

TITLE: The Gaze-Shift Strategy in Drawing

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### Abstract

Alternating the point of gaze between an original (model or sitter, object or scene) and a picture (paper, canvas or digital touch screen) is the most common observational drawing strategy. However, a number of investigations into eye-hand interactions in drawing have revealed the existence of some “blind” drawing taking place (drawing the picture while the eye remains on the original or during gaze shifts between the original and the drawing). These observations of a direct visual-to-motor transformation challenge the commonly held assumption that the gaze-shifting strategy reflects a memory process in which the gaze on the original is used to encode a visual detail to short or long term memory, subsequently retrieved during the gaze on the picture. To study the blind drawing strategy in more depth during naturalistic drawing, we compared three basic drawing tasks - copying, contouring, and drawing of graded zones as lines, where original and picture were placed side by side on a vertical plane. We found that subjects drew almost continuously, thus exhibiting periods of blind drawing while the eye was on the original. The amount of blind drawing increased progressively between the copying task, the contouring task, and the graded zone task. When gaze shifted to the picture, it was generally to a fixation point located in advance of the hand on the part of the line not yet drawn. For individual tests, gaze ratios (gaze duration on original divided by gaze duration on picture) were approximately equal to drawing ratios (drawing duration during original gaze divided by drawing duration during picture gaze). We propose a general gaze-shift strategy that takes into account these observations.

*Keywords:* drawing, copying, eye-hand interaction, blind drawing, drawing strategy

### Introduction

Gaze shifting is probably the most common form of eye movement during observational drawing or drawing from life. It consists of the eyes alternating between an *original* – the model or sitter, object or scene being observed– and a *picture* – the paper, canvas or digital touch screen. During these gaze shift cycles, the hand moves intermittently or continuously, drawing the picture, which is constructed detail by detail with this dynamic pattern of eye and hand interaction.

The strategy at the heart of these alternating gaze shifts during drawing has often been assumed to be based on a visual memory process in which the artist encodes a detail to memory when looking at the original, and then draws it from memory when looking at the picture. For example, art historian David Sylvester, sitting for the artist Alberto Giacometti in 1960 (Sylvester, 1995) remarked: “Working from life is working from memory: the artist can only put down what remains in his head after looking” (p. 47) and cognitive psychologists Phillips, Hobbs, and Pratt (1978) wrote: “Since normal drawing involves looking away from the object being drawn, any information acquired during perception must be remembered while actually drawing” (p.30). However, a number of recent studies have suggested that this sequential process of memory encoding and retrieval may not fully explain what is taking place during gaze-shift drawing. Tchalenko and Miall (2009) studied

subjects copying an original drawing of a cartoon head placed next to the drawing surface, the distance between original and picture being about 25° visual angle. Drawing was on a vertical easel with charcoal on paper. In these tasks, the hand was drawing almost continuously, which meant that while the eye was still on the original, drawing was proceeding “blind” – with at most only peripheral vision. Mean duration of the gaze shift cycle was 1.10 sec, and for about 54% of the time the gaze was on the original, and 46% on the picture. The fact that drawing took place simultaneous with perception of the original suggested a more direct visual to motor transformation process not dependant on memory. In additional tests where the drawing hand and picture were completely blocked from the subject’s view, the original was copied with good shape accuracy, although spatial positioning accuracy was deficient. Based on these results, we postulated a drawing hypothesis (Tchalenko & Miall, 2009) whereby the drawing of shape was the result of a visual to motor transformation that could be executed directly while perceiving the original, and without vision of the hand or the drawing surface; in contrast, correct spatial positioning of the drawn shape on the paper required vision of the hand on the drawing surface. This hypothesis proposes that each detail to be drawn is not retained as a visual memory, subsequently transformed to a drawing action, but is transformed to an action and, we proposed, retained in short term memory as an intended drawing action.

The drawing hypothesis was also supported by functional brain imaging work (Miall, Gowen & Tchalenko, 2009) in which brain activation levels were measured during the encoding and drawing phases of a task directly comparable to the copying task in the eye tracker investigation. In that work, brain activation patterns were consistent with visuomotor mapping during the encoding phase, and no evidence for retention and recall of a mental visual image was found. In a further study of copying using eye tracking, a complex line drawing of a standing nude was placed at a visual angle distance of about 50° from the easel (Tchalenko, 2009a). Drawing took place on a vertical easel with charcoal on paper. With 4 expert artists, mean gaze shift cycle durations was 1.71 sec, and the gaze was on the original about 61% of the time. Drawing proceeded segment by segment rather than continuously, with the hand often starting to draw a given segment while the eye was still on the original, or while it was saccading to the picture. Again the simultaneity of visual perception of the original and of the drawing action suggest a direct visuomotor transformation, without the necessity of a memory encoding phase. Finally, when shifting gaze to the picture, a frequently observed strategy was what we term ‘target locking’, that is, drawing towards a stable eye fixation point that defined the segment’s end point (Tchalenko, 2007). This implies the gaze is providing a spatial target towards which the line is drawn, while the shape of the drawn line is already encoded as an action. All these observations add support for the proposition that a fundamental component of the gaze-shift drawing process is independent of visual memory.

Although blind drawing episodes were frequently observed in the studies mentioned above, their durations were not systematically measured, thus making their role and importance difficult to assess. Another concern about these studies was that many of the reported observations were made during copying tests for which the original itself was a line drawing. Although copying lines is a recognized type of drawing, its use in observational drawing is relatively rare. For example, the frontal view of the human head contains only a few well-defined lines to copy such as the separation line of the lips, the pupil, and sometimes the hair line on the brow. More frequently the task of portrait drawing is one of defining contours of the face and its principle elements: nose, lips, cheeks, etc., a more complex undertaking than copying an existing line. For example, depending on light conditions, the outline of the chin and cheeks can appear softly defined and can change with

the slightest movement of the artist or model. In addition, in line drawing, the artist needs to consider how to depict the borders of graded zones resulting from subtle changes of light falling on the face, or changes of skin tone and texture, using discrete lines. Most drawing from life therefore includes, in varying proportions, copying, contouring, and graded zone drawing, but as yet very little research has concentrated on the latter two, or on drawing tasks where all three were important.

The purpose of the present study is to compare these three types of drawing tasks - copying, contouring, and zone drawing - in a unified experimental setup permitting accurate measurement of hand and eye movement. The main question examined is whether a general strategy in gaze-shift drawing can be formulated across these three different drawing tasks, on the basis of the recorded spatial and temporal eye-hand interaction schemes. We test the two hypotheses: first that the proportion of time spent viewing the original drawing varies with the drawing task being performed, because of the different demands on defining the line to be drawn, and second, that blind drawing occurs across all three drawing tasks and, because it is subsequent to the decision process, the proportion of blind drawing varies with the proportion of gaze time spent on the original drawing.

## Method

### Definition of Cycle, Gaze Ratio, and Drawing Ratio

We define three key measures of the eye-hand interaction during drawing: the gaze shift cycle, the gaze ratio, and the drawing ratio. The gaze shift cycle,  $C$ , is the duration of the interval between two consecutive gazes to the original. It defines the mean period over which an element of the original is viewed, some part of the on-going drawing is observed, and a return to the original is made. The few published measurements of cycle durations during portrait drawing vary from about 1.7s to 5.9s (Cohen, 2005; Cohen & Bennett, 1997; Konecni, 1991; Land, 2006; Land & Tatler, 2009; Tchalenko, 2009a, 2009b; Tchalenko, Dempere-Marco, Hu, & Yang, 2003). The gaze ratio  $G$  is defined as the proportion of time spent viewing the original compared to the picture. A ratio of  $G=1$  indicates equal gaze duration on the original and picture; values less than 1 indicate more time spent on the picture, and values greater than 1 indicate more time on the original. Only a few sample measurements are available in the literature for this parameter: an artist drawing a sketch portrait provided a value of  $G=0.89$  (Land, 2006); the artist Henri Matisse filmed drawing a charcoal portrait with  $G=0.58$  (Tchalenko, 2009b); and a contemporary professional artist compared to a first-time beginner drawing a pencil portrait from life with values of  $G=0.35$  and  $G=1.70$  respectively (Tchalenko, 2009a). Finally, we define the drawing ratio  $D$  as the ratio of drawing time when the gaze is on the original to the drawing time when gaze is on the picture. Drawing which takes place while the eye is on the original is referred to here as “blind” drawing, although in practice some peripheral vision may be available. A recent study by Glazek (2012) comparing expert and novice artists copying familiar and novel line-drawing pictures, provides gaze durations on the original and total drawing durations, but unfortunately these measurements alone do not allow us to infer the parameters  $G$  or  $D$ . While blind drawing has been observed in some of the studies cited above, we have not found specific data allowing calculation of the drawing ratio in the specialized literature.

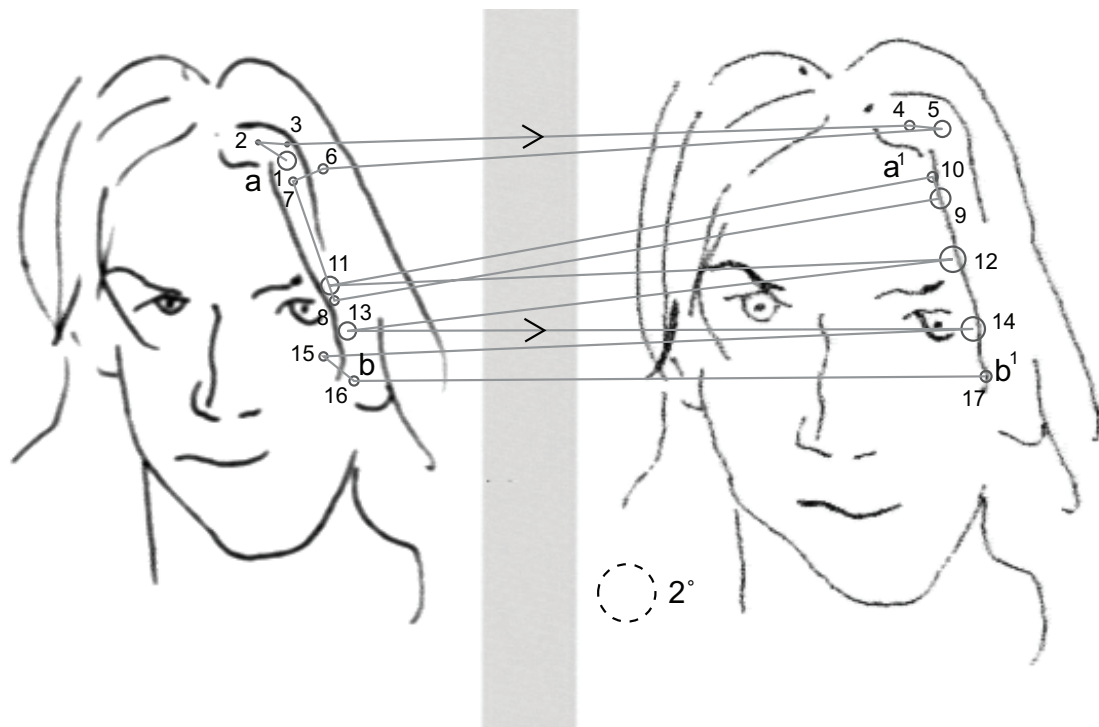
## Experimental Setup

To allow as natural drawing as possible, all movement restriction devices such as chin-rests and forehead supports were avoided. Subjects wore a head-mounted eye tracker (the ASL 501, Applied Science Laboratories, Bedford, MA, running at 50 Hz) and were seated about 50 cm away from a vertical graphics tablet/monitor screen. Head position was monitored with an Ascension Flock of Birds magnetic tracker, with the integrated system providing fixation accuracies better than 1 degree. The graphics tablet/monitor was the Cintiq 21UX (Wacom) with a screen size of 432 x 324 mm and a resolution set at 1024 x 768 pixels. Drawing took place with a stylus directly on the screen. The stylus position was sampled at 25 Hz with a resolution of 1 pixel (better than 0.5 mm) and was then interpolated to 50 Hz. For right-handed subjects, the screen's left half acted as display containing the image – the original - to be copied or drawn, and the right half acted as graphics tablet on which the copy or drawing – the picture - was produced. The actual distance between a stimulus image on the original and its drawn reproduction on the picture varied between 21° and 25° visual angle, depending on the precise point where the subject decided to start drawing. This setup will also be referred to as the side-by-side setup. A scan converter recorded the entire screen continuously as an audiovisual video file (.avi) showing the eye's position provided by the eye tracker (but not seen by the subject) and the progress of the line being drawn. Simultaneously, the combined eye tracker and stylus position parameters were recorded as digitized data for subsequent analysis. During the analysis stage, the video image could be examined frame by frame in conjunction with the corresponding eye and hand data supplied by the eye tracker and graphics tablet. A fixation was identified when the point of gaze remained continuously within a small area covered by 1° visual angle for a minimum of 60 ms (standard ASL algorithm).

After a 9-point eye-tracker calibration, a test session started with a blank screen on which the subject was invited to try out the stylus pen. The principal instruction to 'draw as accurately as possible' was then given together with the explanation that the experimenters were essentially interested in the act of drawing (effort of precision) rather than in the aesthetical result of drawing (attractiveness of the finished picture). Subjects were asked to use lines only, not toning or shading. The experimenters also made clear that drawing could be interrupted at any time if subjects wanted to rest their hand. All participants performed the same set of tasks, in the same order. This involved performing a short practice trial, three drawing tasks, as described below, followed by a debriefing session. The test series started with a trial in which the subject had to copy a line drawing. In two cases where the experimenters felt that the instruction had not been fully understood by the subject, a second trial was performed and proved satisfactory. No time limits were imposed on the tests, and the drawings took between 32 and 186 seconds to complete. Having completed all tests, subjects were interviewed on questions regarding their previous drawing experience and any comments they might have about the tests.

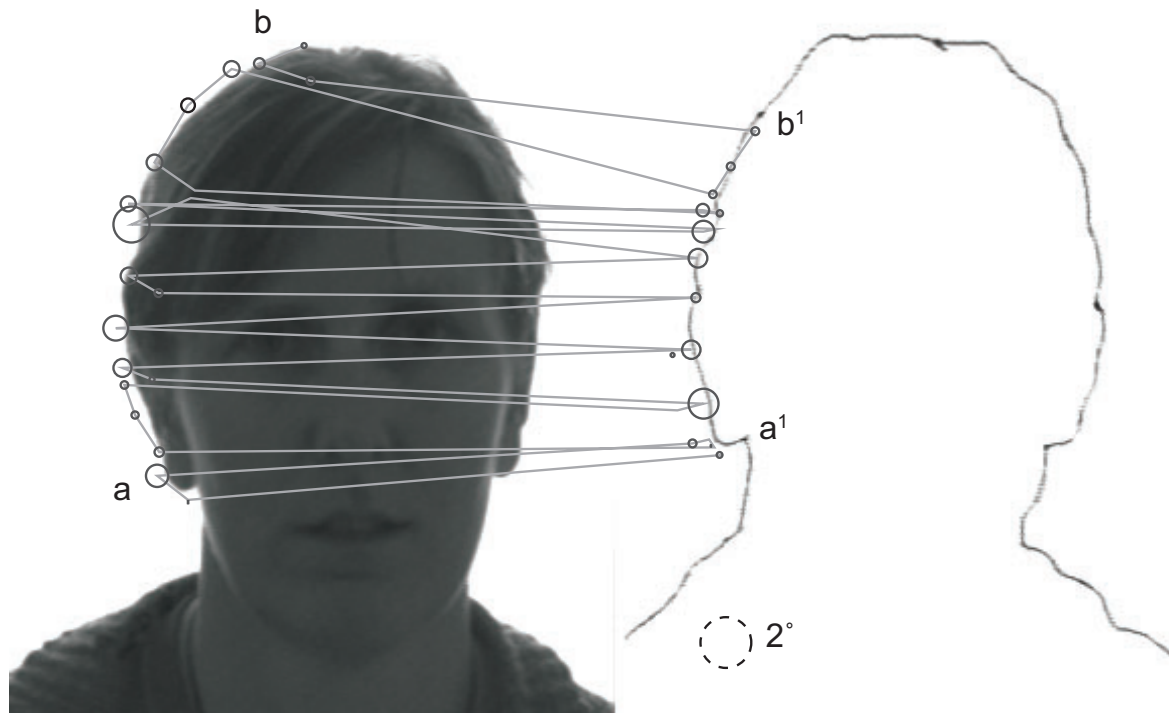
## The Original Images

Two series of tests with identical experimental setups were used in the analysis, but with different original images. In Series A, the copying original was a pen and ink sketch drawing of a face made up of about 30 separate line segments (Figure 1). The contouring original was a high-definition colour photograph of a frontal head lit from the back; this reduced the contrast of internal facial features while emphasizing the overall contour which subjects were instructed to draw (Figure 2). The graded zone original was a high-definition colour photograph of a head lit directionally from the left to produce a graded zone on the face separating light from shade which subjects were instructed to draw (Figure 3).



**Figure 1.** An example of the copying task performed by subject LN. The original is on the left, the picture drawn on the right. Numbered small circles indicate the sequence of fixations and the fixation durations shown for drawing the first hair strand marked a-b (left) and a<sup>1</sup>-b<sup>1</sup> (right). Mean fixation durations for LN were 0.192s on the original and 0.414s on the picture. The dotted circle indicates 2 degrees of visual angle, and approximately 1.2 seconds duration for the fixation.

In series B, a separate group of participants were tested using exactly the same experimental set up and procedure. This series provided us with the opportunity to validate the results found in series A. The original image for the copying tests in series B was a pen and ink sketch drawing of a standing nude by Gaudier-Brzeska as used in Tchalenko (2009a). The sketch, representing a slightly twisted upper torso seen from the back, one hand on hip and the other arm straight down, was made up of approximately the same number of segments as the face of series A. The contour and graded zone stimuli of series B were similar to those of series A, but used photographs of different persons at somewhat higher light/shade contrasts.



**Figure 2.** An example of the contouring task. The original is on the left, the picture drawn by subject LN, on the right. The sequence of fixations is shown as small circles for drawing segment a-b (left) as a<sup>1</sup>-b<sup>1</sup> (right), drawn at the start of the test. Mean fixation durations for LN were 0.260s on the original and 0.317s on the picture. The dotted circle indicates 2 degrees of visual angle, and approximately 1.0 seconds duration for the fixation.

### The Subjects

Participants for both test series A and B were first and second year students at colleges of the University of the Arts London. In series A, the 10 subjects (7 female) had an age range of 21 to 37 years (average 30 years). The results of two subjects had to be discarded, the first due to poor eye tracker calibration and the second due to squinting while drawing. Series B had an age range of 20 to 34 years (average 25 years). All participants gave written consent to the tests, which had the approval of the local ethical committee. In their interviews after tests, most subjects said that their drawing experience varied from very little to moderate. This included drawing experience not connected with observational drawing, such as graphic design or computer arts. Some had attended two-week life courses, which, however, emphasized self-expression rather than the learning of drawing skills. Initial clustering and statistical analysis of the subjects into two groups based on level experience revealed no major differences in any of the analysis carried out on the data. Thus, despite their disparity in past experience, we decided to treat all subjects as belonging to a same group characterized by little to moderate drawing experience across different areas of drawing including observational drawing.

### Definitions and Analysis

Frame-by-frame analyses of the video record provided a direct means of studying fixation locations and timings relative to the lines being encoded and drawn.

*Gaze* is the time during which vision is directed towards a specified region of a scene. A gaze starts when vision first enters the region and ends when it leaves the region. A gaze can include one or several consecutive fixations. *Original gaze* is a gaze directed towards the original and *picture gaze* is a gaze directed towards the picture. *Gaze shift* is the redirection of gaze from the original to the picture or vice-versa. *Mean gaze duration* is the sum of all gaze intervals divided by the number of intervals. *Blind drawing* is drawing during an original gaze. Note that when we use the term blind we do not exclude peripheral vision guidance.

For analysis purposes, a vertical border mid-way between the original and picture was defined to separate the two regions of interest, the *original* and *picture*. It should be noted that gaze durations measured with this method include both fixation and interfixation eye movements. They are therefore slightly longer than conventional dwell durations calculated by considering only fixations. We elected to use this spatially defined measure of gaze durations because the ASL eye tracker had a sample rate of 50 Hz, insufficient to allow accurate measurement of the time course of these brief saccadic eye movements.

The *gaze ratio*  $G$  is calculated as the original gaze duration divided by the corresponding picture gaze duration:  $G=t_o/t_p$ . The start and end of each drawing epoch was recorded from the video record and the drawing durations deduced for periods when the gaze was on the original or on the picture. The *drawing ratio*  $D$  is calculated as the amount of time spent drawing during an original gaze divided by the amount of time spent drawing during a picture gaze:  $D=d_o/d_p$ . The *blind ratio*  $B$ , calculated as  $B=d_o / (d_o + d_p)$ , is the amount of blind drawing as a proportion of all drawing time. Note that when  $D=G$ ,  $d_o/d_p= t_o/t_p$  and hence  $d_o/t_o=d_p/t_p$ . This means that the proportion of time spent drawing when gaze is on the original is equal to the proportion of time drawing when gaze is on the picture.

## Results

### Spatial Pattern of Eye and Hand Positions: Test series A and B

The results of subject LN are used to illustrate the different experiments in Series A. At the time of testing, LN was following a Master of Arts drawing course which did not include observational or life drawing. She did, however, have some experience in both these disciplines. Unless specifically mentioned, the eye and hand behaviour of the other subjects did not contradict LN's results although it will be seen that performance levels could vary appreciably.

In the copying task, LN reported understanding the instructions to mean “transcribe with your own hand, i.e. copy, the line on the screen”, and she tried to include all details, correct line lengths and positions - “everything on the screen”. For all participants, copying was achieved through a segmentation strategy subdividing the original line drawing into segments of one or a few simple lines of uniform curvature, as described in Tchalenko (2009a).

In the copying task, subject LN started by drawing the hair strand **ab** shown on the left panel in Figure 1. Fixations 1-5 took place as she located the stylus' starting point **a**<sup>1</sup> (right panel) and this was followed by fixations 6-8 which demarcated the start and end positions of the segment about to be drawn. The hand started drawing “blind” from point **a**<sup>1</sup> during original fixation 8, continuing during the saccade 8-9 and during picture fixations 9 and 10. Fixation 9 appeared to act as a target lock position as described in Tchalenko (2007), i.e. a



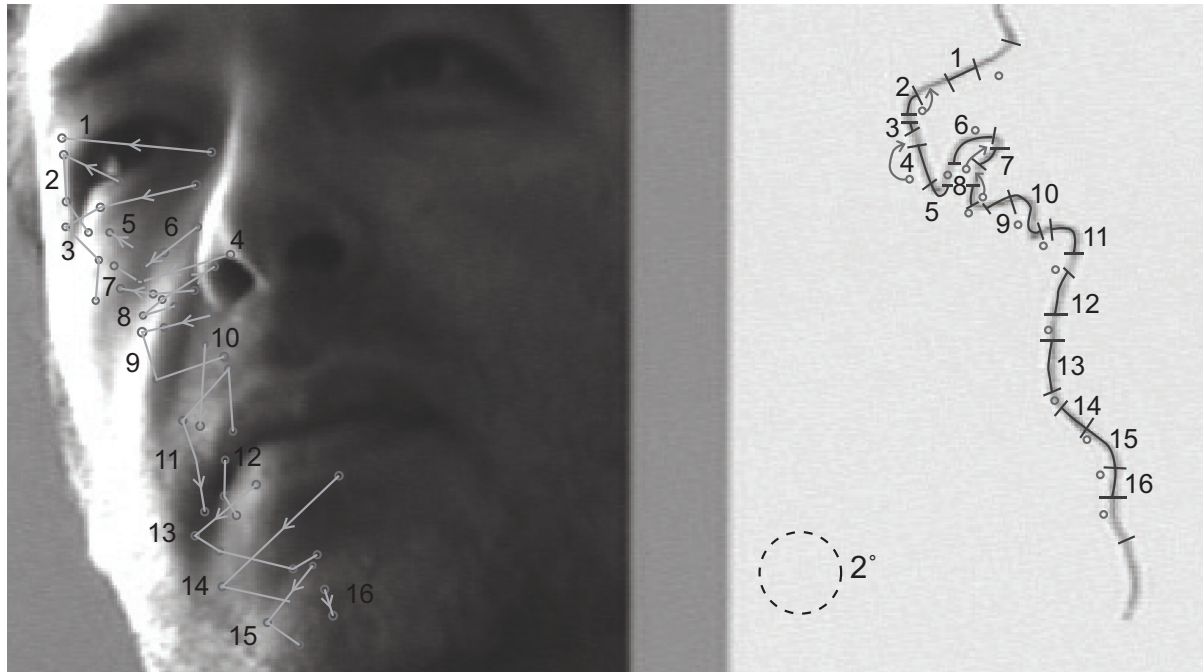
stable gaze point towards which the hand moved during drawing. Gaze then shifted back to the original at fixation 11, followed by another target lock, fixation 12 on the picture during the drawing of segment 9-12. A similar process was used with the next 2 target locking fixations 14 and 17 leading to the end of the line **b**<sup>1</sup>.

The inferred subtasks for drawing the hair strand in the copying task therefore included: examining the strand's starting point on the original (fixations 1-3), transferring this spatial information to the picture (4-5), finding the start and finish of the line's principal section on the original (6-7), starting to draw blind (8), locating a target on the original (11), transferring gaze to this target locking position on the picture (12) and drawing towards this point. The cycle rhythm and gaze ratio regularity seen in this episode were also evident before and after the hair strand event, i.e. during rendering of the right eye's pupil and during the exploration of the right forefront region (Figure 4). Such regularity of the gaze shift pattern while the hand engages in different subtasks suggests a leading role for the eye during this type of eye-hand interaction. After drawing the first hair strand, the gaze-shift rhythm slowed down slightly while drawing the next two hair strands.

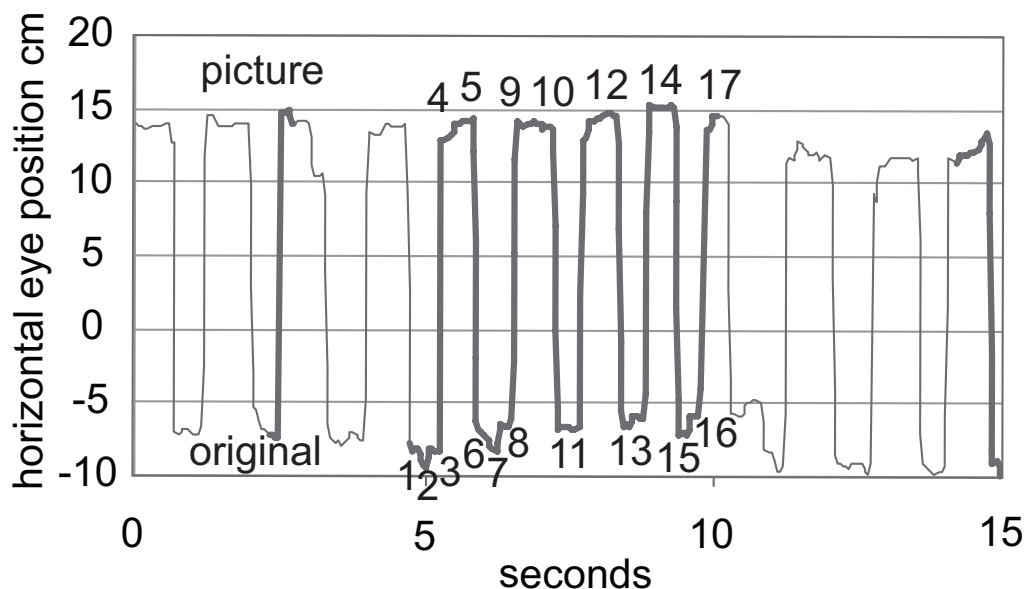
The contouring task produced a fixation pattern very similar to the copying task, for subject LN and the other participants, using single or multiple fixations along the line section of the original during which time the hand drew blind (Figure 2). On shifting gaze to the picture, fixations either landed in advance of the stylus, as target locking fixations toward which the hand would then draw, or on a point very near the stylus, remaining locked there while the hand drew through and beyond that point. This latter variant of target locking is referred to as position locking. It was noticed in copying and contouring that subjects who spent the most time drawing blind shifted gaze to the picture at the very last moment (when the hand had just about completed the segment).

For the graded zone drawing task, LN's fixations on the original were typically in the form of tightly packed sequences of 2 to 5 fixations each (Figure 3 left). The paths of these sequences crossed the zone's borders from dark to light, sometimes also following for short lengths the general direction of the zone's border. This dark to light direction coincided with the direction of the picture to original gaze shift. For example, sequence 3 started in the shade near the nose, crossed the zone under the eye and then followed it downward – a path exploring a region of about 3° diameter. During this time, the hand drew the short segment 3. Gaze then shifted to the picture with a single position locking fixation 4 well ahead of the line being drawn, while the hand continued drawing the line it had started blind. Many of the changes in the line's direction were undertaken blind. With LN, and even more so with LL, blind drawing was noticeably more extensive during this task than during copying or contouring.

The pattern of eye and hand positions observed in Series B was very similar to that seen in Series A. As before, fixations on the original during the encoding phase were accompanied by some blind drawing on the picture, and gaze shifts to the picture ended in target or position locking fixations relative to the drawing hand. The slight difference of original stimuli and the new group of subjects (see Method) did not seem to affect the overall pattern of eye-hand interactions.



**Figure 3.** An example of blind drawing in the graded zone drawing task. The original is on the left, the picture drawn by subject LN, on the right. Fixation locations are shown as small circles. Numbers 1 – 16 on the original (left) are fixation sequences, and on the picture they indicate the corresponding sections of the line (shown in black) being drawn blind. Mean fixation durations for LN were 0.388s on the original and 0.324s on the picture. The dotted circle indicates 2 degrees of visual angle.



**Figure 4.** The time line for the copying test illustrated in Figure 1. Numbers indicate fixations as in Figure 1. Gaze shifts for which no drawing took place are shown fine grey, those with drawing, in thick black. The drawing event starting at time point 2s is the drawing of the right eye’s pupil, and the event at 15s is the drawing of the next adjacent hair strand. Eye data were sampled at 50 Hz.

## Eye-Hand Interaction Metrics

### Test series A.

In all three types of drawing tasks, cycle rhythms and gaze ratios remained relatively unchanged over periods lasting 10 seconds or more and covering different subtask demands (Figure 4). The amount of time spent actively drawing was always less than the task duration, due to short pauses in the hand's movement as can be seen in the case of subject LN (Figure 5). The flat steps in the graph of the cumulative line length show that the hand's drawing action occasionally slowed down and stopped for intervals of about 0.5s during both original and picture gazes. The hand movement data, sampled at the video scan rate of 50 Hz, showed additional shorter non-drawing intervals throughout the tests.

**Table 1:** Gaze, drawing and blind ratio statistics and cycle durations

Test series A									
Parameter	Copy			Contour			Graded zone		
	Mean	Stdv	LN	Mean	Stdv	LN	Mean	Stdv	LN
Gaze ratio G	0.798	0.266	0.672	1.248	0.935	1.071	1.707	0.811	2.252
Draw ratio D	0.823	0.267	0.560	1.216	1.003	0.928	1.852	0.867	1.987
Blind ratio B	0.433	0.050	0.361	0.498	0.151	0.476	0.619	0.177	0.665
Cycle C (s)	1.771	0.318	1.488	2.118	0.137	1.566	2.469	0.485	2.055
Test series B									
Gaze ratio G	1.027	0.365		1.421	0.773		1.923	1.402	
Draw ratio D	1.126	0.527		1.663	1.094		2.093	1.631	
Blind ratio B	0.503	0.115		0.570	0.148		0.619	0.129	
Cycle C (s)	1.582	0.316		2.255	1.208		2.254	0.534	

Group statistics for the Series A (8 subjects) and Series B test (20 subjects) are given for each of the three tasks, Copy, Contour, and Graded Zone. The column labelled LN is the data from one exemplar subject, LN, in series A. Cycle durations are measured in seconds (s); ratios are calculated from durations with gaze on the original versus the picture; see main text for parameter definitions. Mean = group average, Stdv = standard deviation of the group.

Table 1 shows mean gaze ratios (G), drawing ratios (D), blind ratios (B) and cycle durations (C) calculated from measurements of gaze and active drawing periods. Results obtained with the exemplar subject LN are also shown for test series A. A notable feature of these tests was that, for a given subject and test, the gaze ratio G of original to picture gaze duration was strongly correlated ( $r^2 = 0.956$ ) to the drawing ratio D of original to picture drawing durations (Figure 6 top). The relationship between G and D across all three tasks was found by linear regression to be:

$$G = 0.95D + 0.103 \quad (\text{Eqn. 1})$$

with 95% confidence intervals for the coefficient and constant terms spanning 1.0 (0.86:1.04) and 0.0 (-0.04:0.24), respectively. In other words, in this dataset, the relationship was not distinct from  $G=D$ .

The mean gaze ratios increased from 0.80 (+/-0.09 SEM) to 1.25 (+/- 0.33) to 1.71 (+/- 0.29), for the copying, contouring and zone tasks, respectively, although the G and D values for one subject were identified as an outlier in the copying task (Figure 7), and for a different subject in the contouring task. Likewise, drawing ratios increased from 0.82 (+/- 0.08) to 1.22 (+/- 0.37) to 1.85 (+/- 0.30). Mean values of blind to total drawing proportion B were 43%, 50% and 62%, for copying, contour drawing, and zone drawing. The wide distribution of G and D values found in the contour task suggest that some subjects tackled it as a copying task, whereas others, as a graded zone task. Although for each task, ratios differed between subjects, a constant feature of these tests was that for all subjects the graded zone drawing task showed higher gaze and drawing ratios than copying task (Figure 6 bottom). These higher ratios were mainly due to gaze durations increasing on the original while remaining relatively unchanged on the picture.

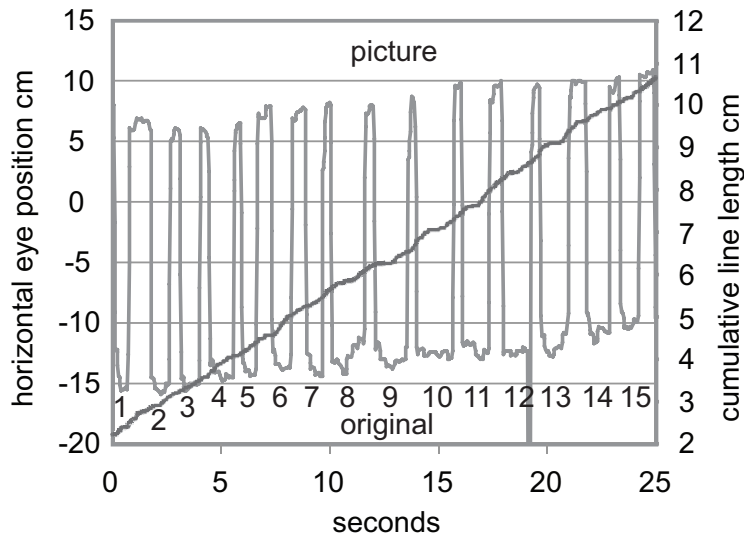
### **Test series B.**

The analysis described for series A was also carried out on the separate test series B made with 20 different subjects and similar stimuli (see Method). The mean gaze ratios for series B increased from 1.03 (+/-0.08 SEM) to 1.42 (+/- 0.12) to 1.92 (+/- 0.31), for the copying, contouring, and zone tasks, respectively, while drawing ratios increased from 1.13 (+/- 0.12) to 1.66 (+/- 0.24) to 2.09 (+/- 0.36), although again 2 subjects had unusually high G and D scores, and are identified as outliers in Figure 7. Mean values of blind to total drawing proportion B were respectively 50%, 57% and 62%. Eighteen out of the 20 subjects drew the graded zone drawing with higher ratios than when copying, the two remaining showing nearly equal values for both tasks (Figure 8 bottom).

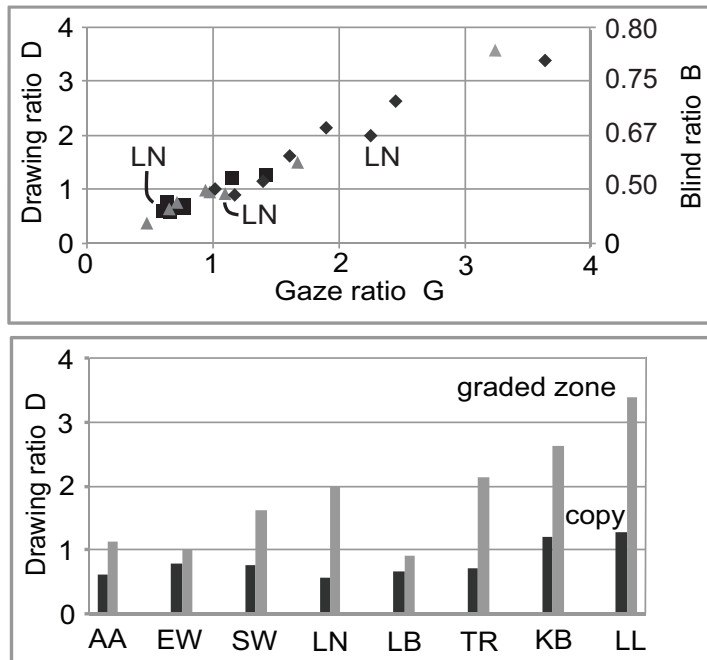
A strong positive correlation was again found between the gaze ratio G and drawing ratio D (Figure 8 top). The relationship between G and D for this group was found to be

$$G = 0.76D + 0.23 \quad (\text{Eqn. 2}),$$

with 95% confidence intervals of 0.67:0.84 and 0.06:0.40, respectively, for the coefficient and constant terms. Thus both Equations 1 and 2 suggest that the values of G and D are approximately equal for each participant although they differ between participants and across trials. To test if this is true, we determined the value of  $(G/D)-1$  for each task and participant, which should be zero if  $G=D$ . This measure is amenable to direct comparison across the full set of data, from all three tasks and both series using a 2-way mixed model analysis of variance (ANOVA) with one main between-subject factor of series (A and B) and one within-subjects factor of task (Copy, Contour, and Graded Zone). The test revealed that the value of  $(G/D)-1$  was not significantly different from zero in any of the 6 data sets, and that there were no significant differences in this measure between tasks ( $F(2,52)=1.00$ ,  $p=0.37$ ,  $\eta^2=0.037$ ) or between the two series ( $F(1,26)=0.61$ ,  $p=0.442$ ,  $\eta^2=0.023$ ). Thus, the approximation  $G=D$  appears to hold across tasks and participant groups. However, additional data sets will be required to resolve if the relationship does differ systematically between participants, for example on the basis of their life drawing experience.

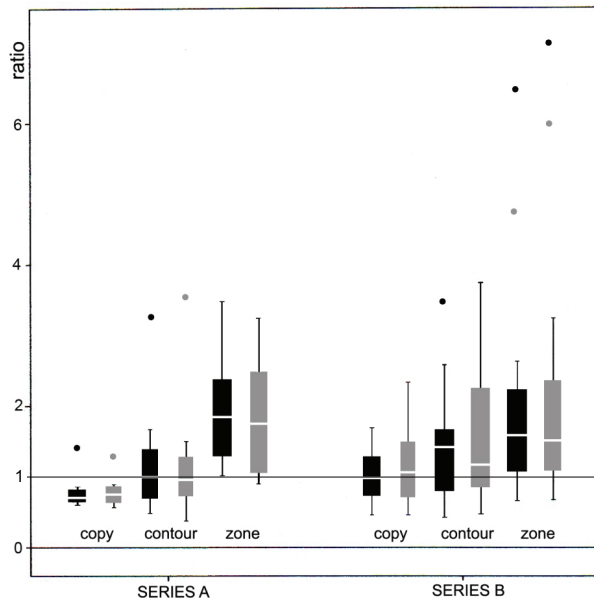


**Figure 5.** The time line for the graded zone test illustrated in Figure 3. Horizontal eye position (grey line, left ordinate axis), and line length (black line, right ordinate axis) were each sampled at 50 Hz. Time is in seconds from an arbitrary start time determined by the computer clock. The gaze shifts repeatedly from the original picture (negative horizontal position values) to the picture (positive values). Drawing takes place during much of the period, with brief pauses indicated by the horizontal segments in the diagonal line – the cumulative length of the line being drawn by the participant. Superimposed numbers 1 to 15 at the bottom of the panel indicate gaze periods on the original, corresponding to sequences shown on Figure 3.

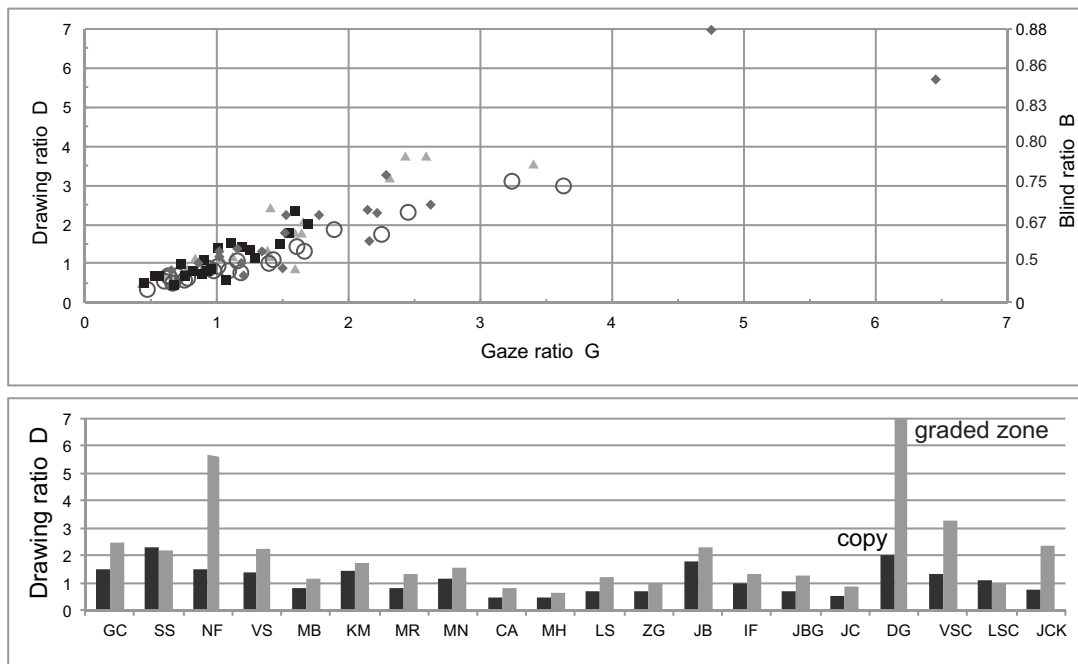


**Figure 6.** Drawing metrics from test series A. Top: comparing gaze ratios, drawing ratios and blind ratios for copying (squares), contouring (triangles) and graded zone drawing tasks (diamonds). Each data point is from one subject.

Bottom: comparing drawing ratio values in the copying and graded zone tests for all 8 participants, identified by their initials.



**Figure 7.** Summary statistics for the gaze and drawing ratios across the 3 tasks and both series of experiments. Each bar plot shows the mean and inter-quartile range for the group, while the vertical lines indicate the range of the data, and dots indicate the data points for outlying subjects, identified as  $>2.3$  SD away from the group mean. Black bar plots are for gaze ratio data, grey bars are for drawing ratio data.



**Figure 8.** Test series B. Top: comparing gaze ratios, drawing ratios and blind ratios for copying (squares), contouring (triangles) and graded zone drawing (diamonds). Larger open circles are the corresponding results for the same three tasks from test series A, for comparison (see Figure 6, top).

Bottom: comparing drawing ratio values in copying and graded zone tests for all 20 participants, identified by their initials.

Additional mixed model ANOVAs confirmed that when compared across series and tasks, the differences in both the G and D ratios were highly significant between the three tasks. For the G-ratio:  $F(1.6,42.0)=14.6$ ,  $p<0.001$ ,  $\eta^2=0.36$ , with degrees of freedom adjusted for non-sphericity with the Greenhouse-Geisser method; and for the D-ratio:  $F(2,52)=9.96$ ,  $p<0.001$ ,  $\eta^2=0.28$ ). However, these ratios were not significantly affected by the series: the main factor of series A vs B was not significant for each data set (for G-ratio:  $F(1,26)=0.19$ ,  $p=0.67$ ,  $\eta^2=0.007$ ; and for D-ratio:  $F(1,26)=0.84$ ,  $p=0.37$ ,  $\eta^2=0.03$ ). Furthermore, the interactions between series and task were also not significant (for G-ratio:  $F(1.6,42.0)=0.11$ ,  $p=0.76$ ,  $\eta^2=0.008$ ; and for D-ratio:  $F(2,52)=0.06$ ,  $p=0.95$ ,  $\eta^2=0.002$ ).

Finally, since these ANOVA tests failed to support a difference between Series A and B, we combined the data across the two groups, ignoring which series the data were from. Using pair-wise t-tests, the differences between the values of G across the three tasks were all statistically significant; the same was true for values of D (hence for both sets of 3 paired t-tests, all  $t>2.2$ , and all  $p<0.034$ ). Thus, we can confidently say that both G and D were smaller in the copying task than in the contouring task, and smaller in the contouring task than in the zone task. Altogether, fundamental eye-hand drawing patterns and timing characteristics found in test series A were reproduced with little change in series B.

## Discussion

### The Gaze-Shift Strategy in Drawing

Most line drawing from life includes three main subtasks: copying or reproducing a pre-existing well-defined line, contouring or delineating the boundary of a three-dimensional entity, and rendering a graded zone or a transition between light and shade with a discrete line. By comparing eye and hand patterns in these three tasks, we observed the following typical characteristics. First, visual information appeared to be captured from the original image in a series of fixations that helped define what would be drawn as a distinct line segment. Each line segment was therefore encoded with the help of one or several fixations on the original stimulus. Next, the hand often started drawing the segment on the picture while the eye was still centred on the original.

The “blind” drawing, in which the hand begins to move while the gaze remains on the original, implies a direct visuomotor transformation of the visual representation of the chosen detail into the corresponding drawing action, rather than a visual encoding into memory, and subsequent recall to guide the hand action, a point we discuss later on. Some time into the drawing of a segment, the gaze would typically shift to the picture to make a target- or position-locking fixation towards which the line would be drawn, and the segment would be completed with the gaze held in this fixed position. The gaze-locking aspect of drawing is analogous to gaze-locking reported in object manipulation tasks, as will be further discussed below. Finally, at about the time the hand finished drawing the segment, the gaze would shift back to the original. This cycle would then be repeated for new segments.

We believe that these anecdotal observations, based on frame by frame review of the eye and hand movements of two groups of participants performing copying, contour drawing, and zone drawing with different stimulus sets, describe the common features of much of the eye-hand interactions that take place during observational drawing. They were supported by detailed quantification of three indices – the gaze shift cycle duration, the G-ratio, defining

the proportion of time spent with gaze on the original compared to the picture, and the D-ratio, the proportion of time spent drawing while the gaze was on the original vs the picture. At one extreme, one might hypothesize that gaze on the original encodes a segment of the image into visual memory, gaze is then transferred to the picture and the drawing is performed. In this case, the G-ratio would reflect the relative viewing vs drawing periods, and might be approximately 0.5, while the D-ratio would be zero. At the other extreme, one might hypothesize that gaze would remain largely on the original, and that almost all drawing was performed blind. In this case, both the G-ratio and the D-ratio would be very high (near infinite), and the gaze cycles long. In fact, our analysis shows that G and D varied between about 0.5 and 4 (Figures 6 and 8), and were very highly correlated across tasks for each participant. This favours the second scenario, where significant portions of the drawing are achieved blind, while the eye is on the original.

The duration of “blind” drawing was lowest in the copying task and greatest in the graded zone task. Hence, across both participant groups, the mean range of gaze ratio extended from  $G = 0.80$  for the copy task to  $G = 1.92$  for the zone drawing task. For the drawing ratio, the means were  $D = 0.82$  and  $D = 2.09$ , respectively. Furthermore, to a first approximation,  $G=D$ , indicating that the proportion of time drawing when the gaze was on the picture did not change significantly from when gaze was on the original. Expressed in terms of the mean blind ratio B, this meant that between 43% and 62% of drawing time was taken up by blind drawing. This observation is important: subjects, although free to combine looking and drawing periods in any way they wanted, were using a strategy of drawing for a significant proportion of the time while looking at the original stimulus.

A likely explanation for the differences in G and D across tasks would be that copying involved essentially the visual capture of an existing line, whereas contouring required, in addition, the resolution of a volume’s edge into a discrete line. This boundary could be constituted of subtle detail, as for example, with the upper head and hair limit, where the subject needed to decide what level of detail of the complex edge to take into account, a decision process that appears to require more time with the gaze on the original. The decisions are probably even less clear in graded zone drawing where the transition between light and shade was gradual, and the resultant boundary line contained a number of complex convolutions. We suggest therefore that, under the test conditions used in the present investigation, our results show that the amount of blind drawing reflected task difficulty: the more difficult the task of determining the line segment to be drawn, the greater the amount of time required for visuomotor encoding during gazes on the original. Since drawing occurred over the majority of each trial, and drawing rates were largely unaffected by gaze direction, the increase in G ratio as the participants look for a greater proportion of time at the original leads to a greater amount of blind drawing achieved.

Our observation that subjects maintained gaze on the original while beginning drawing suggests that during these blind episodes, they were working directly from the original rather than from an image of the original held in working memory. A similar preference for referring to the original source of visual information rather than to a memory image of that source has been observed in block-moving tasks. Ballard, Hayhoe, and Pelz (1995) devised a copying task in which a set of virtual blocks (images on a computer display) of different colours had to be assembled into a pattern that duplicated that of a model. The scan paths of the subjects imply that they rely on visual or spatial memory less than might be supposed, preferring instead the strategy of looking back toward the model to check the colour and the location of each block added to their construction. The idea of referring to the original, external object, rather than to memory was also suggested by O’Regan (1992) who argued



that the outside world may be considered as a kind of external memory store which can be accessed instantaneously by casting one's eyes to locations relevant to the task at hand. In other words, the participants are willing to trade off the cost of making additional saccades between the original and the model, in order to gain the most recent visual input.

Our tests were performed with original and picture placed side-by-side on a same vertical plane and at an average angular distance of  $25^\circ$  from each other. It is likely that some peripheral visual information was available even with this angular separation between original and picture, so we do not imply that “blind” drawing was strictly without any visual control. At this stage, we do not know whether drawing at other angular distances would also follow the behaviour we report here. Blind drawing has been previously reported at both smaller and greater separations, for example in copying tests where original and picture were on a same plane and separated by about  $15^\circ$  (Tchalenko & Miall, 2009), and in copying and drawing tests where they were on different planes separated by about  $50^\circ$  (Tchalenko, 2009a, 2009b). However, the precise rates of drawing were not measured in any of those studies, with the consequence that drawing ratios are not available. A companion study (Tchalenko & Miall, in preparation) has examined the case of line copying with separations increasing from  $2^\circ$  to  $30^\circ$ , and included completely blind conditions where a divider between original and picture precluded all peripheral vision. Blind drawing was observed under those conditions too, and we suggest that considerable drawing can be achieved with complete absence of vision of the hand. However, under more natural drawing conditions, including the arrangement we used here with the original and paper side-by-side, there is a complex mix of actions within each gaze shift cycle. These include the visual fixations on both the original and on the paper that seem associated with the selection of the segment to be drawn and its positioning on the paper; the blind drawing periods in which at best only peripheral vision is used and the line segment is drawn, we suggest, through a direct visual-to-motor transformation; target locked drawing in which the gaze position acts as a spatial reference to which the line is drawn; and the final fixations on the paper to assess the drawn line.

What would be the advantage of working directly from the original rather than from a memory image? Cohen and Bennett (1997) demonstrated that drawing errors have their foundation in the stage referred to here as the original gaze. In a further study of portrait drawing, Cohen (2005) observed that a high frequency of gaze shifts (drawing with frequent reference to the original) was associated with more accuracy. He argued that this is because the high rate of original gazes replaces drawing from an image held in memory with drawing directly from the perceived stimulus. This, in turn, avoids ineffective and distorting strategies such as, for example, assimilating the to-be-drawn stimulus with prior knowledge of a prototype. Although Cohen's task of rendering a realistic, recognizable likeness of a face is different to ours, his argument suggesting the negative influence of working memory on accuracy could equally apply to the present investigation. Prior knowledge of a prototype was also considered by Glazek (2012) who observed that expert artists were less affected than novices by prototype images held in memory. The experts used shorter encoding and longer drawing durations, and produced more accurate drawings. Where blind drawing is used the drawn line may be less influenced by prior knowledge of a prototype, because subjects do not see what is being drawn, that is, they cannot visually guide the hand to produce the preconceived prototypic representation. In this context, the blind drawing strategy suggested by our tests could be seen as a method for overcoming top-down conceptual influences frequently mentioned in the literature on cognitive drawing skills (Cohen, 2005; Cohen & Bennett, 1997; Kozbelt & Seeley, 2007; Lee, 1989; Seeley & Kozbelt, 2008; Thouless, 1932). This is well captured in remarks by Auguste Rodin in 1906 and quoted by his secretary A.M. Ludovici:

*Not once while describing the contour of that form did I shift my eyes from the model. (...) Thus not a thought about the technical problem of representing it on the paper was allowed to arrest the flow of sensations from my eyes to my hand. Had I looked at my hand this flow would have ceased. (Ludovici, 1926, p 139)*

In summary, our tests have shown that the relative proportion of blind to sighted drawing varied between subjects, and across the three tasks. The ratios D and G were strongly correlated across both groups of participants studied and this further suggests that the amount of blind drawing is governed mainly by the proportion of time spent in gazes on the original. It is not known at this stage whether at the lower limit, where little or no blind drawing takes place, the same gaze-shift strategy still applies, or whether a separate strategy of encoding and retrieving from visual short term memory takes over. It may also be possible that the style of drawing affects these strategies. A memory strategy including minimal blind drawing and allowing for a top-down mediation of a line's appearance during drawing may be better adapted to fine detailed stimuli such as formal portraits or landscapes where precision and control of detail are paramount. In contrast, if immediacy and spontaneity are important, as for example in rapid sketching, preliminary outlining of a life drawing, or capturing a subject in motion, the artist may opt for a strategy containing significant blind drawing episodes, and a direct visuomotor transformation of the scene into the hand actions. Further quantified data on rates of drawing would be necessary to answer such questions.

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