive skew of the distribution for number of reversals and duration of percept in the Bistable Figure Task, the data were transformed via a square root (number of reversals) or logarithmic (duration of directions) transformation. Untransformed descriptive statistics are presented in Figure 4. To assess differences in bistable figure perception between art students and non-art students, a mixed-model ANCOVA was conducted with the number of percept reversals as the dependent variable, group as the independent variable, experimental condition as a within-subjects variable, and non-verbal IQ as a covariate. There was an effect of artistic group, F (1, 72) = 13.22, $p < .001$, $\eta_p^2 = 0.16$, and an effect of experimental condition, F (2, 144) = 13.75, $p < .001$, $\eta_p^2 = 0.16$, on reversal rates. Post-hoc tests revealed that reversal rates in the switch condition were reliably higher than in the passive condition, F (1, 72) = 22.05, $p < .001$, $\eta_p^2 = 0.23$, and the hold condition, F (1, 72) = 13.44, $p < .001$, $\eta_p^2 = 0.16$. However, there was no reliable difference in reversal rates between the passive and hold conditions, F (1, 72) = 1.39, p = .24, $\eta_p^2 = 0.02$. There was also no interaction between group and condition, $F\ (2, 144) = 0.18$, $p = .84$, $\eta_p^2 = 0.002$, suggesting that the art students experienced more perceptual reversals than non-art students across all conditions. This was confirmed in post-hoc tests, which revealed that art students reported more frequent reversals relative to the non-art student group in the passive, $F\ (1, 72) = 12.02$, $p < .001$, $\eta_p^2 = 0.14$, switch, $F\ (1, 72) = 4.73$, $p = .03$, $\eta_p^2 = 0.06$, and hold, $F\ (1, 72) = 6.50$, $p = .01$, $\eta_p^2 = 0.08$, conditions.

The same ANCOVA for perceptual reversals was performed with duration as the dependent variable. There was an effect of condition, $F\ (2, 134) = 8.31$, $p < .001$, $\eta_p^2 = 0.11$, an effect of group, $F\ (1, 67) = 7.06$, $p = .049$, $\eta_p^2 = 0.10$, but no interaction between condition and group, $F\ (2, 134) = 0.90$, $p = .41$, $\eta_p^2 = 0.01$. Participants' percept durations were shorter in the switch condition relative to the passive condition, $F\ (1, 67) = 10.41$, $p = .002$, $\eta_p^2 = 0.13$, and hold condition, $F\ (1, 67) = 10.41$, $p = .002$, $\eta_p^2 = 0.13$, while there was no difference in percept duration between the passive and hold conditions, $F\ (1, 67) = 0.57$, $p = .45$, $\eta_p^2 = 0.01$. Post-hoc tests revealed that art students reported shorter percept durations relative to the non-art students in the passive, $F\ (1, 67) = 7.28$, $p = .009$, $\eta_p^2 = 0.10$, and switch conditions, $F\ (1, 67) = 5.08$, $p = .03$, $\eta_p^2 = 0.07$, but there was no between-group difference in the hold condition, $F\ (1, 67) = 0.69$, $p = .41$, $\eta_p^2 = 0.01$, broadly reflecting the results for the percept reversals. In summary, the art student sample witnessed more perceptual reversals, and shorter percept durations in all conditions (passive, hold and switch) of the Bistable Figure Task.

FIGURE 4 HERE

Drawing Tasks

Data Preparation. Participants' drawings were rated by a sample of 10 non-expert student judges from Brooklyn College and six expert judges who were art and design tutors teaching the foundational drawing course at the Pratt Institute. Each judge was asked to rate the quality of each drawing by sorting them into seven categories. Judges were asked to rate the quality of the drawings based on the following rubric:

1. Does the drawing follow a consistent viewpoint?
2. Is the 3D rendering of oval shapes correct (cup, bowl, bottle)?
3. Are the relationships between the objects rendered appropriately?
4. Does the drawing hold together?
5. Is the drawing sitting on a ground plane?
6. Do the details in the picture follow the form of the objects?
7. Does the drawing sit well on the page?
8. Is the line-quality effective in depicting depth?

The judges were not restricted in terms of how many drawings they could put into any one category from 1 being the *worst* to 7 being the *best*. When the judges were satisfied with their distribution of drawings, each drawing was assigned the number of the category in which it was placed in (1 = worst, 7 = best).

Observational Still-Life Drawing Task. Ratings on the still-life drawings were submitted to a Rasch statistical analysis (Rasch, 1980; Wright & Masters, 1982) implemented in the WINSTEPS software program (Linacre & Wright, 1991). Rasch analysis takes into account both the difficulty of each survey item (in terms of receiving a high score from judges), as well as the harshness of each judge, to construct an interval-scale metric of the quality of each drawing. This metric is achieved through an iterative, maximum-likelihood process that minimizes the residuals of the differences between each judged drawing and each survey item until their positions on an underlying dimension are stable. The unit of the metric is the logit, the log-odds probability of a particular drawing receiving a high rating from a particular judge on a particular item. Inter-judge reliability indices (equivalent to Cronbach’s alpha) were very high for both judge groups (artist judges = 0.98, non-artist judges = 0.95). Averaging logit accuracy scores across all judges, drawings made by the art students (*M* = 48.82, *SD* = 2.74) were rated higher than those made by the non-art students (*M* = 45.29, *SD* = 1.83), *t* (75) = 6.75, *p* < .001, *d* = 1.50, 95% CI of difference [2.49, 4.58].[2] The supplementary analysis section provides further analyses of the differences between the expert and non-expert judges on this task.

Limited-Line Tracing Task. Participants' limited-line tracings were rated by the same sample of judges who rated the observational still life drawing task using the same rating rubric. Judges were informed that the quality of drawing was to be determined on the basis of accuracy rather than aesthetic appeal. The resulting ratings were also Rasch-analysed, again showing high reliability, with inter-judge reliability indices of 0.95 for artist judges and 0.97 for non-artist judges. Across all judges, the tracings made by the art students (*M* = 33.17, *SD* = 16.02) were rated higher than those made by the non-art students (*M* = 24.00, *SD* = 12.64), *t* (76) = 2.79, *p* = .007, *d* = 0.63, 95% CI of difference [2.61, 15.73].[3]

Creative Drawing Task. Responses to the Creative Drawing Task were scored by two independent judges according to criteria specified in the ATTA handbook (Goff, 2002). Four key creative facets were derived from the two subtests of the ATTA:

1. Fluency: the ability to produce a number of task-relevant ideas.
2. Originality: the ability to produce uncommon or unique ideas.
3. Elaboration: the ability to embellish ideas with details.

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[2] Averaging raw quality ratings on the 7-point Likert scale across all judges, drawings made by the art students (*M* = 3.54, *SD* = 0.73) were rated higher than those made by the non-art students (*M* = 2.01, *SD* = 0.64), *t* (75) = 9.84, *p* < .001, *d* = 2.23, 95% CI of difference [1.21, 1.83].

[3] Averaging raw quality ratings on the 7-point Likert scale across all judges, drawings made by the art students (*M* = 2.72, *SD* = 0.67) were rated higher than those made by the non-art students (*M* = 2.20, *SD* = 0.52), *t* (76) = 3.80, *p* < .001, *d* = 0.87, 95% CI of difference [0.25, 0.79].

4. Flexibility: the ability to produce a variety of different ideas.

Inter-rater reliability was 0.72 for Test 1 and 0.80 for Test 2. An overall score was calculated for each participant by task and then averaged to create a total creativity score. Art students' creativity scores ($M = 13.32$, $SD = 6.07$) were higher (and had more variability) than the scores of the non-art students ($M = 6.81$, $SD = 2.59$), $t\ (76) = 6.23$, $p < .001$, $d = 1.37$, 95% CI of difference [4.42, 8.59], Levene's test: $F\ (1,76) = 13.76$, $p < .001$.[4]

Correlations Among Drawing Tasks. A series of Pearson correlations were then performed to examine the relationship between observational drawing, limited-line tracing, and creative drawing performance. There was a strong correlation between the Observational Still-Life Drawing Task and the Limited-Line Tracing Task, $r\ (75) = .67$, $p < .001$, and a moderate correlation between the Observational Still-Life Drawing Task and the Creative Drawing Task, $r\ (75) = .47$, $p < .001$. However, there was no correlation between the Creative Drawing Task and the Limited-Line Tracing Task, $r\ (75) = .09$, $p = .42$.

Correlations Between Drawing Tasks and Perception Tasks

Correlations between the main measures derived from the perception tasks and drawing tasks were then examined (Table 4). The correlation matrix reveals a dissociation between the Observational Still-Life Drawing Task and the Limited-Line Tracing Task, in terms of the degree to which the two tasks correlate with various perceptual abilities. While the Observational Still-Life Drawing Task was correlated with non-verbal IQ, MRT accuracy, EFT accuracy, and passive switching in the Bistable Figure Task, the Limited-Line Tracing Task was not correlated with any of these. For the Creative Drawing Task, the patterns of correlations were the same as that of the Observational Still-Life Drawing Task, although correlations between the perceptual abilities and the Creative Drawing Task tended to be stronger. The only correlation that survived correction was between the Creative

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[4] Mann-Whitney *U* test: $U\ (76) = 240.5$, $p < .001$.

Drawing Task and the number of reversals made in the passive condition of the Bistable Figure Task. When controlling for group, no correlations remained reliable.

TABLE 4 HERE

Variance Common to Both Visual-spatial Ability and Drawing

To determine how much common variance was shared between the visual-spatial tasks and the drawing tasks, average *z* scores were calculated for the visual-spatial tasks included in the initial correlation matrix (Table 2) followed by the drawing tasks (the Observational Still-Life Drawing, the Limited-Line Tracing Task and the Creative Drawing Task; Table 4). The visual-spatial z-scores were then regressed onto the drawing *z* scores for all participants who had data points for all tasks ($n = 71$). There was a moderate amount of common variance between the visual-spatial tasks and the drawing tasks, r (69) = .27, F (1, 69) = 5.25, $p = .03$, adjusted $R^2 = 0.06$.

To remove the contribution of drawing to visual-spatial performance, the residuals after regressing drawing scores on visual-spatial scores were calculated. Residuals for the visual-spatial scores for art students ($M = 0.09$, $SD = 0.34$) were significantly higher than non-art students ($M = -0.10$, $SD = 0.36$), t (69) = 2.30, $p = .02$, $d = 0.55$, 95% CI of difference [0.03, 0.36]. Residuals were also calculated when regressing visual-spatial scores onto drawing scores. The residuals for the drawing scores for art students ($M = 0.35$, $SD = 0.77$) were significantly higher than non-art students ($M = -0.36$, $SD = 0.44$), t (69) = 4.83, $p < .001$, $d = 1.14$, 95% CI of difference [0.42, 1.02].

Overall Summary of Results

In sum, the results broadly support the idea that artists possess demonstrable advantages over non-artists not only in drawing performance but also in some aspects of perceptual processing. Besides the advantage in non-verbal IQ observed presently, art students showed enhancements in disembedding in the EFT and in instigating reversals in the

Bistable Figure Task across all conditions, independent of differences in non-verbal IQ (Figure 5). In addition, performance levels on the MRT, EFT, and Bistable Figure Tasks were correlated with both observational and creative drawing ability. In contrast, the ability to identify out-of-focus pictures, avoid interference in the Navon Task, and overcome visual illusions did not reliably differ between art students and non-art students and did not correlate with observational or creative drawing.

FIGURE 5 HERE

Discussion

The aim of the current study was to assess the replicability and underlying theoretical foundations of the growing body of evidence pertaining to artists' advantages in drawing. To achieve this aim, a group of first-year art students embarking on a rigorous foundation year training curriculum in undergraduate art and design were tested on a wide range of visual-spatial and drawing tasks. Their performance was compared with a group of undergraduate psychology students at a similar educational level but with virtually no experience in drawing. The purpose of targeting first-year art students was to assess possible superior perceptual and artistic performance before they began rigorous degree-level training (as in Kozbelt, 2001).

The content of the task battery and the methodology broadly emulated that of Kozbelt (2001) by contrasting the two groups in terms of both their visual and drawing abilities. In this way, it was not only possible to analyze group differences, but also to examine correlations between drawing and visual-spatial skills, in order to assess the nature of the overlap between these two domains. It should be acknowledged that drawing is only one aspect of contemporary artistic skill, but it remains fundamental to many kinds of artistic practice. It is also important to note that drawing underpins expertise in domains external to the visual arts, such as design and the performing arts, and therefore the current findings may apply more readily to an activity (drawing) rather than a group of individuals (artists). This is especially true as the findings demonstrate that the perceptual advantages of art students exist to the extent that they are useful for drawing (Kozbelt, 2001).

Commensurate with the interpretation that drawing is a fundamental activity for students of the visual arts more generally, the art students outperformed the non-art students on each of our three drawing tasks: Creative Drawing, Limited-Line Tracing, and Observational Drawing from a Still-Life. In addition, the art students outperformed the non-art students in several visual-spatial tasks: most notably, the Mental Rotation Task, the Embedded Figures Test, and the Bistable Figure Task. These findings imply that artistic talent and training are associated with enhanced disembedding and manipulation of spatial imagery and visual attention. Further analysis revealed that when group differences in non-verbal IQ were taken into account, the difference in mental rotation accuracy was non-significant, while the differences in disembedding figures and in bistable figure reversal remained reliable.

If one considers the overall pattern of results in the visual-spatial portion of the task battery, those tasks that isolate top-down influences on visual attention appear to be most facilitated among the art students, while tasks driven by bottom-up perceptual processing mechanisms appear largely equivalent between the two groups. This implies that task-benefits associated with artistic ability are a result of enhanced perceptual intelligence (top-down), rather than enhanced sensitivity for visual stimuli (bottom-up).

From a bottom-up perspective, there was little evidence for group differences in interference on reaction time in the Navon Task, the perceptual strength of three different visual illusions, and the Out-of-Focus Pictures Task. Performance on the visual illusions task is related to individual differences in perceptual constancy, which has previously been linked to artistic ability only in very specific task-relevant contexts (Chamberlain & Wagemans, 2015; Ostrofsky et al., 2015; see also a useful discussion of the distinction between perceptual illusions and delusions by Cohen & Bennett, 1997). The null finding on the difference in illusory strength between art students and non-art students across three different visual illusions is in line with previous findings (Chamberlain & Wagemans, 2015; Schlegel et al., 2015).

The two groups also showed statistically equivalent performance on the Out-of-Focus Pictures Task. This task is similar to the Mooney image task (Figure 6), which was also found to be unaffected by artistic expertise in a previous study (Chamberlain & Wagemans, 2015). Both tasks can also be construed as a measure of perceptual closure as participants must match a closed perceptual representation onto an ambiguous image with potentially many interpretations (Verhallen et al., 2014; Verhallen & Mollon, 2015). The tension between accurate interpretation of a stimulus and flexible interpretation relates to a bit of popular advice to novice draftsmen, to “draw what you see, not what you know” – that is, to inhibit knowledge of the identity of the depicted object in the service of accurate depiction of local contours and values. This admonition, common in how-to drawing books (e.g., Edwards, 1989), is fundamentally a bottom-up mode of perceptual engagement, in contrast to more knowledge- and attention-driven top-down processing. The null findings for the Out-of-Focus Pictures Task is one of the starkest points of contrast between the present results and Kozbelt’s (2001) findings. The reasons for this inconsistency are unclear. One possibility is that the present stimuli from the IAPS were mostly straightforward images, while the set used by Kozbelt (2001), taken from an earlier study of insight problem solving (Schooler & Melcher, 1995) sometimes featured unusual cropping or points of view – aspects of the tasks that might in themselves advantage artists, irrespective of general perceptual processing differences. Understanding this issue, and the reason for the empirical discrepancy in the two studies, awaits further exploration.

FIGURE 6 HERE

Art students showed a similar degree of local and global interference on their reaction times in the Navon Task, consistent with earlier findings (Chamberlain & Wagemans, 2015), and there was no correlation between reduced global interference and drawing ability, which runs against the findings of a previous study (Chamberlain et al., 2013). The Navon Task in part measures the deployment of strategic visual attention and therefore can be construed as a top-down task of attentional focus, similar to the Embedded Figures or the Bistable Figure Task. However, the current Navon Task differed from that used in Chamberlain et al. (2013) in a way that may explain the contrasting results. The current paradigm contrasted both attentional level applied to the stimulus (global/local) as well as the salience of the relevant level of the stimulus (global/local), which may have confounded potential differences between the participants, as it required both perceptual integration and attentional focus. This methodology was chosen as it was of interest to compare global and local processing within a single paradigm. It would be worthwhile to further explore paradigms that pit global and local processing directly against one another, in order to assess the extent to which artists' perceptual skills reside in the ability to focus on local detail, or the ability to cohere local detail into a meaningful global form, or how they might flexibly switch between the two. A promising new alternative to the Navon Task may be able to do this more effectively than the current task, which represents global and local stimulus features independently from one another (Campana, Rebollo, Urai, Wyart, & Tallon-Baudry, 2016).

At first glance, this overall pattern of results paints a complex picture of artists' visual processing – particularly since the visual and spatial tasks tended to be weakly correlated within participants (Table 2). This may suggest that artists' enhancements in visual perception tend to be task- or domain-specific. Further evidence for the domain-specificity of artists' abilities was provided by the comparison of the residual scores from regressions between visual-spatial and drawing ability. These two analyses suggest that the art students possess skills in perception beyond those used strictly for drawing, and skills in drawing beyond those associated with perception (likely motoric and memory processes). However, while both group comparisons were significant, the effect size of the group difference for the residuals when regressing visual-spatial ability onto drawing ability was twice as large as the group difference in residuals when regressing drawing skills onto visual-spatial abilities (d = 1.14 vs. d = 0.55). This supports Kozbelt's (2001) assertion that artists' visual-spatial skills are most representative of those developed for their drawing skills. The somewhat larger role found presently for residual visual-spatial performance (after controlling for drawing) might also be partly attributed to the greater variety of visual-spatial tasks in this study, compared to those in Kozbelt (2001).

It can be posited that artist's perceptual abilities are shaped by the procedural knowledge they acquire by training in a specific medium (Kozbelt & Seeley, 2007). As a result, one would expect that different perceptual advantages would be associated with different domains of artistic expertise. For example, it has been shown that artists with expertise in painting show more sophisticated colour naming compared with non-painters, reflected by functional and structural differences in cortical region V4 (Long, Peng, Chen, Jin, & Yao, 2011). Similarly, local and global attentional processing modes may be engaged differentially by working with very fine-tipped drawing instruments in comparison to, say, broad charcoal work. Those perceptual advantages that cut across artistic domains can then be more likely attributed to declarative knowledge dissociated from the motor procedures characteristic of a specific medium.

This set of findings implies that an artist's domain of expertise may be best characterized via the act of drawing (or painting, or printmaking, etc.), rather than a particular class of well-defined visual stimuli, as is commonly found in other domains of expertise

(Bukach, Phillips, & Gauthier, 2010; Kozbelt & Ostrofsky, in press). The pattern of correlations between artistic skills and visual-spatial abilities demonstrates that both creative drawing ability and observational drawing ability relate to visual-spatial abilities; however, partial correlations revealed that these correlations are to some extent dependent on group differences in artistic skill. By contrast, performance on the Limited-Line Tracing Task did not reliably correlate with the visual-spatial tasks. This implies that the Limited-Line Tracing Task could be recast as a visual-spatial task, as it appears far less dependent on the visuo-motor and cognitive skills needed to complete the Creative Drawing and Observational Still-Life Drawing Task. This distinction also emphasizes that the Limited-Line Tracing Task is far from redundant with freehand observational drawing, underscoring its usefulness as an independent indicator of top-down perceptual processing relevant to understanding freehand drawing (see Ostrofsky et al., 2012).

Another key aspect of the current findings is the relationship between performance on the visual-spatial tasks and non-verbal IQ as measured by the Raven’s Progressive Matrices task (RAPM). The RAPM is a visual reasoning test that does not include spatial constructive aspects, in contrast to tests like the Block Design Task, which is included in the Wechsler Adult Intelligence Scale (WAIS-IV; Wechsler, 2008). All tasks, excluding the Out-of-Focus Picture Task, were to some extent predicted by individual differences in performance on the RAPM. However, tasks like the Bistable Figure Test and the Embedded Figures Test contributed to differences between artists and non-artists independently of individual differences in non-verbal IQ. Research investigating the role of IQ in music and chess expertise has produced inconsistent findings. However, it has been argued that in well-defined domains such as music, sports, and chess the role of IQ in performance is minimal, whereas individual differences in creativity in the arts and sciences are more likely to reflect the influence of IQ and other dispositional traits (Simonton, 2006; 2016). Due to the close relationship of visual-spatial tasks with non-verbal IQ found in the current study, in the future it will be necessary to tease apart abilities and traits that are specific to the depictive aspects of artistic functioning and those that relate to more general abilities like creative reasoning.

In further considering the two groups of students examined here, it should also be noted that the art student group consisted of first-year college students, with little formal artistic training beyond high school level – although all students reported drawing on a regular basis, corroborating their commitment to art and design as well as their experience when entering art school. (In passing, we also note some informal comments by Pratt drawing instructors that many of the first-year students had not yet learned how to draw very well, reflecting previous research with art student samples; McManus et al., 2010.) Therefore, the present group differences could reflect a lower bound on artist versus non-artist comparisons. Indeed, as the primary purpose of the data collection was in the service of a longitudinal study, the level of expertise of the art student group at the beginning of their freshman year in college was appropriate. The expectation for the forthcoming longitudinal findings is that, despite already outperforming non-artists from the outset, art students' abilities will be further enhanced as a result of an intensive course in drawing. Their abilities at the termination of the course should then far exceed those of the non-artist group, though there may yet be tasks for which the two groups remain comparable in the current study that later are shown to differentiate the two groups. Therefore, a full account of artists' skills can only be made when researchers have tracked the development of such skill from novice to expert levels. This is a rich avenue for further investigation and will require cross-sectional designs with individuals at multiple levels of expertise as well as longitudinal studies that track individuals over the course of their training. Such designs can identify abilities that predispose an individual to pursue expertise development in the visual arts, versus those abilities that are developed through training and the acquisition of expertise.

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Appendix 1: Supplementary Analysis

Inter-task Correlations

As can be seen from the supplementary correlation matrix (Supplementary Table 1), inter-task correlations were generally low, suggesting to a large extent that the various visual-spatial abilities tested in the context of this study represent independent visual and spatial processes. The only correlations that survived the stringent correction for multiple correlations were the correlation between accuracy on the MRT and EFT and the correlation between number of percept reversals in the hold and passive conditions of the Bistable Figure Task. With a more lenient alpha value < .05, there were significant weak within-task correlations within the visual illusions task and the Bistable Figures tasks. In addition, there were weak correlations between accuracy on the MRT and EFT RT and the three visual illusions. These correlations were negative, indicating that reduced error in the illusion task was associated with faster disembedding and more accurate mental rotation ability. The most isolated task appeared to be the blurred pictures task, which correlated poorly with all other visual and spatial measures. Similarly, interference in the Navon Task was not related to performance on other tasks aside from moderate negative correlations between global interference and reversal rates across conditions in the Bistable Figure Task.

Analysis of Impact of Judge Type on Observational and Limited-Line Tracing Drawing Tasks

When comparing the still life ratings by judge type (expert/non-expert), there was a larger difference between the art students and non-art students when the non-experts rated the drawing compared to when the experts rated the drawing (Supplementary Figure 1). In an ANOVA with group as the between-subjects variable and judge type (expert/non-expert) as a within-subjects variable, there was an effect of group, F (1, 76) = 43.82, $p < .001$, $\eta_p^2 = 0.37$, (art students were better than non-art students) and an effect of judge, F (1, 76) = 17.96, $p <$

.001, η_p^2 =0.17 (non-experts judges gave higher ratings than expert judges). Finally, there was an interaction between judge and student group, F (1, 76) = 10.70, p = 0.002, η_p^2 = 0.10, confirming that non-expert judges showed greater differentiation between the art students and the non-art student, driven only by differences in the ratings given for the art student group.

SUPPLEMENTARY FIGURE 1 HERE

When comparing expert and non-expert judges' evaluations of the Limited-Line Tracing Task, there appeared to be differences in the manner in which art students and non-art students' tracings were evaluated (Supplementary Figure 2). In a mixed-model ANOVA with group as a between-subjects variable and judge type as a within-subjects variable, there was an effect of student group, F (1, 75) = 5.23, p = 0.03, η_p^2 = 0.07, an effect of judge, F (1, 75) = 10.05, p = 0.002, η_p^2 = 0.12, and a marginal interaction between judge and group, F (1, 75) = 2.79, p = 0.10, η_p^2 = 0.04. In terms of the interaction it appears that non-expert judges again differentiated between art students and non-art students more, but in this instance by scoring the non-artists lower than the expert judges. Scores for the art students were equivalent between expert and non-expert judges.

SUPPLEMENTARY FIGURE 2 HERE

Inter-task Correlations for Expert and Non-Expert Judges

Correlations between two of the drawing tasks (the Limited-Line Tracing Task and the Observational Still-Life Drawing) and the visual-spatial task battery were conducted for expert and non-expert judges. It can be seen that significant correlations between observational drawing and visual-spatial tasks (Non-verbal IQ, MRT, EFT, bistable reversals) only hold when the observational drawings are rated by art experts.

Table 1

Frequency of Previous Two Year’s Drawing Practice Among Art Students and Non-art Students Inside and Outside of Students’ Classes

			Everyday	Few times a week	Once a week	Once a month	< Once a month
Art Students	2014	Inside	21	13	2	0	5
		Outside	11	15	10	3	2
	2015	Inside	21	14	1	1	3
		Outside	10	21	4	5	1
Non-art Students	2014	Inside	1	2	2	5	27
		Outside	0	3	1	6	27
	2015	Inside	2	3	3	5	24
		Outside	0	1	4	6	26

Note. ‘Inside’ and ‘Outside’ refer to inside and outside of the students’ classes. ‘2014’ and ‘2015’ refer to calendar years in question.

Table 2

Correlation Matrix of Representative Variables from Each of the Visual-spatial Tasks

	MRT	EFT	Out-of-Focus Pictures	Muller-Lyer Error	Bistable Figure	Navon RT interference
Non-verbal IQ	0.59**	0.51**	0.06	-0.28*	0.22*	-0.22*
MRT	-	0.45**	0.01	-0.36*	0.18	-0.01
EFT		-	-0.16	-0.29*	0.19	-0.09
Out-of-Focus Picture			-	-0.06	-0.02	-0.06
Muller-Lyer Error				-	-0.13	-0.07
Bistable figure					-	-0.10

Note. n=71. **p* < .05, ***p* < .002 (Bonferroni adjusted p-value). Non-verbal IQ = Performance IQ (Raven’s Progressive Matrices); MRT= Mental Rotation Task; EFT = Embedded Figures Test.

Table 3

Mean Error in the Visual Illusions Task

	Overall		Artist		Non-artist	
	M	*SD*	*M*	*SD*	*M*	*SD*
Muller-Lyer (pixel length)	34.77	26.51	32.95	20.73	36.74	31.79
Ebbinghaus (pixel radius)	6.68	14.77	4.49	9.61	9.06	18.69
Rod-Frame (degrees)	1.54	1.76	1.32	1.32	1.80	2.13

Table 4

Correlations Between Drawing Tasks and Visual-spatial Tasks

	Still-Life Observational	Limited-line Tracing	Creative Drawing
Non-verbal IQ	0.25* (0.05)	0.04 (-0.06)	0.35*(0.13)
MRT	0.22*(0.05)	0.06 (0.04)	0.24* (-0.04)
EFT	0.27*(0.06)	0.16 (0.05)	0.35*(0.13)
Out-of-Focus Pictures	0.08 (0.07)	0.07 (-0.05)	0.19 (0.17)
Muller-Lyer	-0.20 (-0.09)	-0.09 (-0.02)	-0.30* (-0.18)
Bistable reversals	0.31*(0.09)	0.14 (-0.03)	0.41**(0.21)
Navon interference RT	-0.14 (-0.08)	-0.19 (-0.14)	-0.05 (-0.003)

Note. **p* < .05, ***p* < .001 (Bonferroni-adjusted). Partial correlations controlling for group are included in parentheses. Non-verbal IQ = Raven's Progressive Matrices; MRT= Mental Rotation Task; EFT = Embedded Figures Test.

Supplementary Table 1

Correlations Between Limited-line Tracing and Still-life Drawing and the Visual-spatial Task Battery for Expert and Non-expert Judges

	Still-Life Observational		Limited-Line Tracing	
	Non-experts	Experts	Non-experts	Experts
Non-verbal IQ	0.08	0.29*	-0.06	0.04
MRT	0.03	0.29*	0.04	0.02
EFT	0.14	0.29*	0.04	0.13
Out-of-Focus Pictures	0.10	0.05	-0.09	-0.005
Muller-Lyer	-0.11	-0.22	-0.09	-0.02
Bistable reversals	0.28*	0.26*	0.13	0.06
Navon interference RT	-0.13	-0.12	-0.09	-0.16

Note. *$p < .05$

Supplementary Table 2

Correlations Between Visual-spatial Task Measures (*n* = 71)

		MRT		EFT		Out-of-Focus Pic	Visual illusion error			Bistable figure perception			Navon Interference	
		Acc	RT	Acc	RT	Acc	ML	EB	RF	Passive	Hold	Switch	Global	Local
MRT	Acc	-	0.16	0.45***	0.25*	0.01	-0.36*	-0.26*	-0.21	0.18	-0.02	0.21	-0.16	-0.05
	RT		-	0.14	0.34*	-0.01	0.16	-0.24*	-0.22	-0.05	0.14	0.04	-0.14	0.04
EFT	Acc			-	0.16	-0.16	-0.29	-0.09	-0.11	0.19	0.10	0.05	-0.32*	-0.05
	RT				-	-0.004	-0.05	-0.26*	-0.24*	-0.19	-0.09	0.14	-0.13	-0.13
Blurred picture	Acc					-	-0.06	0.01	-0.05	-0.02	-0.15	-0.03	0.02	-0.11
Visual illusion error	ML						-	0.26*	0.23*	-0.06	0.01	-0.05	0.10	0.10
	EB							-	0.08	0.14	0.19	0.20	-0.13	0.13
	RF								-	-0.01	-0.01	-0.14	0.10	0.12
Bistable figure perception	Passive									-	0.50***	0.34*	-0.34*	0.08
	Hold										-	0.33*	-0.15	0.21
	Switch											-	-0.27*	-0.07
Navon Interference	Global												-	0.05
	Local													-

Notes: * *p* <.05, ** *p* <.0006 (Bonferroni adjusted alpha value)

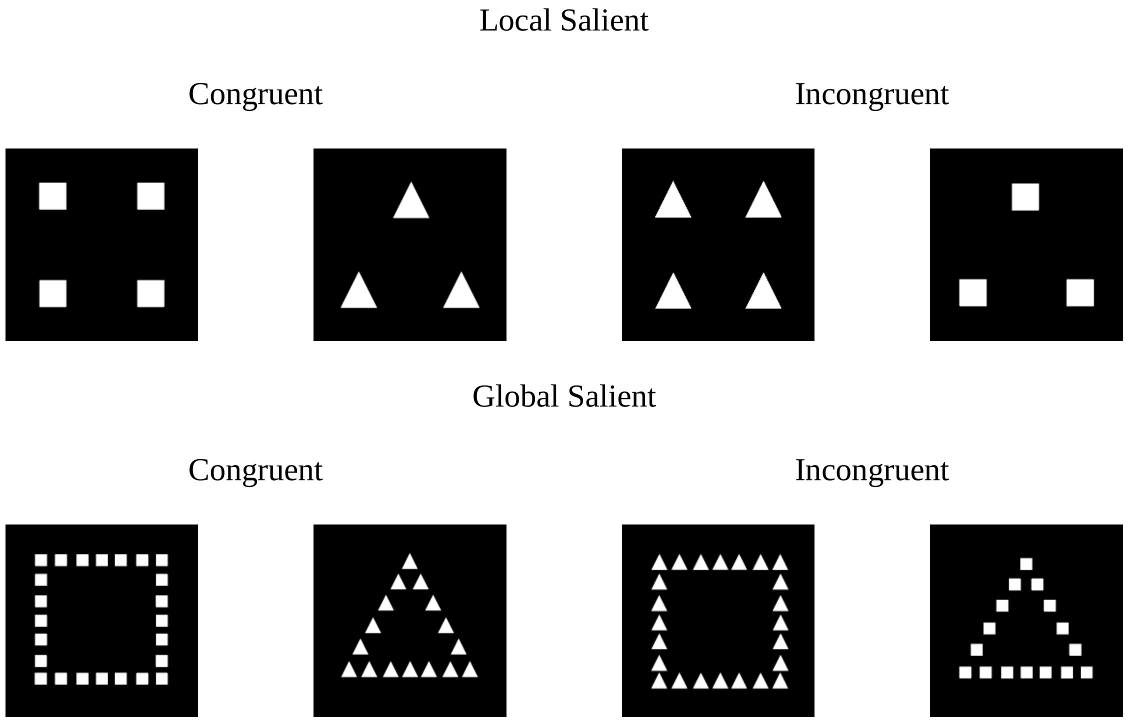


Figure 1. Navon Hierarchical Shape Task Grouped by Salience (Local/Global) and Congruency (Congruent/Incongruent)

Figure 2. Photograph of the Observational Still-Life (top) and Drawings by an Art Student (bottom left) and Non-Art Student (bottom right)

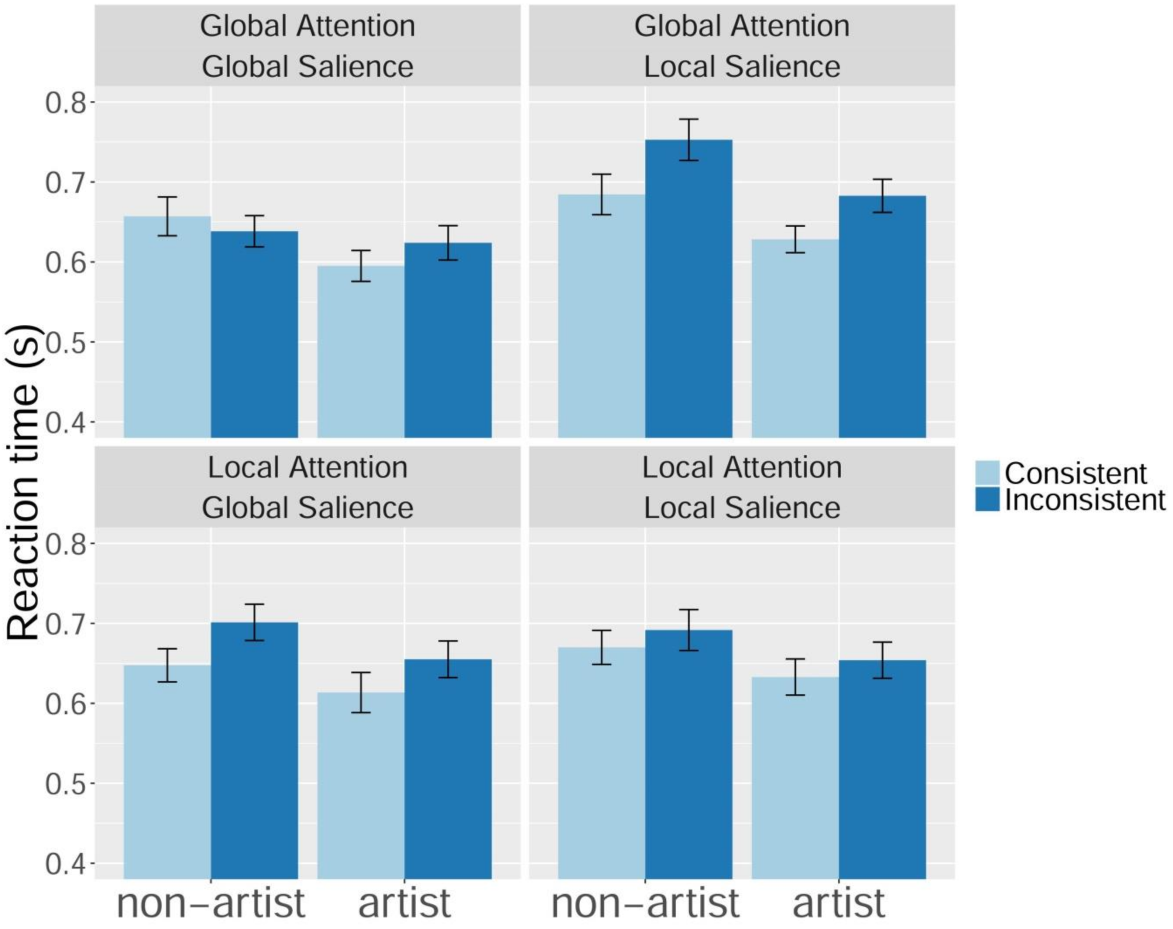


Figure 3. Untransformed reaction times on all Navon trials by salience, attentional level and group for correct trials. Error bars represent ±1 standard error of the mean. Statistical analyses used natural logarithm-transformed reaction times.

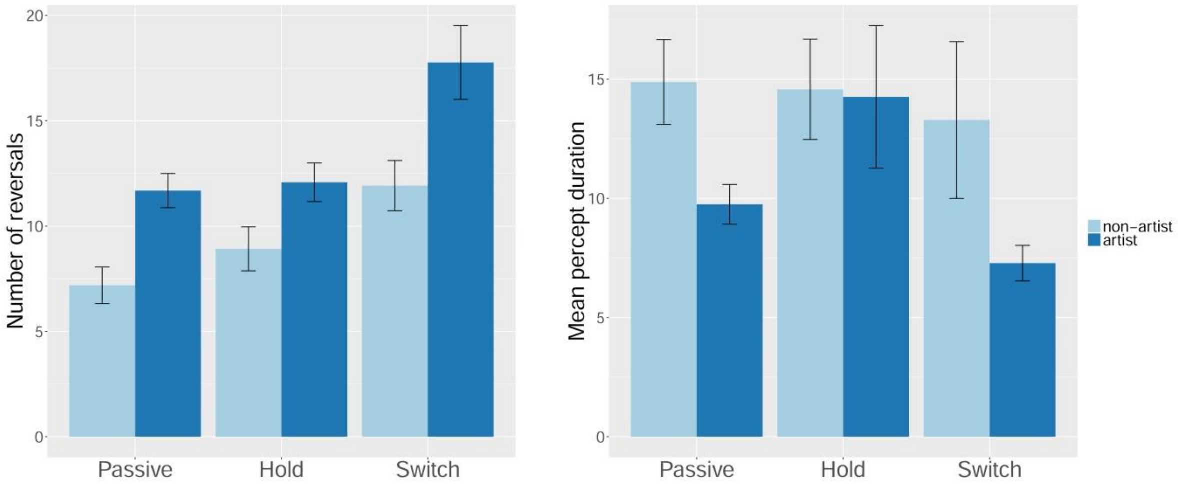


Figure 4. Untransformed Percept Reversals and Duration Across Conditions and Group in the Bistable Figure Task. Error bars represent ±1 standard error of the mean. Statistical analyses used square root-transformed number of reversals and natural logarithm-transformed percept durations.

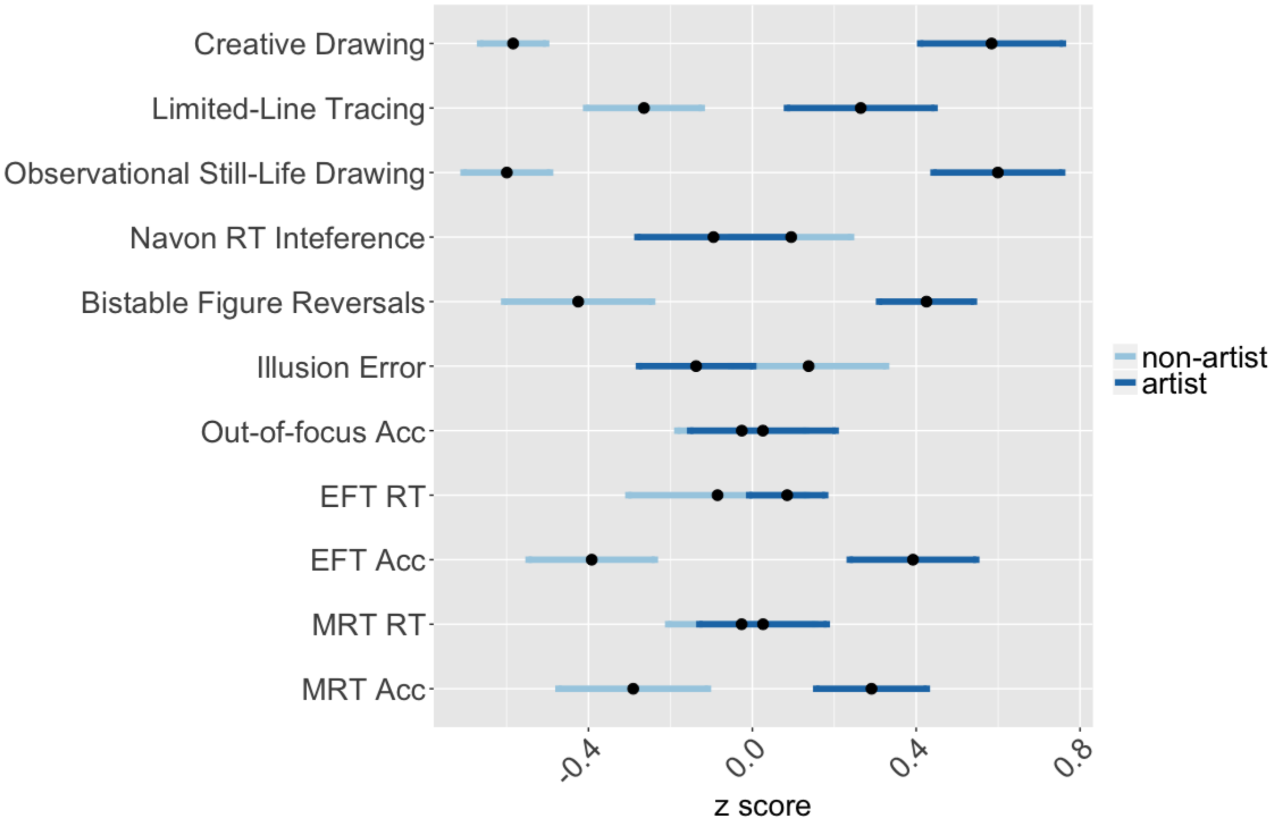
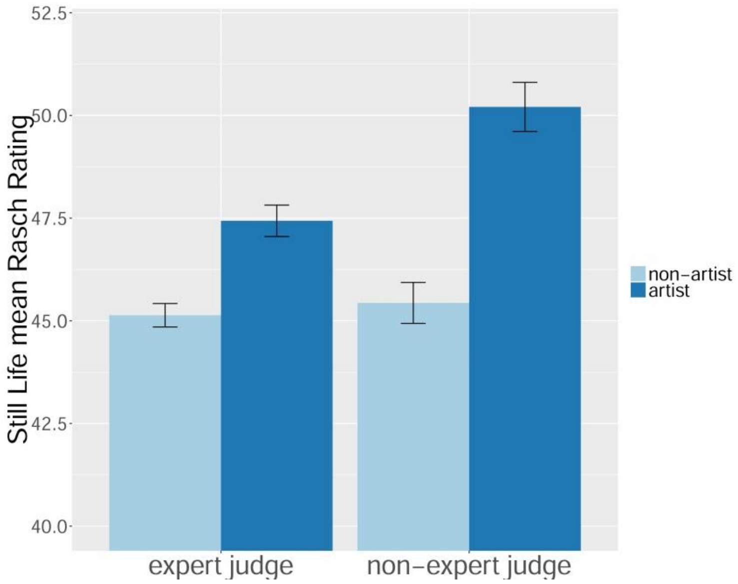
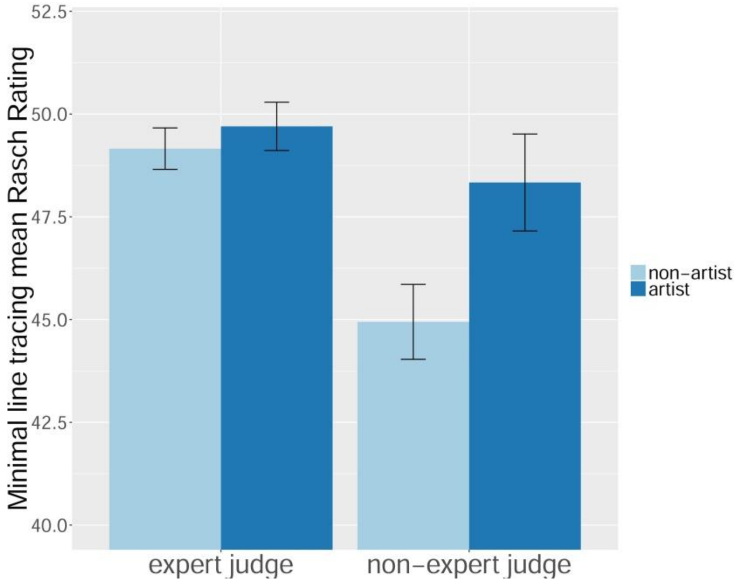


Figure 5. Average z-scores (x-axis) with 1 +/- standard error by group (artist/non-artist) per task (y-axis). EFT=Embedded Figures Test; MRT=Mental Rotation Task; RT=Reaction Time; Acc=Accuracy.

Figure 6. Examples of a black and white image (left) that has been made into a Mooney image (center) and blurred as in the Out-of-Focus Pictures Task (right)



Supplementary Figure 1. Rasch Rating Scores Provided by Expert and Non-expert Judges



Supplementary Figure 2. Rasch Ratings by Student Group (art/non-art) and Judge Type (expert/non-expert)