

## The artist's advantage: Better integration of object information across eye movements

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**Abstract.** Over their careers, figurative artists spend thousands of hours analyzing objects and scene layout. We examined what impact this extensive training has on the ability to encode complex scenes, comparing participants with a wide range of training and drawing skills on a possible versus impossible objects task. We used a gaze-contingent display to control the amount of information the participants could sample on each fixation either from central or peripheral visual field. Test objects were displayed and participants reported, as quickly as possible, whether the object was structurally possible or not. Our results show that when viewing the image through a small central window, performance improved with the years of training, and to a lesser extent with the level of skill. This suggests that the extensive training itself confers an advantage for integrating object structure into more robust object descriptions.

**Keywords:** artists, drawing, gaze-contingent, object recognition, eye movements, visual integration.

### 1 Introduction

Why are some people better at drawing than others? This question is not as trivial as it may seem at first. Drawing is one of the earliest visuomotor tasks that humans mastered, arriving well before writing (at least 40,000 BCE against 3200 BCE) and perhaps emerging around the time at which language evolved. This order of appearance is also seen in child development, where young children start to learn handwriting by drawing the letter's shape, but with practice the drawing and the writing processes become dissociated, with writing becoming more automated (e.g. Adi-Japha & Freeman, 2001; Feder & Majnemer, 2007). Drawing and writing both require a fine motor control, so why do many people master writing but fail at accurate drawing? One key difference is the amount of time spent learning to write versus learning to draw. While most children in developed countries spend many hours learning to write, only a subset extensively practice their drawing skills. What are the consequences of this extensive training? Does it alter the way a trained draftsman sees the world, creating a more photorealistic perception? Or does training leave perception unaffected and instead change the robustness of the representations of objects and scenes, creating more stable codes for complex object structure just as master chess players create stable codes or chunks, for complex chess configurations (Gobet & Simon, 1996).

The motivation for our study derives from Cohen and Bennett's (1997) description of three factors that contribute to better drawing accuracy: motor coordination, the perception of the model, and the selection of the relevant, to-be-drawn object's features. These authors ruled out coordination as a factor because both artists and non-artists had equally accurate hand movements in a tracing task. The second factor—more veridical perception by artists of the to-be-drawn object (e.g. “the innocent eye” of Ruskin, 1912)—can also be ruled out. Initially, it was reported that individuals with better drawing skills saw objects more veridically, that is, they were less affected by size or shape constancies (Cohen & Jones, 2008; Mitchell, Ropar, Ackroyd, & Rajendran, 2005; Ostrofsky, Kozbelt, & Seidel, 2012, for their size constancy task). However, many failed to show that artists' perceptual judgments are veridical (McManus, Loo, Chamberlain, Riley, & Brunswick, 2011; Ostrofsky et al., 2012, for their shape constancy task; Perdreau & Cavanagh, 2011, 2013). In particular, we (Perdreau & Cavanagh, 2011) found no differences between artists and non-artists in size, lightness, and shape constancies. Indeed,

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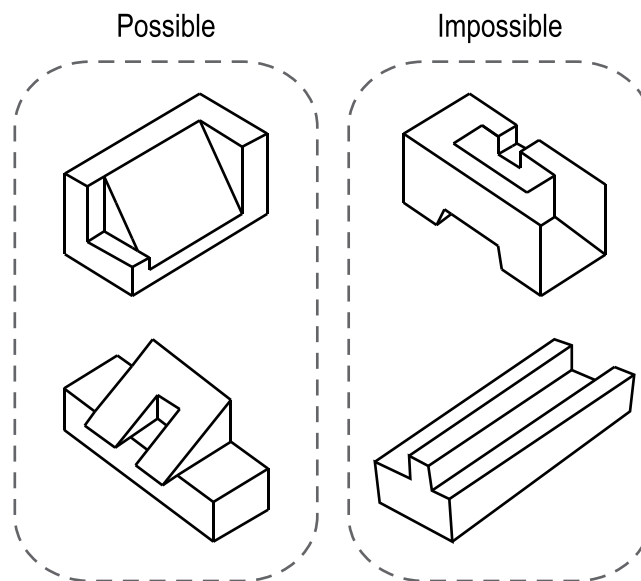
even across studies reporting a link between drawing skill and ability to discount visual constancy, the reduction in visual constancy (ranging from 0%, Perdreau & Cavanagh, 2011, to 5% to 10%, Ostrofsky et al., 2012) is far from the 100% reduction required if visual artists had indeed a veridical perception of the object as suggested by the innocent-eye hypothesis (Ruskin, 1912; see also Perdreau & Cavanagh, 2013, for a discussion of this point).

If neither motor coordination (Cohen & Bennett, 1997; Kozbelt, Seidel, ElBassiouny, Mark, & Owen, 2010) nor more photorealistic perception (McManus et al., 2011; Ostrofsky et al., 2012; Perdreau & Cavanagh, 2011) explains the artists' advantage, which leaves the third factor (Cohen & Bennett, 1997): the selection and representation of the relevant object structure. Indeed, recent studies report that more skilled artists reproduced significantly more junctions in a drawing task than novices (Kozbelt et al., 2010; Ostrofsky et al., 2012), suggesting better knowledge of what must be selected from the object to produce an accurate drawing. However, although the selection of the relevant features is a necessary step, it is not the only requirement. What may be more important is the representation of the spatial relations between these features, as these relations underlie the object's structure and proportions (Tchalenko, 2009).

Here again, studies have provided evidence for this advantage for spatial relations in artists. For instance, artists are better and faster at encoding complex sets of lines than novices (Glazek, 2012) and also better at recalling complex Rey-Osterrieth figures after relatively short delays ( $\leq 30$  s; McManus et al., 2010). In these tasks, the object's structure must be encoded and also maintained in memory. These abilities repeatedly come into play during a drawing task as the object is processed sequentially over numerous gaze shifts between the object and the drawing (Cohen, 2005; McManus et al., 2010). Interestingly, Glazek's study (2012) found that more skilled subjects tend to have more motor output—draw more—than novices during the same fixation duration, whatever the object's complexity. This suggests that drawing accuracy might be related to the ability to encode more structural information from a single fixation. However, in Glazek's study, participants were free to scan the entire object while drawing it and could thus encode information present in both central and peripheral vision. These studies show the importance of selection and representation of spatial relations but they did not compare the relative contribution of these two components.

The present study addresses the role of these two processes to examine whether an artist's advantage lies in (1) the ability to construct a robust, global representation in visual memory (visual chunks) across fixations or (2) the encoding of larger spatial extent of the object's structure on each fixation (visual span). To do so, we designed two experimental tasks using a gaze-contingent moving window and a gaze-contingent moving mask that controlled the amount of visual information available from central and peripheral vision (e.g. Geisler, Perry, & Najemnik, 2006; Rayner, McConkie, & Zola, 1980). In the first experiment, the moving window only allowed the participants to see the center of their vision field (window radius varying from  $1^\circ$  to  $5^\circ$ ), the surround being masked. Participants had to identify, within a limited time, whether the stimuli were structurally possible or impossible objects (see Figure 1 for examples). However, making such a decision requires either seeing the entire object or building up a mental representation across individual glimpses, for both possible and impossible objects share the same local features (vertices and junctions; e.g. Biederman, 1987; Soldan, Hilton, & Stern, 2009). If the artist's advantage is explained by the ability to build and maintain a more robust description of an object's structure, then they should be able to perform better with sparser inputs, constructing an internal model of the object from smaller samples (i.e. smaller window sizes). In other words, they may have access to more complex and robust codes for objects—bigger chunks (e.g. Chase & Simon, 1973)—that allow them to hold more complex structures in memory as they build up a representation from small samples. In contrast, our second experiment was identical except that it used a gaze-contingent central mask (from  $5^\circ$  to  $10^\circ$  of radius) that left the surround visible. The motivation for this task was to evaluate whether training and skill in drawing lead to better integration of structural information in *peripheral* vision. This increase in integration area on each fixation might be developed in order to process the global structure of an object while focusing on the local features currently being drawn, allowing them to be more appropriately placed relative to the overall structure. If this is the case, both experienced and skilled participants should be able to integrate information across larger visual spans (e.g. Rayner, 1998; Reingold, Charness, Pomplun, & Stampe, 2001) and be more tolerant of this central scotoma.

To foreshadow our results, our data support the idea that the artists' advantage lies, at least in part, in a better integration of the visual information picked up from different locations as the eyes move over



**Figure 1.** Examples of possible and impossible objects used in the two experiments.

a scene (experiment 1) but not in a better integration of that information across space (experiment 2). Moreover, we show that this advantage increases monotonically with the experience in drawing, and to a limited extent with drawing skill when foveal information is available.

## 2 Experiments

In two experiments, participants determined whether a test object was structurally possible or impossible while viewing the figure through a gaze-contingent window of various sizes (experiment 1) or with a central scotoma with various sizes (experiment 2). To evaluate the ability to integrate object structure from across fixations and across space, we compute a critical window size that led to 75% correct responses. By correlating the estimated critical window size and scotoma size with drawing skill and experience, we examined whether artists can better construct an accurate memory representation of the test object from smaller samples.

## 3 Method

### 3.1 Material

All the experiments used the same apparatus. The participant's head was always held by a chinrest so that his or her eyes were approximately 57 cm from the center of the screen. The stimuli were projected on a 22-inch CRT screen, with a resolution of  $1024 \times 768$  pixels and with a frame rate of 120 Hz. The experiments were programmed in MATLAB using the Psychophysics and Eyalink Toolbox extensions (Brainard, 1997; Cornelissen, Peters, & Palmer, 2002; Pelli, 1997), and were run on an Apple computer.

Participants' eye movements were recorded with an eye-tracking system (Eyalink 1000 monocular, 35-mm lens) at a 1000-Hz sampling rate. The eye tracker was always calibrated for the participant's dominant eye. Finally, eye movement events and saccades were parsed using the Eyalink 1000 algorithm (saccade acceleration threshold =  $9500 \text{ deg/s}^2$ , saccade velocity threshold =  $35 \text{ deg/s}$ ).

### 3.2 Stimuli

The majority of the possible and impossible objects were taken from the studies of Schacter, Cooper, Delaney, Peterson, and Tharan (1991) and Soldan et al. (2009), used with the authors' permission (Figure 1). The rest of the objects were designed by one of the authors (PF). In order to avoid any ambiguities about the objects' nature, we first asked 20 independent observers, not participating in the experiments, to judge all the line drawings as structurally possible or impossible. We specifically instructed them, according to Schacter et al.'s procedure (1991), that each object's edges were necessarily represented with lines, that surfaces were flat and could only face a single orientation, and that

the drawings represented solid and 3D objects. The 20 independent observers saw all the objects in a random order. For the main experiments, we only kept the objects that had an inter-observer agreement of 95% or better, leaving 85 possible objects and 66 impossible objects. However, we used two random subsets that were different across the experiments. These subsets had 30 objects of each category. Objects were distributed among the trials so that they were repeated three times within the same experiment, but never in the same orientation and never with the same window size. The objects' pictures were presented at  $21^\circ \times 21^\circ$  of the visual angle and were centered on the screen.

### 3.3 Gaze-contingent display

In the "moving window" experiment, the gaze-contingent display was a circular, fully transparent area with a diameter that was the independent variable, whereas it was a circular, fully opaque area in the "moving scotoma" experiment. Their position was continuously updated and centered on the subject's fixation location provided by the eye-tracking system. We measured the effect of window and mask diameter on task performance with eight different sizes ranging from  $1^\circ$  to  $5^\circ$  in radius ( $1^\circ$ ,  $1.5^\circ$ ,  $2.1^\circ$ ,  $2.6^\circ$ ,  $3.1^\circ$ ,  $3.7^\circ$ ,  $4.2^\circ$  and  $5^\circ$ ) in the "moving window" experiment, while the scotoma radius ranged from  $5^\circ$  to  $9.8^\circ$  ( $5^\circ$ ,  $5.7^\circ$ ,  $6.4^\circ$ ,  $7.1^\circ$ ,  $7.8^\circ$ ,  $8.4^\circ$ ,  $9.1^\circ$  and  $9.8^\circ$ ).

### 3.4 Participants

Twenty-six participants were tested (mean age of  $28.3 \pm 1.9$  years, 11 males, 15 females). Twenty-four of the participants ran in both experiments. One participant ran only in the first experiment and one only in the second. All the participants were informed of the experiment's purpose and risks, and all gave their informed consent before starting the experiment. Finally, all participants were paid 20 euros for the entire session. The characteristics of participants are described in [Table 1](#).

For convenience in this article, we have referred to our more skilled and trained participants as artists even though there is no real definition for "artist" or "visual art," and clearly drawing accuracy alone does not make someone an artist. Nevertheless, using this very general label is not unreasonable, for drawing is a common task in many different artistic activities (e.g. illustration, movie or dance; for a discussion of this point, see Seeley & Kozbelt, [2008](#)).

### 3.5 Procedure

Each experiment included 9 blocks of 20 trials each, and began with a practice block of 8 trials. Each block was preceded by a calibration of the eye movement monitor. The first block served as a baseline, where the objects were fully visible, while the eight other blocks used the gaze-contingent window. Except for the presence of the window, the procedure was identical for all the blocks.

Each trial started with a fixation dot at a randomly chosen location within the image. The subject had 1 s to fixate it for 250 ms. After this fixation test, the gaze-contingent display ([Figure 2](#)) appeared centered on the fixation dot's coordinates. The participants had to report whether the object was structurally possible or impossible as fast as possible by pressing the appropriate key ("L" if possible, "S" if impossible). The display only remained for 10 s, and participants had to give their response within this time. In the cases where the participants did not, a new screen appeared asking them to give a response.

We tested eight window sizes in addition to the full-view condition tested during the first block ("baseline"). There were 20 trials per window size, 20 trials for the baseline condition, and thus 90 trials per object category (possible and impossible), for a total of 180 trials.

### 3.6 Evaluation of drawing skill

Participants' drawing skills were evaluated, first with a short set of questions about their drawing experience and then with a drawing task where they had 15 min to make a pencil drawing of a  $31^\circ \times 21^\circ$  gray-scale photograph of an octopus (the same as used by Kozbelt et al., [2010](#)). The participants were instructed to copy the original as realistically and accurately as possible, that is, without emphasizing aestheticism and creativity. They were allowed to use all the drawing techniques they knew and to erase and correct their drawing as many times as they needed. Once the 15 min were over, the model disappeared from the screen.

To score the subject's drawing skill, we asked eight independent judges, blind to the participants' identities, to evaluate the accuracy and the realism of the productions. Accurate drawings respected the model's proportions, the position and shape of the shadows, and details of the texture. During the judging, the drawings were presented on a computer screen simultaneously with the model. In a first step, the raters could look at all of the drawings, without making a decision, to get an idea of the range of

**Table 1.** Participants. Some of our participants were or are following a formal training in visual arts (reported in the “School” column. Years of experience corresponds to full years of weekly training. “Years of experience” was set to 0 for participants with no training in drawing. The “Rating” column reports mean rating that participants obtained in our drawing task. Handedness is reported as follows: “R” for right-handed, “L” for left-handed. Finally, in the “Gender” column, “F” and “M” correspond to female and male, respectively.

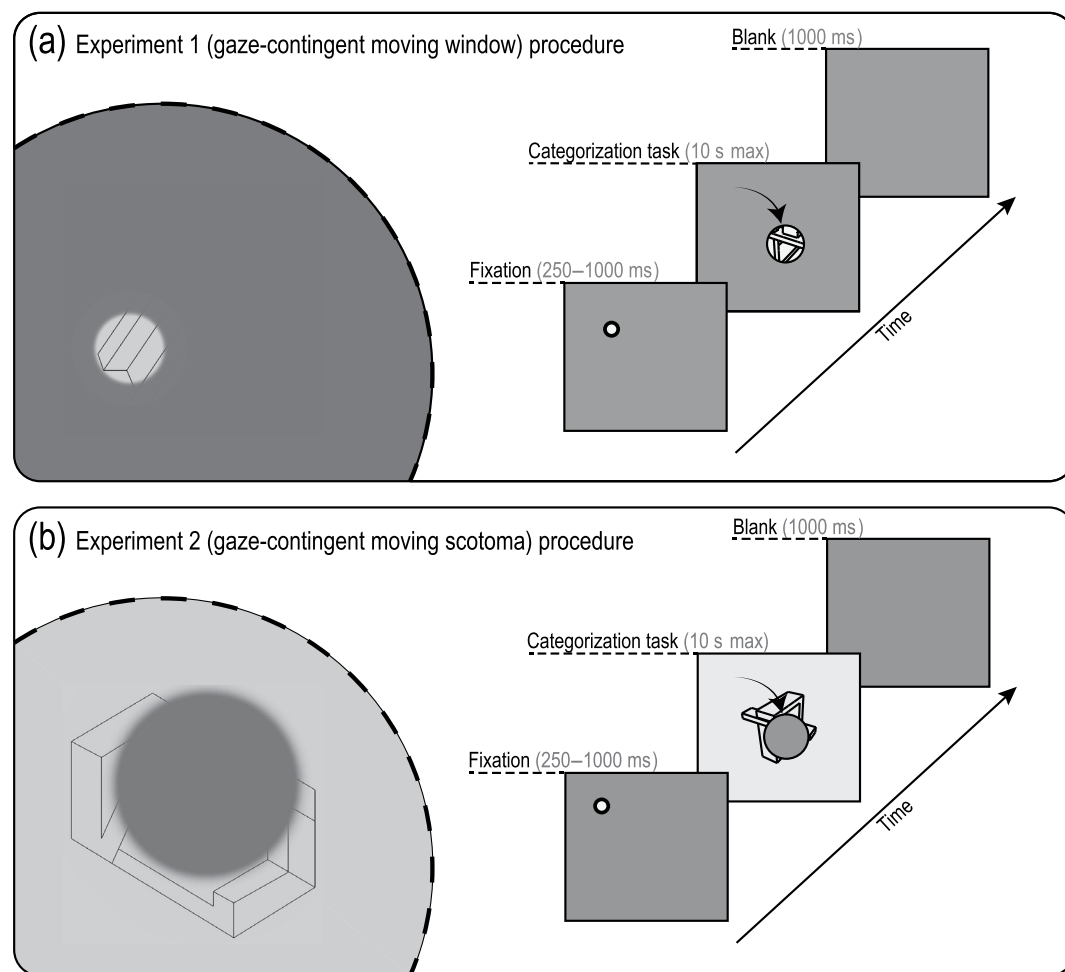
Name	Age	Handedness	Gender	School	Experience	Rating
AC	28	R	F	0	0	1.69
AF	20	R	F	0	0	2.31
CC	38	L	M	0	0	4.72
DG	22	R	F	0	0	2.59
JZ	52	R	M	0	0	1.50
LM	22	R	M	0	0	1.47
LMO	18	L	M	0	0	1.56
MDM	23	L	M	0	0	3.25
PS	19	R	F	0	0	1.47
LC	24	R	M	0	1	1.09
JS	40	R	M	0	2	2.81
IV	44	L	F	0	3	5.16
ML	27	R	F	0	3	6.16
TC	31	R	F	0	3	3.28
CR	22	L	M	1	4	4.00
CL	44	R	F	1	5	2.72
GC	21	R	F	1	7	5.00
AG	28	R	F	1	8	6.59
BE	25	L	M	1	10	3.81
AL	24	R	F	1	15	4.94
LRF	25	R	F	0	15	4.34
TH	22	L	M	0	15	5.44
VP	23	L	M	1	15	6.00
LD	31	R	F	1	20	5.28
SD	33	R	F	1	20	3.19
YM	54	L	F	0	28	2.66

skills (Figure 3). Then, in a second pass, the drawings were presented in a random order and the judges rated each on an 8-point scale (1 for a very low accuracy and 8 for the best accuracy). This ratings cycle was repeated five times with the drawings in a new random order each time. All the judgments were consistent within and between the raters (Cronbach’s  $\alpha$ ; intra- $\alpha$ :  $0.94 \pm 0.01$ ; inter- $\alpha$ : 0.97). The mean of the judges’ ratings was taken as each participant’s drawing score (Table 1).

## 4 Results

### 4.1 Accuracy

The data of the two baseline blocks (unobstructed, full view of the line-drawn objects) were pooled together (from both experiments 1 and 2), giving 40 baseline trials. Participants who did not reach 75% correct responses in the baseline condition were excluded from the analysis ( $n = 3$ ). However, in the first experiment, one subject’s behavior strongly deviated from others and could reasonably be considered as an outlier (mean Cook’s distance = 0.44; Bollen & Jackman, 1985; Cook, 1979). Although this subject reached the 75% criterion in the baseline condition, she never exceeded 50% correct in the test

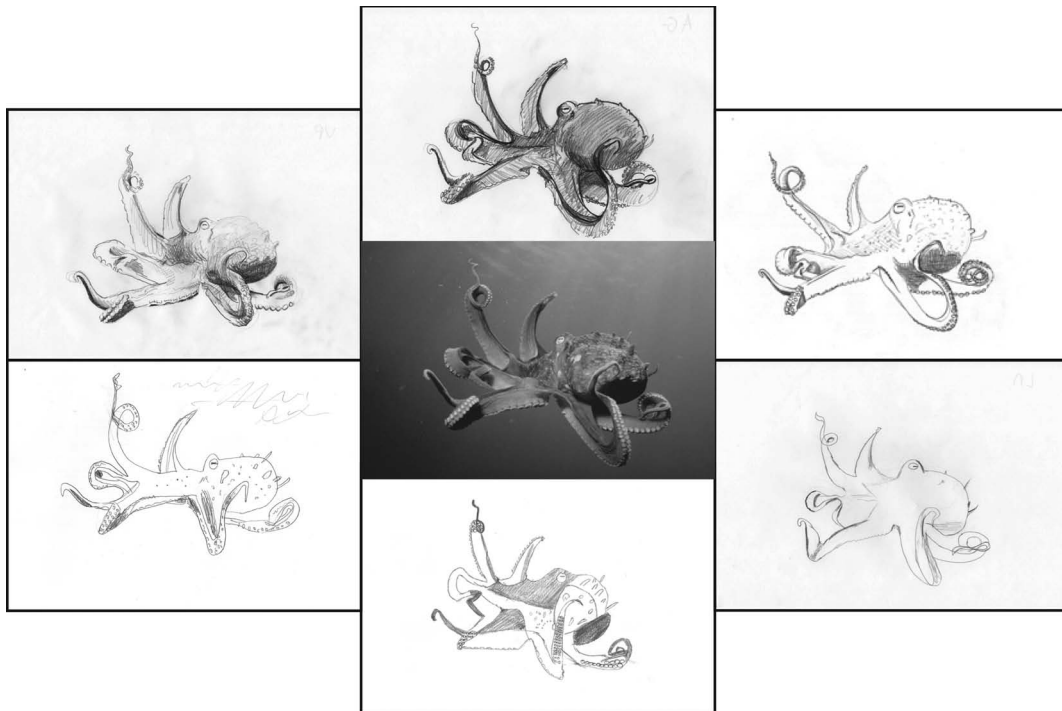


**Figure 2.** Trial procedure. (a) The trials started with a fixation dot appearing at a random position. Once the participant fixated it for 250 ms, the gaze-contingent window appeared, allowing the participant to only see the center of his or her vision (except in the baseline block, where the stimuli were fully visible). The participant had to respond, as fast as possible, whether the partially hidden object was structurally possible or impossible. If the participant did not respond within 10 s, the object and the window disappeared and were replaced by a screen asking him or her to give a response. (b) In experiment 2, the procedure was similar to that of the first experiment, except that we manipulated a gaze-contingent moving mask (scotoma) that blocked central vision.

conditions, seriously skewing her threshold value. In the following section, we will present the results without this subject but, overall, this had little effect on the results. Consequently, 21 participants were included in the first experiment's analyses and 22 participants in those of the second experiment.

We used two approaches to evaluate the influence of drawing skill and years of experience: (1) we took their drawing skill and self-reported years of experience in drawing as indexes to correlate with their performance; (2) we split our participants into two groups, separately accordingly to their drawing rating (skilled vs. unskilled) and their years of experience (trained vs. untrained). For drawing accuracy, participants were considered as unskilled if their rating was smaller than the median of all ratings, whereas were taken as untrained participants who had no experience in drawing.

To measure the critical window and scotoma size in the possible versus impossible task, we plotted each participant's performance against the size of the viewable area. Psychometric curves were then fitted (Figure 4) with Weibull functions using a maximum likelihood method (Prins, 2012; Wichmann & Hill, 2001a, 2001b). This resulted in a mean deviance (quality of fit) of 4.90 (SE: 0.58) for the first experiment's fits, and of 8.43 (SE: 1.11) for the second experiment's (all  $p$  values  $>0.05$ ). The participant's critical window and scotoma size were both defined as the viewable area leading to 75% correct responses. In both experiments, reaction times decreased as performance increased with window size, ruling out a speed-accuracy trade-off [Exp. 1:  $r(7) = -0.98, p < 0.0001$ ; Exp. 2:  $r(7) = -0.96, p < 0.0001$ ].



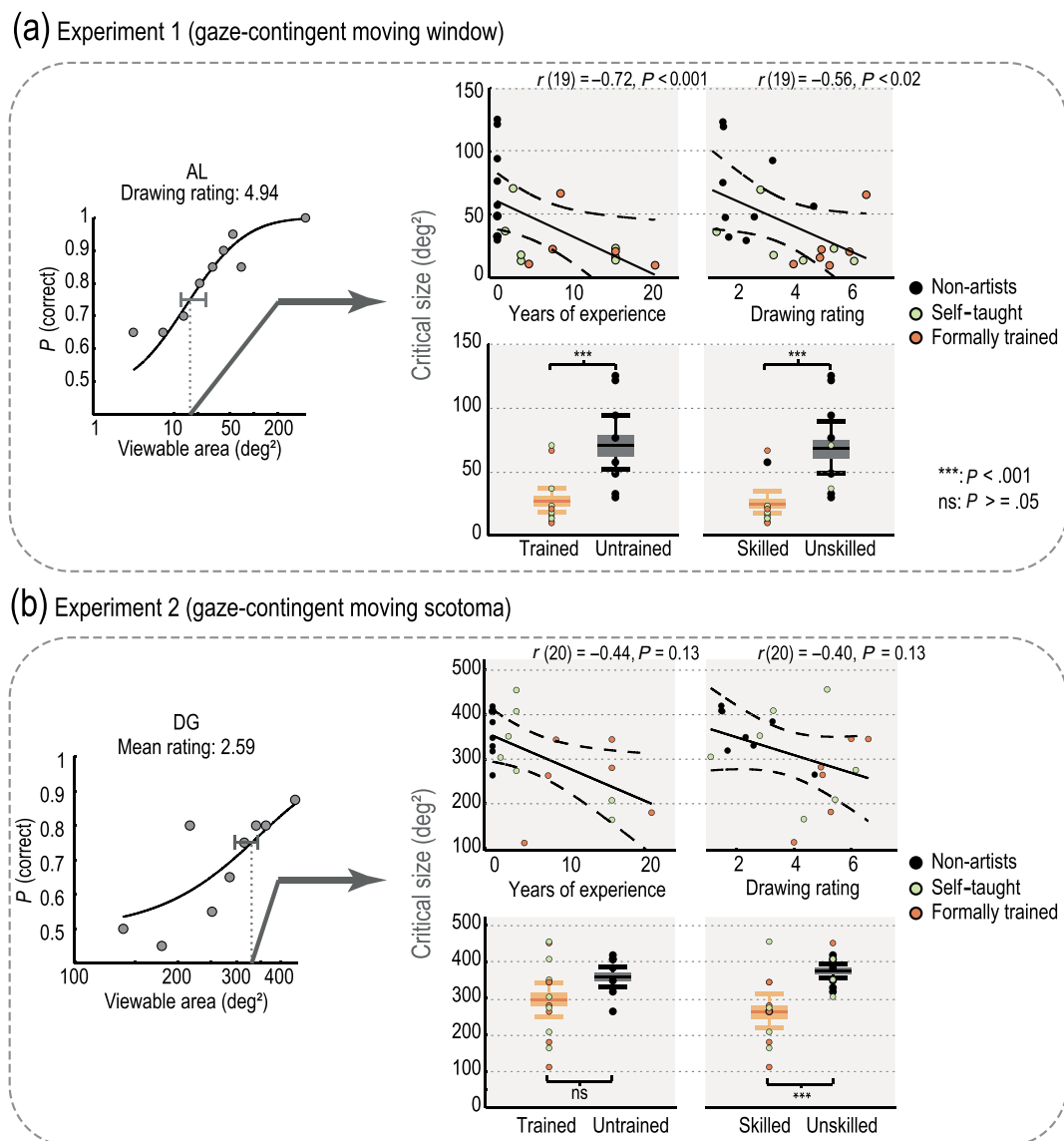
**Figure 3.** Examples of hand drawings made by the participants during the drawing task. Drawings presented in the lower row are those judged as less accurate, while the upper drawings were judged more accurate.

We then plotted each participant's critical window size and critical scotoma size against his or her drawing score and separately against his or her years of drawing experience. Because the distribution of our data violated assumptions of bivariate normality, we used a non-parametric, rank-based Spearman's correlation to evaluate the relationship among these variables ( $p$ -values are adjusted for multiple comparisons with a Holm–Bonferroni sequential procedure; Holm, 1979). The confidence intervals of the correlation coefficients were computed with non-parametric bootstraps (10,000 runs) and we used the percentile method for the confidence interval computation (DiCiccio et al., 1996).

In the “central window” experiment, we found (Figure 4) a significant negative correlation between the critical window sizes and the drawing scores [ $r(19) = -0.56 (-0.83, -0.12), p < 0.02$ ] as well as a significant, negative correlation between the critical window sizes and self-reported years of drawing experience [ $r(19) = -0.72 (-0.82, -0.62), p < 0.001$ ]. The finding that both are significant is not very surprising since drawing scores and experience were also strongly correlated [ $r(19) = 0.75 (0.52, 0.88), p < 0.001$ ] and shared about 56% ( $R^2$ ) of their variance. In contrast, in the “moving scotoma” experiment, no significant correlation was found between critical scotoma size and either drawing skills [ $r(20) = -0.44 (-0.72, -0.16), p = 0.13$ ] or drawing experience [ $r(20) = -0.40 (-0.70, -0.09), p = 0.13$ ].

Similar results were found when comparing the participants in groups for both drawing accuracy and experience. The critical window sizes of the more skilled participants were significantly smaller than those of novices [skilled: 24.85 (5.74), unskilled: 68.50 (11.23),  $t(19.0) = -3.56$ , CI (95%) =  $[-69.32, -17.99]$ ,  $d = -1.56$ ,  $p < 0.004$ ], as well as when considering experience [trained: 26.94 (6.00), untrained: 70.56 (12.03),  $t(19.0) = -3.50$ , CI (95%) =  $[-69.69, -17.54]$ ,  $d = -1.54$ ,  $p < 0.004$ ]. However, despite insignificant correlations between critical scotoma sizes and both experience and drawing accuracy, the group comparisons show a significant advantage for more skilled participants in the second experiment [skilled: 262.73 (29.12), unskilled: 375.09 (14.31),  $t(20.0) = -3.46$ , CI (95%) =  $[-180.03, -44.68]$ ,  $d = -1.48$ ,  $p < 0.005$ ], but not for more experienced participants [trained: 295.74 (28.15), untrained: 359.46 (19.07),  $t(20.0) = -1.58$ , CI (95%) =  $[-147.57, 20.14]$ ,  $d = -0.70$ ,  $p = 0.13$ ].

These results suggest that increased drawing practice and drawing skill are related to increased ability to integrate object structure from smaller samples of foveal information (experiment 1). Is there any difference between the contribution of drawing practice and drawing skill in this task?



**Figure 4.** (a) Scatter plots of the subjects' critical window size against subjects' years of experience and drawing accuracy. We first fit Weibull function to each participant's proportion of correct response and we took the critical window size as the size leading to 75% correct response (the left panel shows an individual fit). We then correlated participants' critical sizes to their experience and drawing rating (right panel, top row). We found a significant negative correlation between the subjects' critical window size and their amount of training as well as with their drawing skills (dotted lines are 95% confidence interval of the regression line). Similar results were also found when comparing groups of participants made accordingly to levels of skill and of experience (box plots in the right panel, bottom row; error bars are 95% confidence intervals of the means). This effect cannot be attributed to age, which was not correlated with critical window size, or to a better knowledge of what is an impossible or a possible object, represented by how subjects performed in the baseline condition, which was not correlated with years of experience. (b) Scatter plots of the subjects' critical scotoma size. We did not find a significant correlation between the participants' critical scotoma size and either their amount of training or their drawing skills. However, we found a significant advantage for more skilled participants when splitting the participants into two groups according to drawing scores although not when they were divided according to years of experience.

To compare the two correlation levels—for years of experience and for drawing score, which are themselves correlated—we used Fisher's Z transformed correlation coefficients (Meng, Rosenthal, & Rubin, 1992). We found no significant differences between these correlation coefficients in the first experiment [ $r_{\text{ratings}} - r_{\text{years}} = -0.16$  ( $-0.67, 0.14$ ),  $Z(18) = -1.30$ ,  $p = 0.17$ ].

One simple explanation of the link between years of practice and better performance with smaller window sizes in the first experiment is that participants with more drawing practice were just better



overall at the possible versus impossible task. However, when the drawings were in full view in the baseline condition, there was no correlation between performance and years of experience [Exp. 1:  $r(19) = 0.32 (-0.03, 0.67)$ ,  $p = 0.47$ ; Exp. 2:  $r(20) = 0.30 (-0.05, 0.54)$ ,  $p = 0.56$ ]. Another explanation is that years of drawing experience simply reflect the participant's age irrespective of drawing experience. However, this was not the case either. We found no correlation between critical window sizes and the participants' age [Exp. 1:  $r(19) = 0.03$ ,  $p = 0.90$ ; Exp. 2:  $r(20) = 0.13$ ,  $p = 0.56$ ], where if anything, the (non-significant) effect is the opposite of that of experience: participants got worse (although not significantly worse), requiring larger window sizes, as they got older.

In contrast to experiment 1, experiment 2 showed no link between years of practice and better performance and central scotoma size. Nevertheless, we again checked the possible contributions of secondary variables and, as in experiment 1, we found no significant correlations between age and critical scotoma size or between baseline performance and years of experience [age:  $r(20) = 0.13 (-0.28, 0.54)$ ,  $p = 0.56$ ; baseline performance:  $r(20) = 0.30 (-0.05, 0.65)$ ,  $p = 0.50$ ].

We next analyzed possible learning effects. Our test objects were presented three times with different rotation angles in each experiment, and some of them already appeared fully visible in the baseline condition. Since it is known that visual artists show an advantage in recalling complex figures after a delay of 30 s (McManus et al., 2010), it is possible that our results could be due to a learning effect that would be greater in more skilled subjects. To test this hypothesis, we computed the participants' mean performance for each block of trials and we ran a linear regression for each individual to determine if there were any improvements across blocks in either experiment. Participants' slopes were on average significantly higher than 0 [Exp. 1:  $t(20) = 10.75$ , CI (95%) = [0.03, 0.05],  $p < 0.001$ ; Exp. 2:  $t(21) = 4.76$ , CI (95%) = [0.01, 0.03],  $p < 0.01$ ], suggesting indeed the presence of a learning effect. However, when correlating individual regression slopes against participants' experience and drawing accuracy separately, we found no evidence of a greater learning rate in more skilled participants with the critical central window size in experiment 1 [ $r_{\text{years}}(19) = 0.35 (0.01, 0.68)$ ,  $p = 0.24$ ;  $r_{\text{ratings}}(19) = 0.30 (-0.05, 0.66)$ ,  $p = 0.24$ ] or with the critical central scotoma size in experiment 2 [ $r_{\text{years}}(20) = 0.37 (-0.04, 0.69)$ ,  $p = 0.19$ ;  $r_{\text{ratings}}(20) = 0.48 (0.22, 0.73)$ ,  $p = 0.17$ ].

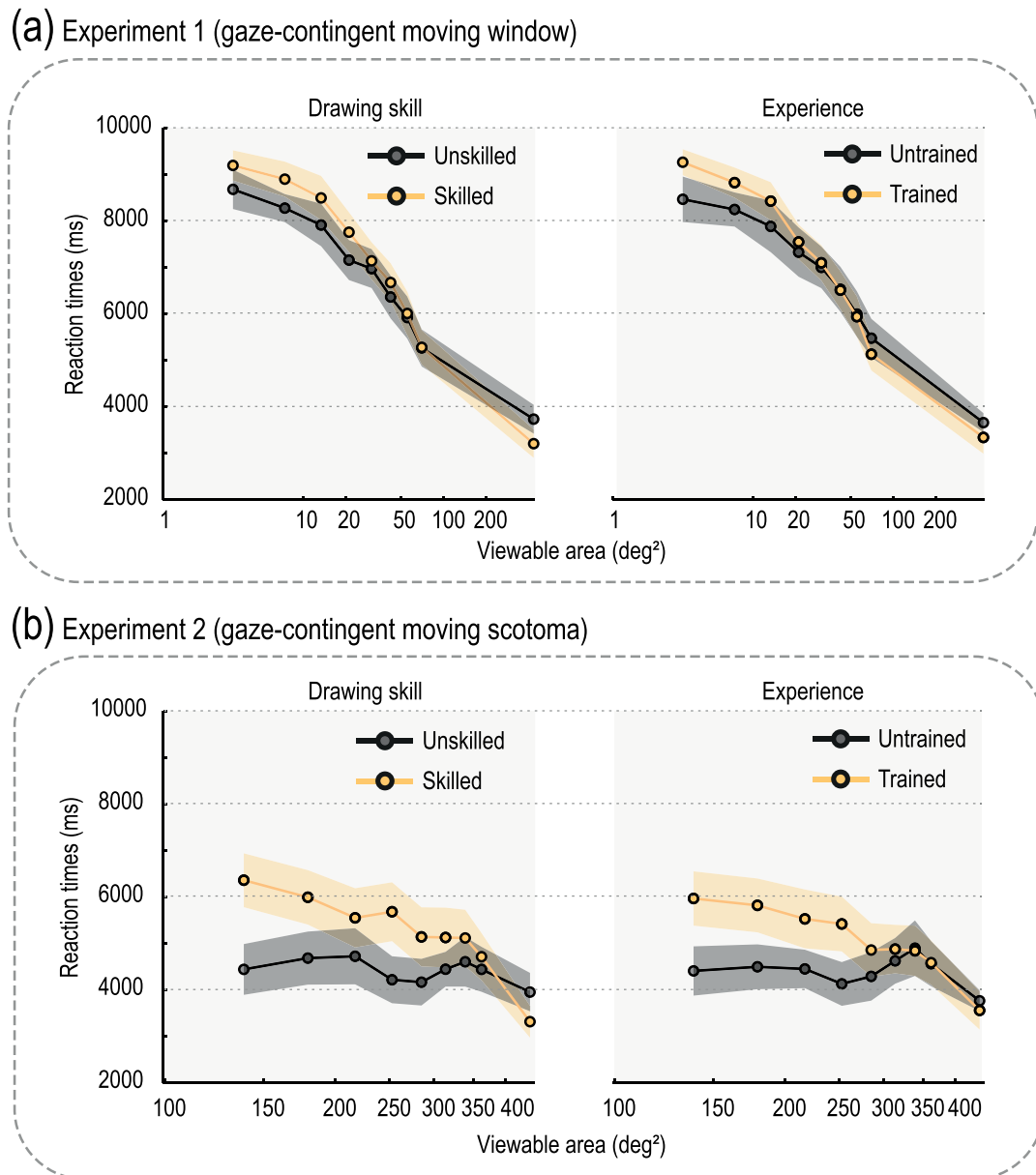
Finally, we examined whether there was any performance advantage for the 20 of 60 objects that were seen in the baseline condition and then seen again in the subsequent central window and scotoma test conditions. To do so, we computed the mean performance for the objects seen in both the baseline and test conditions and compared that to the mean performance for the objects only seen in the test conditions (using an arcsine square root transformation). There was no significant difference between these two categories in either experiment [Exp. 1:  $t(42) = -0.44$ ; Exp. 2:  $t(42) = 0.69$ ].

#### 4.2 Reaction times

Not surprisingly, participants classified the objects more quickly when more of the image was visible (Figure 5). Specifically, linear contrasts showed that participants' reaction times significantly decreased as the viewable area increased [Exp. 1:  $F(3.42, 20) = 100.1$ ,  $p < 0.000$ ,  $\eta_p^2 = 0.83$ ; Exp. 2:  $F(4.59, 21) = 8.80$ ,  $p < 0.000$ ,  $\eta_p^2 = 0.29$ ].

To measure whether this effect of window size on participants' reaction times changed with their experience or accuracy in drawing, we computed linear regressions with window sizes (baseline excluded) as predictors and reaction times as independent variable for each participant. We found no significant correlation between either experience or accuracy and participants' reaction time regression slopes in the first experiment [experience:  $r(19) = -0.45 (-0.728, -0.169)$ ,  $p = 0.12$ ; accuracy:  $r(19) = -0.41 (-0.71, -0.10)$ ,  $p = 0.13$ ], whereas these variables were significantly related in the second experiment [experience:  $r(20) = -0.62 (-0.78, -0.46)$ ,  $p < 0.006$ ; accuracy:  $r(20) = -0.59 (-0.77, -0.41)$ ,  $p < 0.008$ ]. This suggests that in the presence of a moving scotoma, more experienced and more skilled subjects took more time when less peripheral information was visible. However, this had no effect on these participants' performances, since we found no correlation between critical scotoma sizes and either experience or drawing accuracy.

Finally, mean reaction times were not correlated to participants' drawing experience in either the test phase [Exp. 1:  $r(19) = -0.003 (-0.44, 0.44)$ ,  $p = 0.99$ ; Exp. 2:  $r(20) = 0.01 (-0.41, 0.44)$ ,  $p = 0.99$ ] or the baseline condition [Exp. 1:  $r(19) = -0.42 (-0.71, 0.12)$ ,  $p = 0.12$ ; Exp. 2:  $r(20) = -0.42 (-0.71, 0.13)$ ,  $p = 0.10$ ]. In contrast, we found that reaction times in the baseline conditions were related to drawing accuracy in the first experiment [Exp. 1:  $r(19) = -0.56 (-0.76, -0.35)$ ,  $p < 0.03$ ; Exp. 2:  $r(20) = -0.48 (-0.73, -0.23)$ ,  $p = 0.07$ ], whereas these variables were not correlated



**Figure 5.** (a) Mean reaction times (RTs) against the viewable area sizes (baseline excluded) for the first experiment (central window). RTs significantly decreased as the viewable area increased. This effect of window size did not significantly differ across levels of experience or of drawing accuracy. (b) Mean reaction times for the second experiment. As in the first experiment, RTs decreased as the viewable area increased.

in the test conditions with partial visibility [Exp. 1:  $r(19) = 0.006$ ; Exp. 2:  $r(20) = 0.02$ ;  $P \gg 0.05$ ]. The correlation between drawing score and reaction time in the first experiment baseline condition is only marginally significant but it suggests that more skilled (but not more trained) participants took less time to categorizing possible versus impossible objects when they were fully visible. Perhaps this advantage did not appear in the baseline accuracy results because of a ceiling effect under full visibility. This might suggest that more skilled participants are indeed faster at encoding complex set of lines (Glazek, 2012). Whatever the case, this reaction time advantage for skilled participants was no longer seen when the stimuli were partially visible.

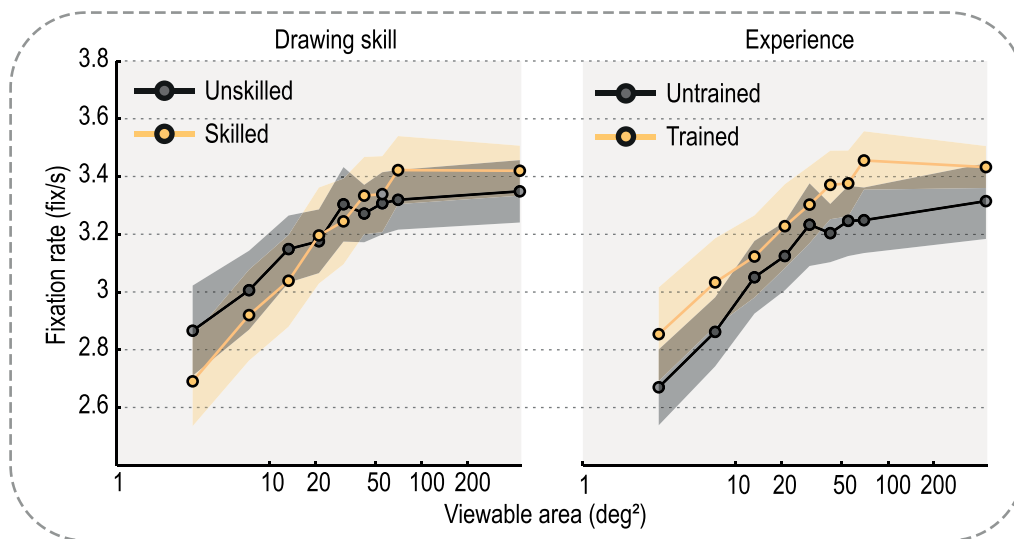
#### 4.3 Eye movements

We next analyzed whether artists used different strategies to explore the test images and that could explain the better performances of our skilled and experienced participants in our tasks. We began by

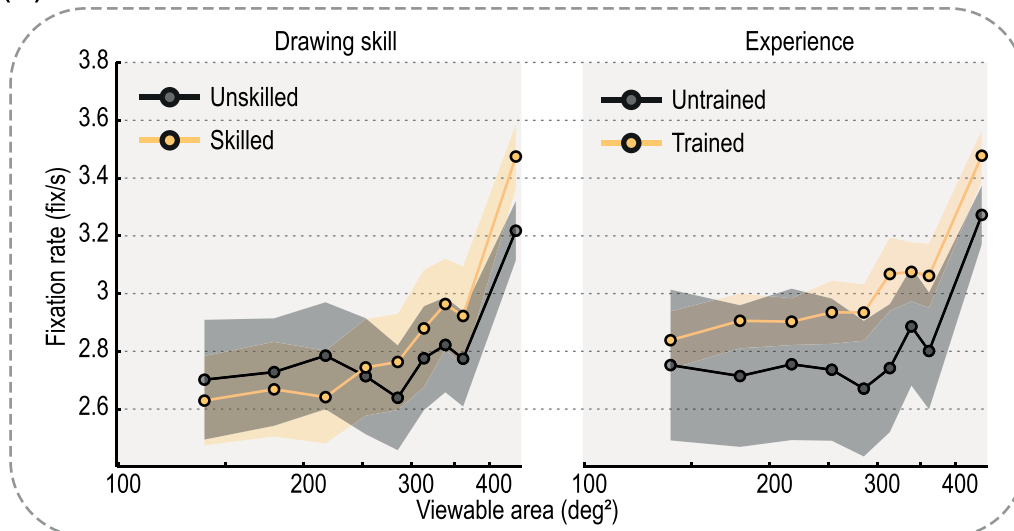
characterizing the effects of the window and scotoma size on the number and duration of fixations, independent of drawing skill or experience. We computed the average number of fixations per second made during each trial (Figure 6). A repeated-measure two-way ANOVA with linear contrasts ran on subjects' fixation rates and window sizes as factors shows that fixation rates increased with the window's size in the "moving window" experiment [ $F(1, 20) = 29.67, p < 0.000, \eta_p^2 = 0.54$ ], as well as in the "moving scotoma" experiment [ $F(1, 21) = 27.22, p < 0.000, \eta_p^2 = 0.57$ ].

Are any of these eye-movement properties affected by the participants' experience or skill? We first analyzed whether fixation rates were related to the better performances found in our more trained

(a) Experiment 1 (gaze-contingent moving window)



(b) Experiment 2 (gaze-contingent moving scotoma)

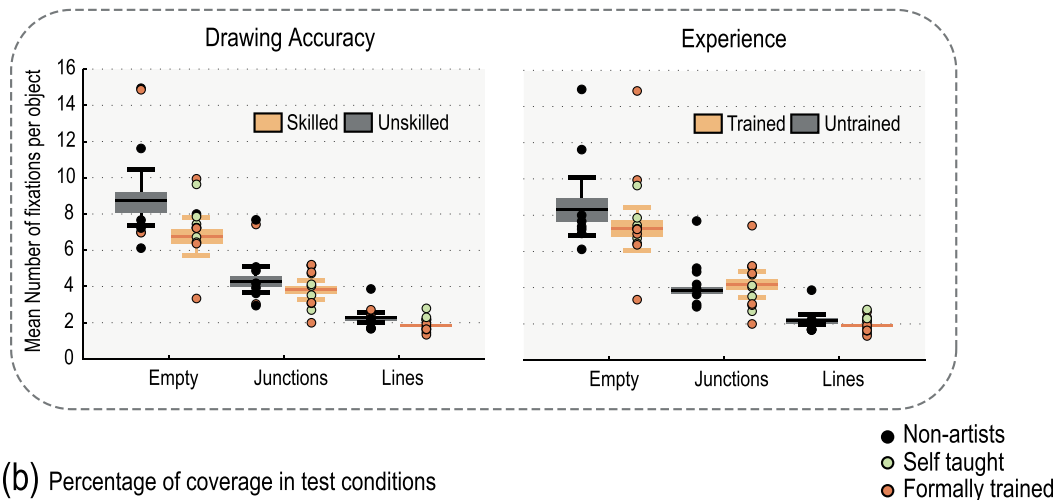


**Figure 6.** (a) Mean fixation rate as a function of window size. In experiment 1, the fixation rate (number of fixations per second) significantly increased with window sizes. (b) Fixation rate also linearly increased with viewable area size in the second experiment. However, in both experiments, this effect of window size did not differ with skills or experience in drawing.

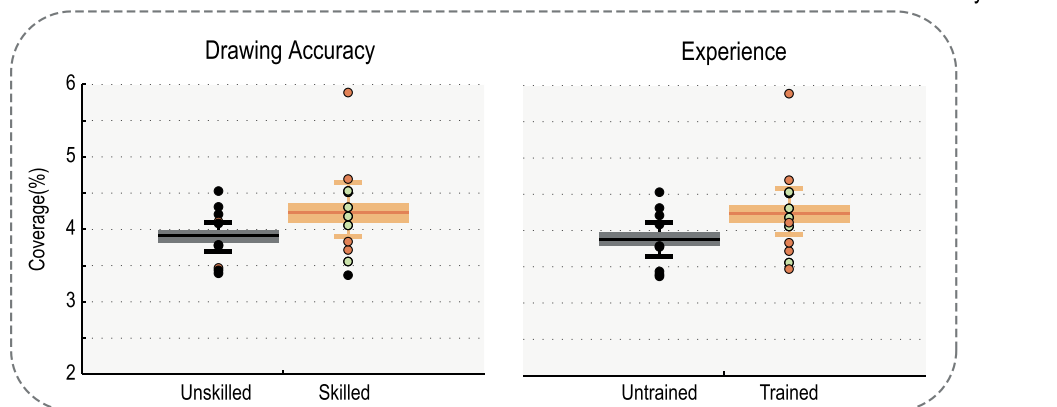
and skilled subjects. However, none of the correlations between either years of experience and drawing ratings with mean fixation rates was significant in either experiment [all  $P \geq 0.05$ ].

Next, we analyzed the fixation patterns from the full-view conditions, where participants could make saccades toward visible features, to see if they revealed any strategy for classifying the objects that might differ with experience and drawing accuracy. We constructed fixation maps for every object and classified each fixation as falling on (within a  $1^\circ \times 1^\circ$  region; gaze position accuracy:  $0.15^\circ$ ) empty space, a line segment (but not a junction) or a junction (using Harry corner detector, Harris & Stephens, 1988, and Canny filter, Canny, 1986, to define these features). The frequency of fixating these features is shown in Figure 7(a) for participants split into skilled versus unskilled groups (left panels) and trained versus untrained groups (right panels). The results show that most fixations in the baseline conditions fell on empty space (nearest line or junction at least  $0.5^\circ$  distant), and that participants fixated significantly more junctions than line segments [respectively,  $t(40) = 5.84$ ,  $p < 0.0001$ ;  $t(40) = 9.83$ ,  $p < 0.0001$ , and  $t(40) = 6.68$ ,  $p < 0.0001$ ]. However, neither more skilled or more trained subjects showed more frequent fixations on empty space [drawing skill:  $t(19) = -1.82$  ( $-4.18, 0.29$ ),  $p = 0.08$ ; experience:  $t(19) = -0.93$  ( $-3.45, 1.32$ ),  $p = 0.36$ ], on junctions [drawing

(a) Most frequently fixated features in the baseline condition



(b) Percentage of coverage in test conditions



**Figure 7.** (a) Summary box plots of the most frequently fixated features in the baseline conditions with participants grouped according to their drawing accuracy (left panel) and experience (right panel). Error bars correspond to 95% confidence interval of the means. We first extracted junctions from every object and we then binned every image into  $1^\circ \times 1^\circ$  areas of interest. All areas without any information were taken as “empty blocs,” while areas with segments information but not junctions were labeled “lines blocs.” Finally, areas with a junction present in was considered as a “junction bloc.” We then computed the total number of fixations made by the subjects for objects seen in baseline (full view) trials. We found no correlation between these results and participants’ training or skill. (b) Summary box plots of fixation coverage. Subjects’ fixation coverage was computed using Wooding’s procedure (Wooding, 2002) on fixations made in the test conditions (baseline excluded). We found no significant link between subjects’ fixation coverage and their years of experience or the ratings of their drawing.

skill:  $t(19) = -0.81 (-1.61, 0.71)$ ,  $p = 0.43$ ; experience:  $t(19) = -0.62 (-0.83, 1.53)$ ,  $p = 0.54$ ], or on line segments [drawing skill:  $t(19) = -1.91 (-0.89, 0.04)$ ,  $p = 0.07$ ; experience:  $t(19) = -1.18 (-0.78, 0.22)$ ,  $p = 0.25$ ].

Finally, we examined whether more trained and skilled participants were more efficient in placing their eye movements in order to sample a larger extent of the image in each trial. To do so, we computed how much of each image landed on participants' foveas as they scanned the image in the moving window conditions (experiment 1, baseline excluded), using Wooding's procedure (Wooding, 2002). We counted only the 2°-diameter foveal area for each fixation ( $d_{\text{crit}} = 50\%$ ,  $\sigma = 2^\circ$ ). Participants covered on average 4.1% (SE: 0.1) of the test images (Figure 7b) and the extent of coverage did not differ between novices and either the more skilled or more trained participants [drawing skill:  $t(19) = 1.32 (-0.19, 0.85)$ ,  $p = 0.20$ ; experience:  $t(19) = 1.44 (-0.16, 0.88)$ ,  $p = 0.16$ ].

Altogether, these results provide no evidence for different fixation patterns between skilled or experienced subjects and novices. This suggests that the better performance found in more trained and skilled participants may be due to a more robust internal representation rather than a different pattern of visual exploration.

## 5 General discussion

This study investigated whether drawing skill and years of practice in drawing lead to a more efficient analysis of objects and scene organization. Making a drawing requires an accurate integration of the to-be-drawn object's features in order to reproduce it in proper proportion. Our hypothesis was that training would (1) increase the size of the integrated object structure (larger visual chunks) and (2) improve the ability to encoding information from a larger extent of peripheral vision (larger visual span). To test these hypotheses, we designed two experiments using a gaze-contingent moving window and moving scotoma that controlled the amount of information available in central and peripheral vision, respectively. Our participants had to categorize line drawings of objects, seen through these central or peripheral samples, as either possible or impossible.

The results of experiment 1 demonstrated that both the number of years of drawing experience and drawing accuracy reliably predict better performance in the identification of an object's structure from small foveal samples. This result was not explained by the participants' age or by overall skill in discriminating possible from impossible objects. Our first hypothesis was confirmed.

In addition to improving the integration of sequentially acquired samples from central vision, training might also improve integration over larger spatial areas in each fixation. This larger visual span should allow accurate performance even with larger amounts of central vision blocked out. However, when we varied the size of a moving central mask in our second experiment, we found no significant correlation between the participant's experience in drawing or drawing scores and their critical scotoma size. Our second hypothesis was not confirmed: we found no evidence that the artist's training affects the efficiency in the use of peripheral information.

Moreover, we found no significant difference in the fixation patterns of our participants. The more skilled and trained subjects did not fixate salient features (junctions or vertices) more frequently nor did they scan a larger extent of space during each trial to see more of the object. In the absence of any strategic differences in scanning the images, our results suggest that the artists' advantage must be in the representation of the information sampled from the partial images.

Although we found a relation between drawing experience and skill and the performance in our tasks, it still remains unclear what is acquired when learning to draw. Our tasks were perceptual, so we are unable to assess the contribution of changes in motor coordination in our findings. Moreover, drawing accuracy and drawing experience shared about half of their variance, so that we are not able to conclude whether this advantage for more trained subjects is the result of training or simply a pre-existing, innate ability that led them to pursue drawing. Despite this ambiguity, we favor the effect of practice as a source of improved performance in our experiments. We have two reasons for this: first, performance was more correlated to years of experience than drawing skill itself; and years of experience is an imperfect measure of the choice of a career in art since many in our population are just starting their training. Moreover, it has been shown that children's drawing skill is improved by training and by learning drawing rules (Rand, 1973), suggesting that experience—the time spent at practicing—may play a crucial role in developing drawing skills. As hypothesized by Gombrich (1960), learning explicit rules is indeed a first step in the acquisition of drawing skills, but it has to be embodied through practice, thus becoming an implicit visuomotor knowledge or schema. Nevertheless, to

show that training causes the improved performance in our tasks, we would need longitudinal training experiments that control for the subjects' initial drawing skill.

### 5.1 Visual integration and drawing

If the artists' advantage arises from a better integration of visual samples into a more robust representation of object structure, how is this related to the demands of drawing? Several studies have examined the contribution of object representation to drawing skills (Cohen & Bennett, 1997; Glazek, 2012; Kozbelt, 2001; Kozbelt et al., 2010; Ostrofsky et al., 2012). A trained draftsman might have a more coherent representation of an object to make an accurate copy of it and that "coherence" might be specifically tuned to the requirements of reproducing it. For example, Kozbelt et al. (2010) and Ostrofsky et al. (2012) have shown that people more skilled in drawing selected and reproduced more structural information (e.g. vertices and junctions) than those who were less skilled. The relevant structural information must also be combined with accurate spatial relations between elements. While constructing a drawing, these spatial relations are built up across many sequential eye movements, where local samples of the original scene are independently encoded at every fixation location (Coen-Cagli et al., 2009; Locher, 2010). Consequently, a key requirement for constructing an accurate representation of the objects in a scene must be to integrate these local samples, spaced appropriately according to the size of each eye movement and this integration must require a representation that is robust enough to retain its accuracy during this building process. Our results showed that participants with more training and better accuracy in drawing are indeed better able to integrate samples of information across eye movements. Constructions of robust representations have been observed in expert chess players who develop robust representations of the structure of the chess pieces (Curby, Glazek, & Gauthier, 2009; Gobet & Simon, 1996; Reingold et al., 2001). We suggest that drawing accuracy might similarly arise from the ability to represent more complex sets—or chunks—of relevant visual information obtained from small local samples. In particular, while creating drawings, the artist is continually focusing on small portions of a scene in order to reproduce it patch by patch, all the while keeping track of the larger organization of the object and the scene in order to place each element appropriately (Coen-Cagli et al., 2009; Tchalenko & Miall, 2008). Over thousands of hours of training, we suggest that this particular style of attention to the scene leads the artists to develop robust representations that are optimal for the step-by-step production of the drawing and the motor planning of hand movements.

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