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Chapter 33

Eye Movement and Voluntary Control in Portrait Drawing

J. Tchalenko, L. Dempere-Marco, X. P. Hu and G. Z. Yang

In drawing portraits from life, the eye plays a central role as it is the means by which visual input is acquired from the external world, as well as the means by which the hand is guided as it draws and the results are evaluated. Eye movements were measured in 12 subjects ranging in skill from the professional to the novice. A fundamental paper-to-model-to-paper rhythm was investigated, as well as eye-hand coordination patterns and the spatial accuracy with which a pre-drawn line could be followed with the eye. Although more subjects drawing in different ways need to be examined, this first quantitative observation of the artist at work has opened the field for the direct study of the cognitive processes involved in drawing and artistic creativity.

Introduction

A central question of the picture production process in art is how does the artist transform a vision of the external world into the drawn or painted work. In portrait drawing from life, the question concerns the way the artist acquires visual information by looking at the model and then produces an interpretation of this information by drawing on the paper. The eye has the central role in this process, as it is the means by which visual data is entered into the brain, as well as the means by which the hand is guided and the results are evaluated. Our approach was therefore to study the painter's eye movements in order to establish the ground data required to start understanding the picture production process. The lack of any previous data on the subject led us to investigate the basic eye-hand coordination pattern, and enquire into the eye control skills shown by experienced painters. Our present study is restricted to artists who draw portraits from life in a realistic style.

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Most artists drawing from life construct a portrait detail by detail, and they are continually moving their gaze from the paper (P) to the model (M) and back again. This P–M–P cycle structures the entire portrait drawing work. The action during the cycle, at least with professional painters, is precise, rhythmically repetitive and uninterrupted by extraneous events, and hence apposite to the study of eye movement with eyetrackers. The context of such a study is that of a real-life situation observed with the help of instruments more commonly associated with laboratory testing.

Prior to our study, the eyetracker does not seem to have been used with painters. In fact, Konecni (1991) seems to be the only investigator who timed eye movements as portraits were being drawn. He used a video camera to time the glances of six subjects drawing sketch portraits, and found a frequency of glances to the model varying between 19 and 25/minute, with little apparent differences between artists and novices. We will see that these movement rates agree well with our own findings. The work reported in Tchalenko (1991) involved about 100 hours of video film of a painter taken from the model's point of view during the painting of a portrait, and eventually became the starting point for our eyetracker studies. It was partly inspired by Lord (1980) who sat for Alberto Giacometti and described the drawing process in considerable detail, albeit not on the level of eye and hand movements. Despite this lack of quantitative eye movement data, several references shed indirect light on our subject. Within the cognitive literature, Livingston and Hubel (1995) and Frith and Law (1995) outlined how brain imaging studies in other areas can inform us on drawing skills. The visual information of a scene is divided into individual processing components on the basis of which the brain computes the necessary movements for drawing. More pertinent to the present study, Solso (2000) and Solso (2001) described some fMRI tests we performed on HO, the principle subject of our eyetracker studies, as he was drawing while his brain was being scanned. The feasibility of this type of investigation and the preliminary results are presented and discussed. Cohen and Bennett (1997) and Snyder and Thomas (1997) examined the question of preconceived notions the drawer — novices in the first reference and autistic children in the second — may, or may not, have about the form of objects in the external world that they are drawing.

A question we are sometimes asked is whether our approach has common ground with the theories on art suggested by art historians. Gombrich (1963) is probably the most frequently quoted reference on the subject. His starting point is the analysis of the finished picture and he shows how Nature was interpreted, and how paintings and drawings were viewed, at different periods of History. His conclusions are essentially about the changing perception of works of art. The starting point for our present study is quite different. It is a direct observation of the painter at work, and in particular of the artist's eye movements. We only refer to the finished picture, which can be either by an expert or a novice, when it provides information on the movement of the drawing hand. Our analysis concentrates uniquely on the physiological processes taking place during the act of drawing. Eventually, when sufficient data will have been gathered, such observations may form the basis of future art theories.

Eyetracker Studies

The eye's different functions — input of visual data, output of the drawn line and evaluation of the results — are determined and driven by the requirements of the painter's task. The hand leads the task, while the eye supplies the appropriate information as and when required. Thus the eye when it looks at the model is not reacting to unsolicited visual stimuli, but is voluntarily moved to pinpoint a particular detail required at that particular moment in time. It is moved away from that point when the painter deems that sufficient information has been captured. This behaviour is different from our normal way of perceiving the external world, and perception and cognition studies made in areas such as face recognition or the viewing of pictures will not necessarily be relevant to drawing from life.

A consequence of the task-driven nature of portrait drawing is that, at all times, the painter's eye movements are under his, or her, control. Moving from paper to model or vice-versa, from one detail to another, staying fixed or moving together with the pencil, etc. are all volitional actions in the sense that the artist may chose to do them differently or not at all. The basic parameters of the painter's eye and hand movements are outlined in the following two sections of this chapter, "Eye Movements" and "Eye-Hand Coordination". As these eye movements are repeated many hundreds or thousands of times during the making of a portrait, and many millions of times during the lifetime of a painter, they take on for each artist a characteristic structure and rhythm. The question of whether a painter acquires in this way a greater eye control than the non-painter is discussed in the last section, "V. Eye Control."

Throughout this study, our priority was to provide the artist with as normal working conditions as possible, in particular allowing free movement with minimum vision restrictions. The modern eyetracker device (ISECS) of our latest tests is simply a pair of spectacles without cable attachments. Our main systematic work was however done on slightly earlier equipment (EYEPUTER and ASL 501: see Appendix I for all equipment characteristics). The experimental set up first devised with subject HO (Miall & Tchalenko 2001) was subsequently adopted for all drawing tests with other subjects (Table 33.1). It consisted in seating the painter in front of a drawing board held vertically on an easel at arm's length. The model was seated next to the board and at a same average distance from the artist's eyes. This distance was decided upon because it suited the artist and simplified subsequent eyetracker computations. For self-portraits, the mirror image was similarly made to be at the same distance as the board.

In some tests with HO we also recorded the hand's position with the help of a motion sensor. For the 5-hour *Portrait of Nick*, the eyetracker was worn for about 10 to 15 minutes at the start of each hourly session; for all other tests it was worn throughout. Eyetracker output was in the usual form of digital data file and video scene of the painter's view with superimposed gaze point as filmed by a head-mounted camera. Independently, a continuous close-up video recording of the drawing board was also made for each artist, in order to verify the hand's position and follow the picture's progress.

Table 33.1: Eyetracker tests: subjects tested and equipment used. For equipment abbreviations and explanations see Appendix I.

Subject	**Ability**	**Drawing test & equipment**	**Eye control test & equipment**	**Reference**
HO	Full-time painter, mainly portraits. Work in many international galleries and collections.	Select model (EP) *Portrait of Nick* (EP) Portrait *Luke 2* (EP) Self-portrait (EP) Memory Luke 3 (501) From photo (EP)	QuickGlance	Miall and Tchalenko (2001) Tchalenko (2001a) Tchalenko (2001b)
3 controls (for HO)	Novices, do not draw	From photo (EP)	EP	Miall and Tchalenko (2001)
ME	Painter, draws very frequently, work in galleries and collections	Self-portrait (ISECS)	ASL 504	Tchalenko *et al.* (2001) This chapter (2002)
JT	Ex-art school, draws very frequently.	Self-portrait (ISECS)	ASL 504	Tchalenko *et al.* (2001) This chapter (2002)
PL	PhD art school, draws regularly.	Self-portrait (ISECS)	ASL 504	Tchalenko *et al.* (2001) This chapter (2002)
CS	2nd year art school, draws.	Portrait of B (ASL 501)		This chapter (2002)
DL	2nd year art school, draws .	Portrait of B (ASL 501)		This chapter (2002)
IA	2nd year art school, draws.	Parallel lines (ASL 501)		This chapter (2002)
BD	1st year art school, draws occasionally.		ASL 504	Tchalenko *et al.* (2001) This chapter (2002)
MM	PhD art school, does not draw.		ASL 504	Tchalenko *et al.* (2001) This chapter (2002)

Eye Movements

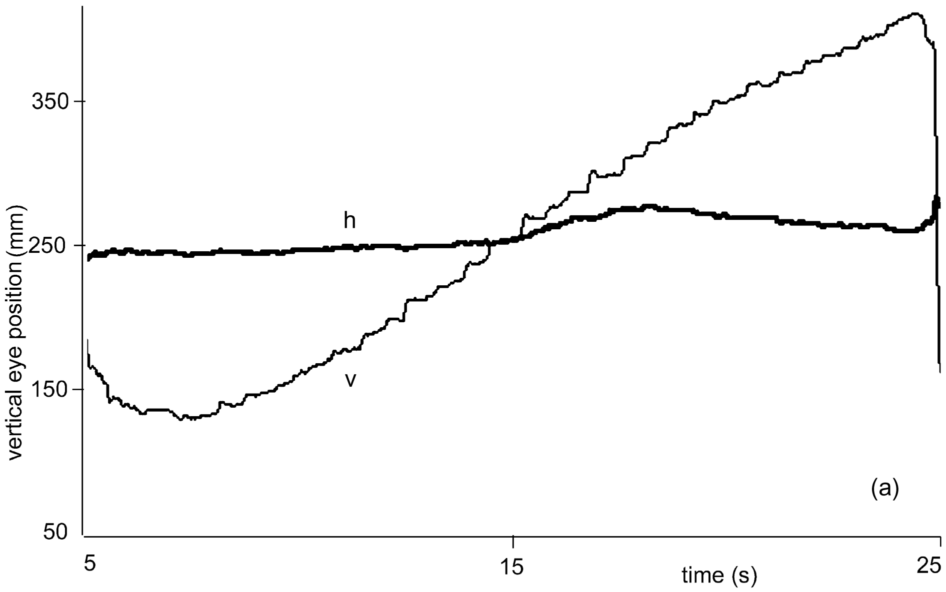
We will first examine separately the two basic fixation types occurring during drawing, those located on the paper (P) and those located on the model (M), before considering their alternation in the P-M-P cycle.

Location of Fixations on the Paper

For all subjects studied we found that fixations on the paper when actually drawing were located slightly away from the pencil tip, at a distance of about 0.5 to 1.0 degree, and in the position least occluded by the drawing hand. As the subjects we studied were all right-handed and drawing on a vertical board from a seated position, when drawing a horizontal line fixations were located above the line and near, or slightly ahead, of the starting point, and when drawing a vertical line they were located to the left of it. With HO who attributes extreme importance to the precision of single lines, a fixation remained stable until the pencil had moved about 1 degree from the starting point, at which stage a saccade would occur to reposition the next fixation in the same relationship to the line as previously. In this way, the eye was continually lagging behind and catching up with the pencil in fits and starts, suggesting that the eye's function was one of evaluating the segment that had just been drawn as well as of guiding the pencil. With ME who draws more rapidly and with many more lines than HO, fixations followed the same pattern but with more flexibility: they were less stable and moved back and forth along the line as it was being drawn. In none of the cases studied did the eye follow the pencil in a smooth pursuit movement. Ballard *et al.* (1992) had already observed in their block-moving exercise that smooth pursuit was not used even in cases where it could have been. When, during the drawing of a line, the artist stopped his pencil to refer back to the model and then returned to the paper, the fixation on the paper also followed the above pattern. We shall refer to this behaviour as the "normal" eye position when drawing.

To our knowledge, these eye movements on the paper during drawing have not been documented to date. We tested subject IA who was skilled at drawing closely spaced parallel lines. In Figure 33.1a, the subject was drawing a vertical line, top to bottom, about 20 cm long and about 1 mm (about 0.1 degree) to the right of a reference line. The vertical eye position shows the catching up movement from one fixation to another, while the horizontal position remains nearly constant. The average distance between one fixation and the next was 0.9 degree.

The behaviour was the same when the line was drawn at greater distances from the reference line: fixations were centred on the reference line and followed the pencil downward in episodes. However, beyond 1 cm distance, the behaviour changed. Figure 33.1b is for a line drawn 2 cm (about 2 degrees) away. Both vertical and horizontal eye positions were now changing, indicating that the eye was moving back and forth between the reference line and the "normal" drawing position as the line was being drawn. Seeing the reference line in parafoveal vision was obviously not adequate for drawing a parallel line, so the eye alternated between the reference and the drawn line.



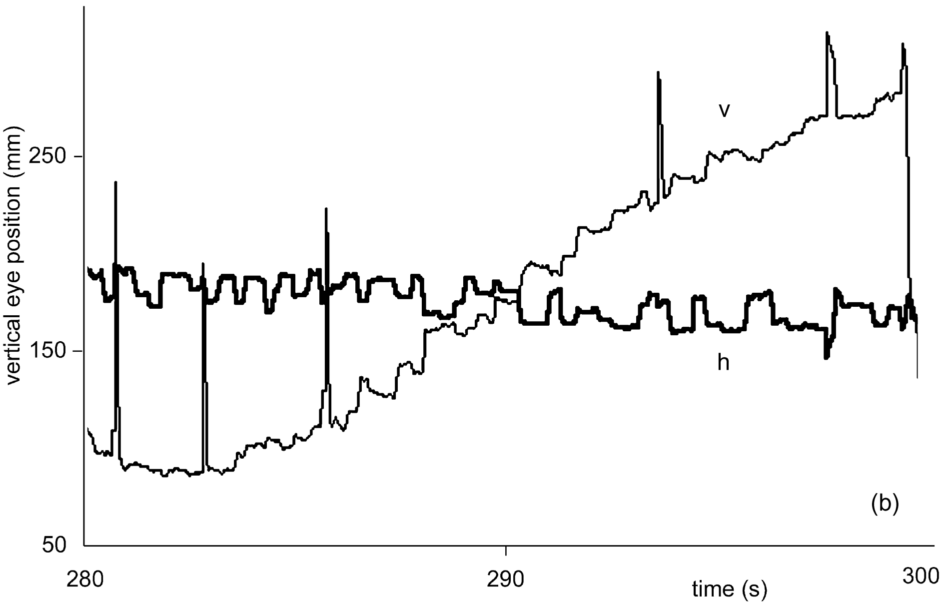


Figure 33.1: Fixation location when drawing parallel vertical lines. Subject IA. Line drawn is (a) 1 mm and (b) 2 cm away from reference line. h horizontal eye position, v vertical eye position.

Location of Fixations on the Model

All subjects with some experience in drawing (HO, ME, JT, PL) showed stable single fixations on the detail of the model that they were drawing. This feature was especially marked with HO: a saccade originating on the paper would find its target after one or two adjustment saccades and then lock onto the point for the duration of the fixation, i.e. one second or more. Fixation durations and frequencies are given in Table 33.2. For HO with whom we have done the greatest number of systematic tests, average fixation duration was 0.6 to 1.0 s and rate 12 fixations/minute. We compared HO's performance to that of three non-drawer control subjects in a separate test of drawing a quick portrait from a photograph (Miall & Tchalenko 2001). This showed that novices did not maintain single stable fixations, producing instead several, often quite separate, short fixations, referred to here as multiple fixations.

How does this eye behaviour of the artist differ when seeing a face but not drawing it? We gave HO the task of selecting a model for drawing from four possible candidates he had never seen before. The subjects entered his field of view one at a time and sat down in front of him as he was wearing the eyetracker, and we measured his eye movements for the first 30 to 40 seconds.

With all four faces the first fixation was always on the person's left eye,[1] but after that, with one exception, the patterns were all totally unpredictable (Figure 33.2). With this type of test, we never observed a systematic scanning pattern outlining the person's contours and features, as found by Yarbus (1967), albeit for photographs rather than live faces. The exception showed a concentration of fixations on the two eyes, as when "eye contact" occurs between two persons, and the painter eventually selected that candidate to draw. Locher *et al.* (1993) working from photographs of faces found that subjects acquired essential "human contact" information in the first 100 ms flash presentation of a face, and in our case we think that something of this nature occurred during the first of HO's fixations on the candidate's left eye. After this first fixation, the lack of consistent scan path pattern suggests that the painter was not assessing any

Table 33.2: Fixations on the model: basic timings.
Data on HO from Miall and Tchalenko (2001). All other data from this chapter.

Subject and drawing type	**Portrait duration**	**Fixation / minute**	**Range of fix. duration (s)**
HO *Nick, Luke 2, etc.*	12 min–5 hrs	12	0.6–1.0
HO *brief sketches*	2 min	22	0.6–1.0
ME *Self-portrait*	30 min	24	0.4–1.8
JT *Self-portrait*	30 min	22	0.8–2.0
PL *Self-portrait*	30 min	28	0.3–1.2
CS *model's eye*	15 min	multiple	1.0–1.8
DL model's eye	15 min	28	0.7–1.9

Figure 33.2: Fixations on seeing a live face for the first time. Subject HO, first 13 seconds. This is one of the three candidates that HO did not select to draw.

particular feature of the face to determine his choice of candidate, but was probably reacting spontaneously to the person in front of him, and opting for the one he felt most empathy with. This is indeed what HO confirmed to us after the test.

The clearest measurable difference between the drawing and non-drawing situation was in the fixation frequencies on the model: 12/minute when drawing, 140/minute when not drawing. The latter rate is situated at the lower end of everyday life activities for most people (Rayner & Pollatsek, 1992). Average fixation duration showed a smaller difference: 0.6 s — 1.0 s when drawing and 0.4 s when not drawing. These values apply to HO: for the drawing situation, they are taken from a large number of eyetracker studies (see Table 33.2), and for the non-drawing situation, from tests lasting 30 to 40 seconds.

Paper to Model to Paper Time Sequence (P–M–P)

Figure 33.3 and Table 33.2 show the time sequence of fixations on model and paper for painters of varying degrees of professionalism and experience. All subjects entered a regular working rhythm from the outset and maintained it throughout the session, although variations would occur for particular parts of the drawing (see Miall & Tchalenko, 2001). As found by Pelz *et al.* (2001) for simple block-moving tasks, the overall regularity of the painter's rhythmic pattern constituted the task's coordinative structure, and reflected its intrinsic dynamics and specific subtask demands.

Compared to HO, the other three subjects who drew regularly (ME, JT, PL) showed higher frequencies of looking to model (22–28 fixations/minute instead of 12 fixations/minute), but durations of the same order, indicating that they were spending less time looking at the paper. Although HO's portraits contained fewer lines, he spent more time drawing each line, reflecting his concern with precision and detail.

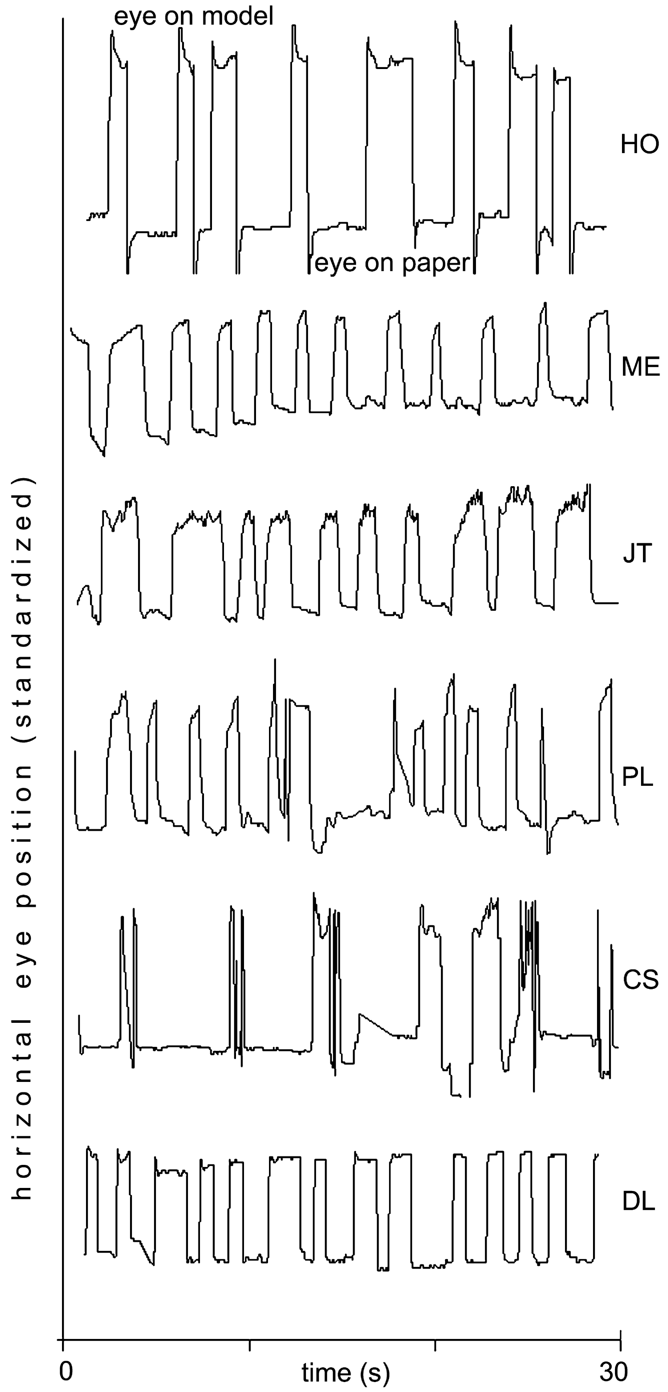
The last two examples shown in Figure 33.3 are from tests with art school students who had some experience in drawing but no formal training in drawing from life. They were asked to draw the model's eye. Subject CS followed a P–M–P rhythm comparable to HO's, but fixations on the model were multiple (up to about 10 per glance) with many lasting less than 0.10 s. Furthermore, fixations were not targeted on any specific detail but were located at various points of the face. It is unlikely that any useful visual input could take place under these conditions (Rayner & Pollatsek, 1992), and indeed, the resulting drawing was of a generic eye unrelated to the model's. In contrast, subject DL's fixations were single and stable, but close-up video film of the hand showed that it was continuously marking lines on the paper, even when the eye was on the model, and that these lines were not closely connected to what the eye was targeting on the model. In both these cases, the basic P–M–P eye movement cycle, although present, was not fulfilling its role of capturing specific visual information from the external world, interpreting it and laying it down on the paper. As suggested by Suppes *et al.* (1983), with unskilled operators the eye may wander while the subject is wondering what to do next.

Eye-hand Coordination

On pages 000–000 we described the simplest case of interrelation between the eye's fixations on the paper and the hand drawing the line. Taking into account the fixations on the model and the P–M–P cycle, we can now explore the broader picture of eye-hand coordination during the drawing process.

Fixations in the Vicinity of the Hand

Figure 33.4 shows the first line drawn in HO's 5-hour *Portrait of Nick*. It depicts the back edge of the model's upper eyelid of the right eye, and is about 5 cm long and concave downwards with a changing curvature. It was drawn left-to-right with the pencil stopping twice on the paper's surface while the eye went back to look at the model — hence the three sections E1–E2–E3. The temporal movement sequence, analysed on the basis of eye tracker and video data, indicates that the eye and hand were working together, with coordination between them maintained by delaying the


eye on model
eye on paper
HO
ME
JT
PL
CS
DL
horizontal eye position (standardized)
0
time (s)
30

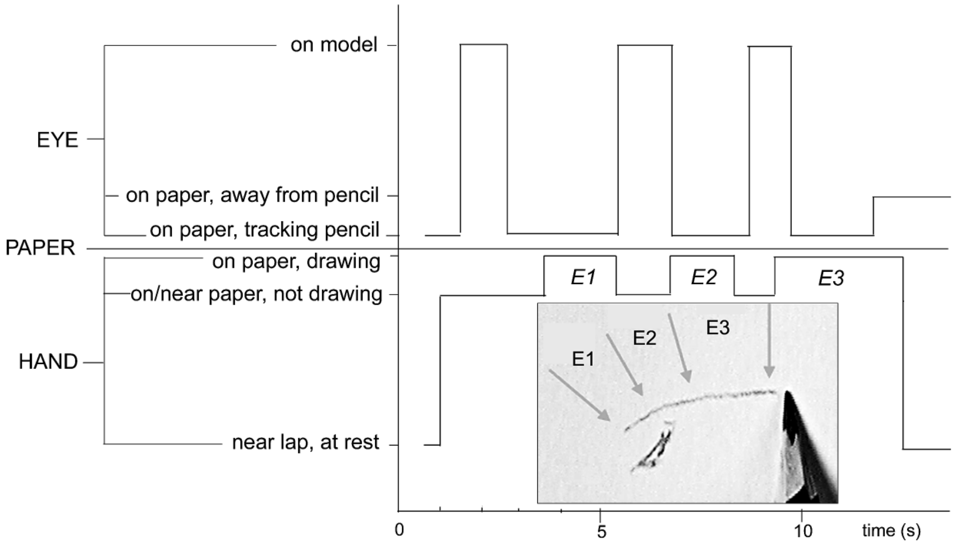


Figure 33.4: Schematic representation of horizontal eye and hand positions when drawing a simple line (Humphrey Ocean, *Portrait of Nick, 1998*).

hand movements until the eye was available for guiding the movement, as in the block-moving exercises described in Pelz *et al.* (2001). We can interpret this behaviour as being the simplest case of a fading visual memory, with the hand drawing until the memory needs to be refreshed, although the timing is exceptionally long if thought of in terms of mental image maintenance and visual buffer memory (Kosslyn, 1994). Two factors may favour such extended timings: (1) the information required to continue an existing line is essentially restricted to a single element — the line's angle, and thus forms part of the abstract schematic representation underlying our memory for scenes (Intraub, 1997); and (2), seeing the line as it is being drawn reinforces the mental image and thus aids in its memory maintenance, as for the subjects in Epelboim *et al.* (1995) who were making us of a visual display as an extension of their memory.

Figure 33.3: Comparative P-M-P time sequences during drawing. Each graph represents the horizontal eye position, with looking at the model shown as high levels, and looking at the paper as low levels. (The *Y* axis distance between the two levels represents the horizontal physical distance between model and paper, and has been standardised on the graph to facilitate temporal comparison between subjects). JT's apparent eye movement when looking at model is due to head movement and is not a fixation instability.

Fixations Away from the Hand

The before-last line drawn in the same portrait represents the outer contour of the hair on the model's right side (Figure 33.5). At 20 cm it is also the longest single line of the picture. Of gentle uniform curvature, it was drawn in two consecutive strokes, H1–H4 and H5–H6, with the hand resting at the lap in between. H5–H6 was then reinforced to become H7–H8.

Drawing started at H1 after several long fixations on the model, and the eye followed the pencil downwards with two small saccades, before leaving the trace for three fixations elsewhere on the picture while the hand continued to H4. There followed several fixations on the model, after which the eye and hand met at the start of H5, but instead of the eye then following the pencil, it fixated elsewhere on the paper and on the model, as shown in Figure 33.5. By the time the pencil had reached H6 the eye was back on the model. The line just drawn, H5–H6, was then reinforced very precisely to become H7–H8, with, as before, the eye only coinciding with the pencil at the start. In summary, a curved line about 10 cm long (H5–H6) was first drawn, and then very precisely reinforced (H7–H8), with the eye only locating the starting point and then entirely foveating elsewhere. This eye-hand behaviour is shown schematically in Figure 33.6.

The H1–H8 line denotes a more complex eye-hand coordination than E1–E2–E3. The painter now draws 10 cm before referring back to the model, suggesting that the 1.7 cm retained in E1–E2–E3 constituted a deliberate strategy, a sort of minimal memory solution as found by Ballard *et al.* (1992) for their block-moving exercises.

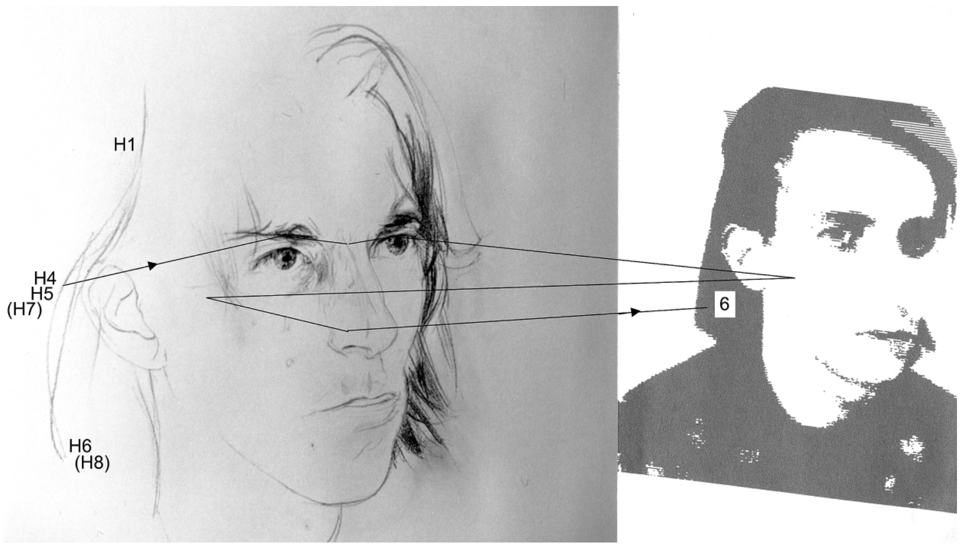


Figure 33.5: The eye's movement path between the paper (left) and the model (right) during the drawing of line H5–H6 (Humphrey Ocean, *Portrait of Nick, 1998*).

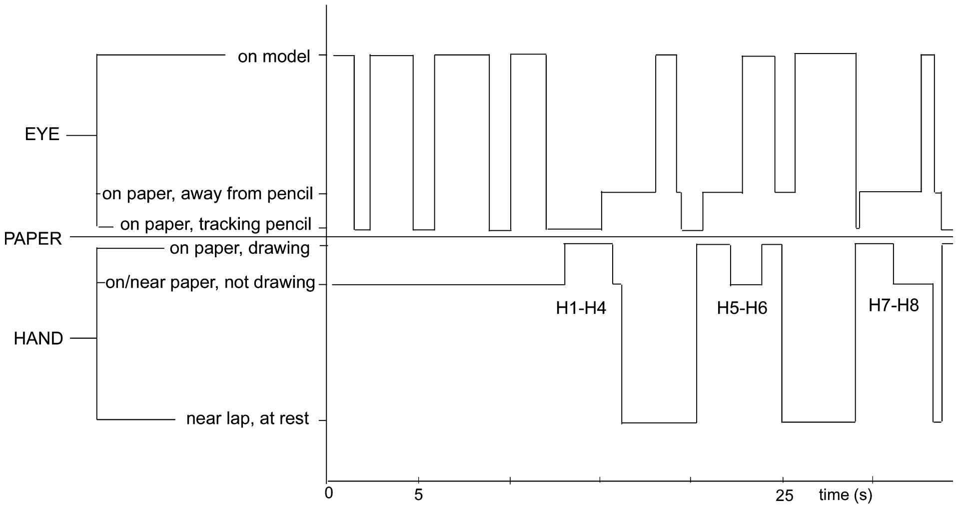


Figure 33.6: Schematic representation of horizontal eye and hand positions when drawing a complex line (Humphrey Ocean, *Portrait of Nick, 1998*).

Rather than keeping the entire E line in memory, the painter referred back to it in episodes. With the H1–H8 line, his strategy was different: during most of the drawing, his fixations were centred on other parts of the picture not directly related to that line, thus allowing for perception of the "picture so far" to become an additional input into the drawing process, for example by situating the line with respect to others previously drawn.

The reinforcing of H5–H6 into H7–H8 highlights the complexity of the cognitive process. Whereas drawing without seeing could be explained by motor commands based on a visual mental image, retracing a 10 cm line perfectly about 10 seconds after the original, and without ever having foveated the original, suggests the presence of a motor memory component to the drawing process. It is the memory of the action — not the memory of the vision — of drawing H5–H6 that allowed the painter to draw the identical H7–H8.

The two types of lines seen above have in common the fact that they are not reproducing lines which have a separate existence on the model's face. E1–E2–E3 is the painter's resolution of a zone of changing light, colour and texture above the model's right eye; to draw it, the painter relied on the visual information provided by that zone. H1–H8 is the painter's resolution of a combination of features: the shape of a single strand of hair, the general shape of the hair on that side of the face and the left limits of the picture; to draw it, the painter required at least as much visual information from the picture drawn so far as from the model's face itself. The drawing process is therefore a continually changing balance between the use of visual input from the external world and visual input from the growing picture, and the painter's eye movements are a good indication of the state reached by that balance at any given stage of the drawing.

Further Observations on Eye-hand Coordination and Motor Memory

Two sets of observations on subject HO are considered important enough to be added to the above remarks, even though future work with other painters is needed to confirm their generality. The first concerns a feedback loop between eye and hand occurring as the painter fine-tunes the line he is drawing; the second concerns the painter's acquisition of a long-term memory of the drawn picture.

Not infrequently painters rehearse a line they are about to draw by repeating the hand's action several times with the pencil tip just off the paper's surface. We studied this with HO who would at times practise a line with a dozen, or more, strokes as his pencil gradually approached the paper until it started marking the surface. During this hand movement, fixations remained stable and near the line, or were occasionally interrupted as the painter looked at other parts of the drawing or at the model.[2] Figure 33.7 is a motion sensor record of the pencil's movement during the drawing of one of the lines forming the lips in *Portrait of Nick*. The first 10 strokes were off the paper and the line was only drawn during the last four strokes. Close-up video film showed that the pencil path described an elongated ellipse encompassing the future line, gradually narrowing down onto the line's starting point. This suggests that the initial motor command to the hand was being adjusted in steps as the eye was observing the hand's movement, and that the process continued until the result corresponded to the mental image of the line the artist wanted to draw.

How long does a painter retain the memory of a portrait drawn some time ago? We tested HO by asking him to redraw the 12-minute portrait *Luke 2* described in detail in

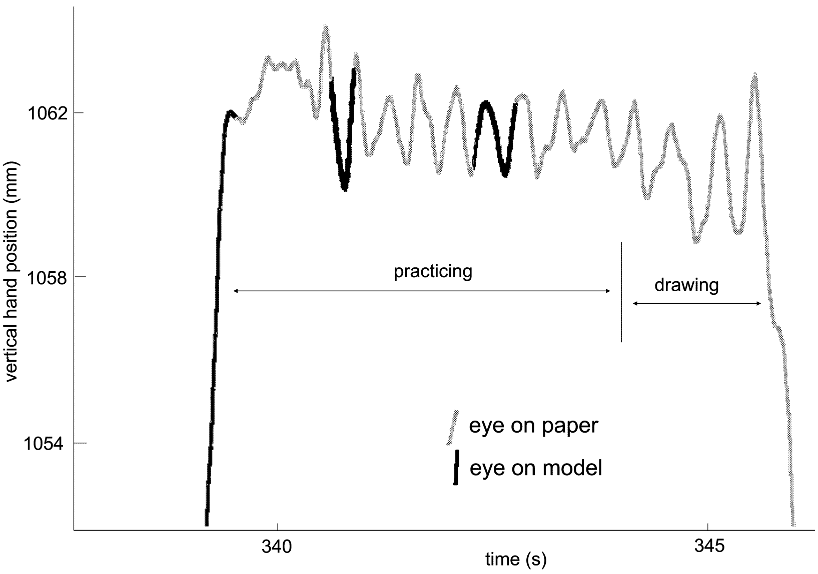


Figure 33.7: Horizontal hand position while practicing a line (Humphrey Ocean, *Portrait of Nick, 1998*).

Miall and Tchalenko (2001), and which he had not seen for over one year. Fixations were now entirely located on the paper, with no observable sign of refresh or memory recall such as aversion fixations (Rayner & Pollatsek, 1992), pauses or glances away from the drawing. The overall lines of *Luke 3* were almost exactly the ones of *Luke 2*, although the new lines were individually much longer, i.e. drawn with far fewer strokes. For example, the line representing the contour of the nose was drawn in four segments in *Luke 2*, and as single segment in *Luke 3*. It suggests that the artist retained a near-perfect long term memory of the drawing he had made one year earlier, but not of the drawing act itself as had been the case with the buffer memory described in IV.2.

Eye Control

Voluntary Control of Eye Movements

We have already noted that the experienced painter differed from the novice in his ability to repeatedly target saccades onto a small detail of the model's face, and to lock-on to that detail in a steady fixation. This suggests an eye control factor which can also be demonstrated with the "eye signature test" in which the subject writes his/her name on a blank screen with the eyes alone and without seeing either the cursor or the line (Tchalenko, 2001a). A smooth and accurate movement of this type is generally considered impossible (Kowler, 1990), but taking into account the straight-line trajectories of saccadic eye movements, we found that subjects who drew regularly from life were generally much better at producing legible results than those who did not (Figure 33.8).

A stricter test of eye control consists in moving the eye slowly from one point to another, a task first examined by Yarbus (1967). Figure 33.9a,b compares the eye's movements between the corners of a square in saccadic and in slow movement. For the latter, and unknown to the subject who has the impression of moving smoothly, the eye's trajectory is made up of smaller segments in an alternation of *constituent saccades* and inter-saccadic intervals referred to here as *fixations*. Preliminary tests on 15 subjects with a simplified eye tracker (Quick Glance) suggested a strong correspondence between the ability to trace a line in this way and write one's name (Tchalenko, 2001a,b), and we decided to see whether the method could be quantified and used to differentiate between subjects of differing aptitudes in drawing from life. We give below the first results of this study.

Tracing a Line by Eye: Temporal Behaviour

Tracing is defined here as the eye's movements when joining points or following a line displayed on the computer screen or on a blank paper. Tests were made with an ASL 504 eyetracking system used at the maximum sampling rate of 0.020s (50Hz). Subjects were seated 65cm from the computer screen and provided with a back head-rest, but were not clamped.

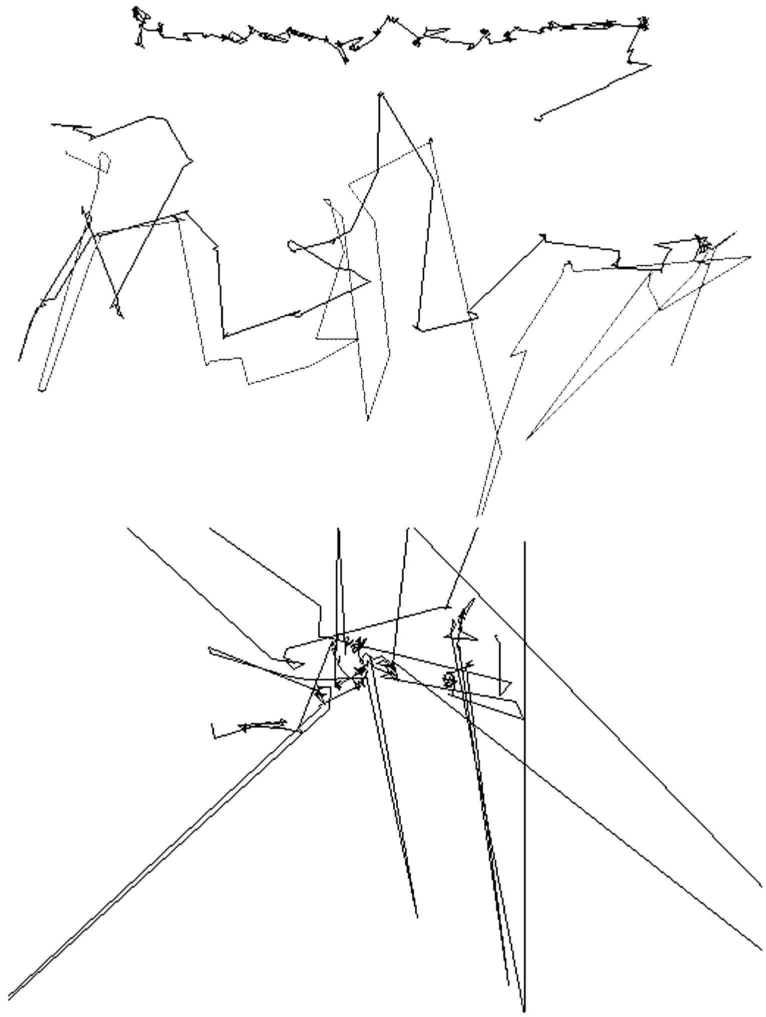


Figure 33.8: Eye signatures. Subjects writing their names with their eyes alone. All signatures are at the same scale: top "Humphrey", middle "John" two consecutive tests illustrating consistency, bottom "Carol".

Tracing a spiral was found to be a good test for tracing ability as it combined in one exercise a variety of movement directions and curvatures (Figure 33.9c). Subjects followed the original reference line from the centre outward and tests were repeated three times at different speeds. Furthermore, each subject was tested at three different times of a same day in order to ascertain reproducibility of results. The questions examined were, firstly, how regular was the overall movement in time, and, secondly, how accurate were the fixations with respect to the reference spiral.

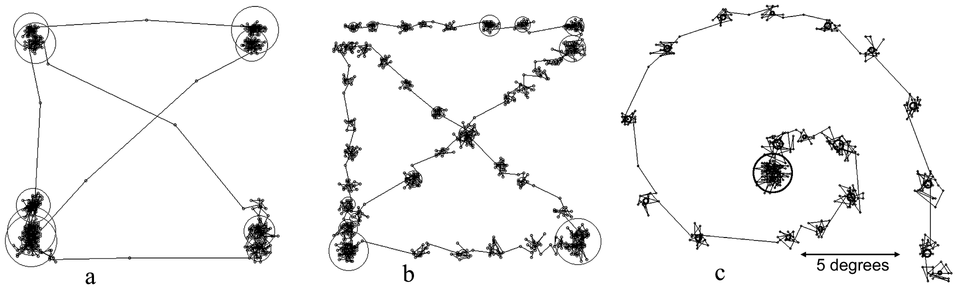


Figure 33.9: Saccades (a) and slow movement (b) between the corners of a square, and slow movement following a spiral (c). The reference spiral is not shown. Subject JT was not seeing the cursor or the line being drawn. Circles represent fixations calculated from 50Hz sampling points, as explained in Appendix I.

Defining *average saccade amplitude* (a) as the mean amplitude of the constituent saccades, and *tracing speed* (V) as the average speed at which the eye traces the drawn line from beginning to end, we found that saccade amplitude for the five subjects tested systematically increased in linear proportion to tracing speed (Figure 33.10):

$$a = 0.21\text{V} + 0.83 \quad (1)$$

The theoretical equation for this relationship based on the known dynamics of saccades is also shown on Figure 33.10 as Equation 2 (see Appendix II for computation and discussion) and is seen to be in reasonable correspondence with our empirical data for tracing speeds above 10 degrees/s. However, despite the fact that the five subjects tested were of very different drawing skills, Equation 1 applied equally well to all of them, and it was not possible to discriminate between drawing abilities on this basis alone. We think that this may be partly due to the fact that at very low tracing speeds, where the difference between subjects is greatest, very small saccades become confused with system noise, and our method is no longer appropriate for this type of study.

Tracing a Line by Eye: Spatial Accuracy

To assess how accurately the eye was targeting the line being traced, we measured the angular distance between each 50 Hz sampling point and its orthogonal projection onto the line. We called this distance the *Spatial Accuracy* (SA). Figure 33.11 shows an example of results for subject JT at an average tracing speed of 12 degrees/s. Standard deviations calculated with respect to the mean SA value were remarkably consistent for each subject, unaffected by tracing speed and identical for straight line and spiral tests (Table 33.3). The ranking obtained corresponds well with subjects' drawing experience, suggesting that the standard deviation of Spatial Accuracy is a valuable measure of a subject's eye control capabilities.

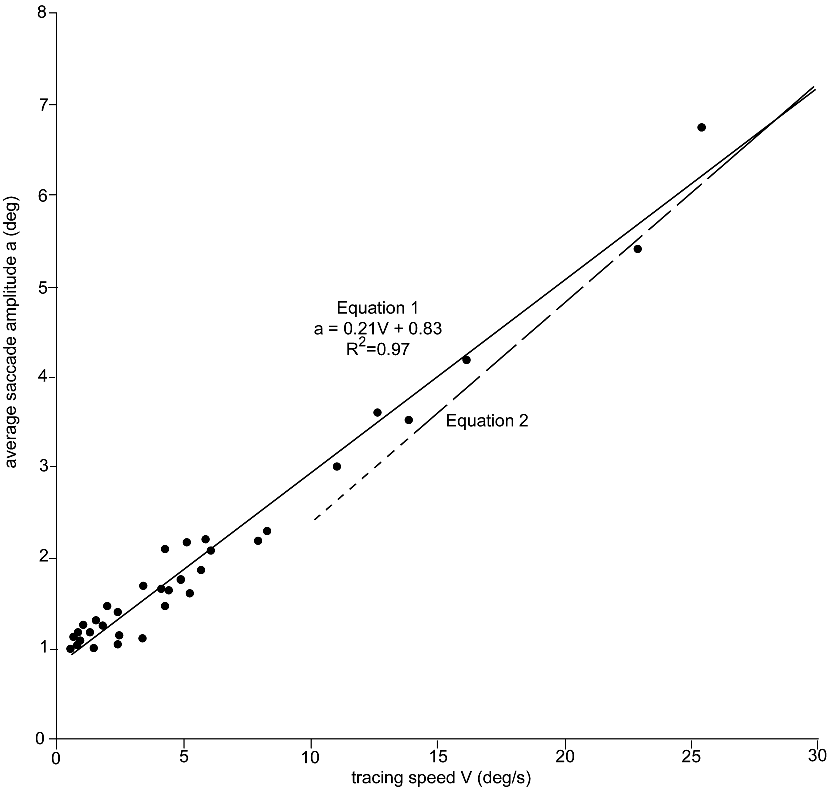


Figure 33.10: Tracing a spiral by eye. Relationship between constituent saccade amplitude (a) and tracing speed (V). Results are for five subjects: JT, BD, MM, ME, PL.

Concluding Remarks

In this first study of eye movements in portrait drawing from life we investigated the picture production process and established some of the basic physiological parameters involved. If we were to generalize on the basis of the 12 subjects of different abilities studied so far (Table 33.1) we could postulate the following description of the drawing process.

Drawing from life entails eye movements from paper to model and back — the P–M–P cycle — at a rhythm of between 12 and 28 fixations on the model per minute, and fixation durations on the model of 1s or over, precise values depending on the artist and the type of drawing — quick sketch or fully drawn portrait. The function of the glance to model being to acquire detailed visual information, this is best achieved with single and stable fixations. The information is then available in the painter's visual memory for about 2 seconds before needing to be refreshed, although in the advanced

Table 33.3: Spatial accuracy tests: mean and standard deviation values in angular degrees.

Subject	**JT**	**ME**	**MM**	**BD**	**PL**
Spiral at average speed (3 tests /subject)	0.38 ± 0.07	0.47 ± 0.08	0.54 ± 0.16	0.78 ± 0.20	1.13 ± 0.27
Spirals fast, average, slow (9 tests / subject)	0.40 ± 0.08	0.46 ± 0.10	0.52 ± 0.14	0.74 ± 0.21	1.25 ± 0.28
Straight lines fast, av., slow (9 tests /subject)	0.37 ± 0.09		0.57 ± 0.19	0.88 ± 0.34	
Spatial accuracy (SA) Average of all above tests	0.38 ± 0.08	0.47 ± 0.09	0.54 ± 0.16	0.80 ± 0.25	1.29 ± 0.28

stages of the drawing, work may proceed for longer periods on the basis of the lines already existing on the paper. There is also some evidence of a motor component to the painter's memory. On the paper, the artist's fixations do not coincide with the pencil point but are located at a distance of 0.5 to 1 degree, and as the pencil moves, small saccades keep up with the line as it is being drawn. Closed-loop type situations may arise between eye and hand when the hand practices a line to be drawn without actually marking the paper, gradually honing in to its final position and direction.

As eye movements during drawing are essentially volitional and controlled by the subject, the question arises whether experienced painters have better control over these movements than beginners. One way of assessing this is by observing the eye movements when following — or tracing — slowly a pre-drawn line. Although the subject is under the impression of moving smoothly, eye movements are actually decomposed into an alternation of constituent saccades and fixations, with a linearly proportional law between average saccade size and overall tracing speed. The accuracy with which the tracing takes place, i.e. the subject's eye control, can be quantified by measuring the standard deviation of the distance between gaze point and the line being traced. Our results show that the practice of drawing from life is clearly associated with a higher degree of eye control measured in this way.

The P–M–P cycle, which we have observed with all subjects studied, forms the universal principal of life drawing, and future studies with different subjects should in time refine the results reported here. Detailed observation of the way individual painters work — such as Humphrey Ocean's practice movements — will gradually enrich our rather schematic present knowledge. The subject of eye control, which has only been touched upon so far, may prove to be the most rewarding aspect of this study as it unites drawing with another fine-controlled eye-hand skill, i.e. surgery.

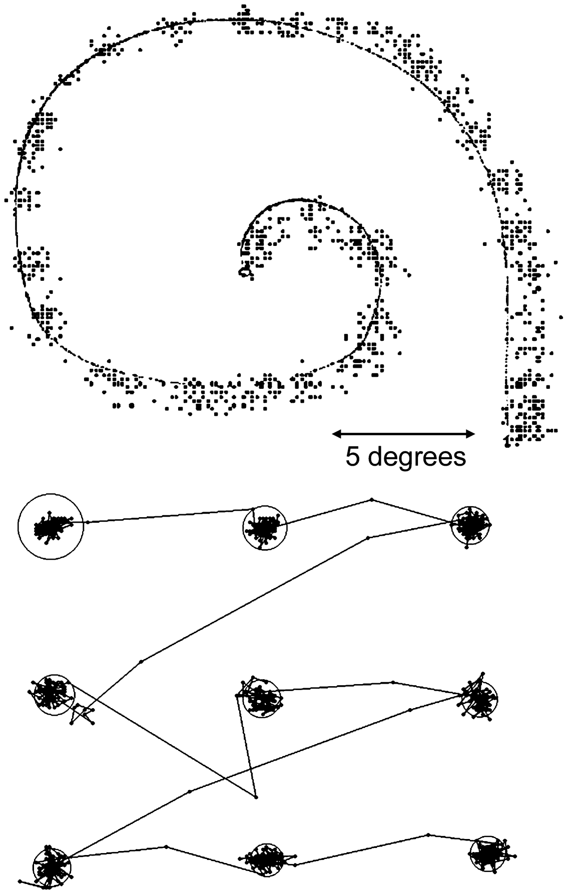


Figure 33.11: Spatial accuracy during tracing by eye. The continuous spiral is the reference line followed by the eye. The nine-point calibration test preceded the spiral tests. Subject JT.

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Notes

1 HO is right-eyed, although we don't know if this is significant.

2 We wish to correct an initial conclusion reached in Miall and Tchalenko, 2001 where it was mentioned that the eye followed the practicing hand in a tracking or smooth motion. Further analysis of the material revealed that the head oscillation mentioned in endnote 15 was more important than originally appreciated and that the painter was moving his body synchronously with the rehearsing stroke. Corrected fixation positions were, however, stable and not different from normal drawing.

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Appendix I — Eyetracker Equipment

The Painter's Eye Movements was a Wellcome Trust 1998 sciart project undertaken with the University Laboratory of Physiology, Oxford, on their AlphaBio Eyeputer (EP) eyetracker. This is a head-mounted 30 Hz system providing fixation accuracies better than 2 degrees. A Polhemus Fastrack motion-analysis system provided simultaneous recording of the pencil position.

Investigations with subjects AE, CS, DL, IA and HO for the drawing of *Luke 3* were carried out in 2000 at Camberwell College of Arts, London (CCA) as part of the ongoing Drawing & Cognition project, using a 50 Hz head-mounted ASL 501 (Applied Science Laboratories) system providing an accuracy better than 1 degree. Concurrently, the Eye Control study that developed from a preliminary investigation at CCA with a simplified eyetracker (QuickGlance by EyeTech Digital Systems) was followed by a Wellcome Trust 2001 sciart project undertaken jointly by CCA and the Department of Computing, Imperial College of Science, Technology and Medicine, London. We used the ASL 504 System (50 Hz), a remote device with nothing attached to the subject who is seated with a back head-rest in front of a computer screen. Maximum accuracy is 0.5 degree. We adopted a standard ASL fixation algorithm using an improved visual angle calculation. In this dispersion algorithm, a fixation is initiated when the standard deviation of the x and y screen coordinates of 5 consecutive points (0.100 s duration) are below 0.5 degrees. New threshold restrictions are then applied as the fixation grows in duration before the next saccade. As part of the same project, three artist subjects ME, JT and PL were investigated with an ISECS eyetracker by QinetiQ, U.K. This is a 25 Hz device which looks, and feels, like a pair of spectacles, and provides an accuracy of about 1 deg. All these systems provide measurements in data file form as well as a video film with a superposed cursor marking the eye's gaze position.

Appendix II — Tracing a Line by Eye: Theoretical Relationship

For single saccades greater than 5 degrees in amplitude, Becker (1991) suggested the following correlation between the duration (D) of a saccade and its amplitude (a):

$$D = D_0 + d.a \tag{1a}$$

where $D_0 = 0.025$ s and d = 0.0025 s/deg.

For a tracing path consisting of a succession of saccades alternating with fixations, the overall duration (Δ) can be written as:

$$\Delta = N.D + N.F \tag{1b}$$

where N is the number of constituent saccades or fixations, and F the average duration of a fixation. Our spiral tests showed that values of F are about 0.300 s for saccades of 3 degrees and decrease asymptotically to 0.200 s for saccades greater than 5 degrees. This dependence of inter-saccadic fixation duration on tracing speed may reflect the fact that, in saccade sequences, individual saccades are controlled by an organized plan for the entire sequence, as suggested by Zingale and Kowler (1987). Taking $F = 0.200$ s and solving for Equations 1a and 1b leads to:

$$a = 0.225.V \,/\, 1–0.0025V \tag{2}$$

Equation 2 was found to provide a good approximation of our data for tracing speeds above about 10 degrees/s. At lower tracing speeds, as saccade amplitudes approach 1 degree, the algorithm adopted to differentiate between saccades and fixations may no longer be ideal for describing the observed movement. Higher sampling rates and greater system accuracies will be required to ascertain whether very slow voluntary eye movements can still be adequately described in terms of a succession of saccades and fixations.