A Painter's Eye Movements: A Study of Eye and Hand Movement during Portrait Drawing

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TECHNICAL NOTE

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ABSTRACT

The mental processes that allow an artist to transform visual images—e.g. those of his model—into a picture on the canvas are not easily studied. The authors report work measuring the eye and hand movements of a single artist, chosen for his detailed and realistic portraits produced from life. His eye fixations when painting or drawing were of twice the duration of those when he was not painting and also quite different from those of novice artists. His eye-hand coordination pattern also showed differences from that of novices, being more temporally consistent. This preliminary work suggests that detailed and quantitative analysis of a working artist is feasible and will illuminate the process of artistic creation.

How does a painter transform a vision of the external world into a picture on the canvas? Much work has been reported on aspects of visual processes and on perception of finished artwork [1], but so far cognitive psychologists and art historians have had little to say about the actual picture-production process [2].

An artist drawing from life shifts his or her gaze many hundreds of times, from the subject matter to the paper or canvas and back again. Less often, longer periods will be spent just looking at the sitter or at the emerging picture. Clearly, this shift of gaze is a fundamental aspect of picture production, and a direct consequence of the subject-to-picture transformation taking place in the artist's brain [3].

With the help of the eyetracker, an instrument that can accurately measure eye movements, together with a sensor recording hand movement and close-up video filming, we set out to investigate how one artist produces pictures. Humphrey Ocean paints or draws realistic portraits from life, hence both his visual input and his manual output are observable to an outsider. This work, combined with an appreciable amount of existing data on this particular artist, comprises a detailed case study upon which we later hope to elaborate.

A PRELIMINARY STUDY: *DOUBLE-PORTRAIT*

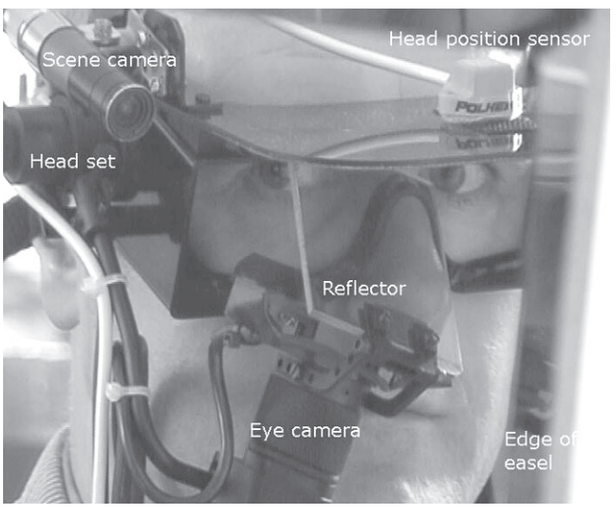
One of us (Tchalenko) had participated in a previous project, *Double-Portrait,* during which Ocean was filmed nearly continuously from the model's point of view [4] while he was painting the camera operator and sound engineer. The resulting video material allowed approximate timing [5] of the painter's gaze and body movements, and in this way the key factors governing the picture-production process could be identified. The first of these concerned the number of times the painter looked at his model. During a 20-×-30 cm preliminary pencil sketch that he completed in 12 minutes, he fixed his gaze 157 times on the model [6] at a rate of 13 times per minute, with an average fixation duration of 0.92 seconds. For the final 130-×-100-cm painting, completed in about 100 hours over 12 days, we estimated that he made over 25,000 fixations on the model at a rate of 6–12 per minute (after allowing for pauses for mixing paints, adjusting canvas, etc). Average fixation duration was slightly over 1 second. Hence, the artist was interrupting his work about 12 times a minute to look at the model for about 1 second each time.

Based on this work, we undertook a detailed study of eye and hand movement in the same artist.

TRACKING EYE MOVEMENTS: METHODS

The eyetracker (an AlphaBio Eyeputer) is a specialized video-camera system mounted on a headset (Fig. 1) and coupled to a computer. The infrared-sensitive camera records a close-up image of the eye while the computer calculates the position of the center of the pupil. The headset includes a second "scene" camera filming the scene in front of the head. Ini-

Fig. 1. The eyetracker was mounted on a helmet and incorporated an eye camera recording the pupil position and a scene camera recording the view in front of the subject. The head-position monitor allowed calculation of the gaze position of the eye even during head movement. A similar monitor was attached to the artist's pencil. (Photo: John Tchalenko)



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tially, the eyetracker had to be calibrated by asking the artist to steadily look at a set of fixed targets. After this, the coordinates of each point in space that the artist viewed could be calculated in real time, superimposed on the scene camera image and digitally stored on the computer for detailed analysis.

For this project we combined these recordings with those from a hand-movement sensor (a Polhemus Fastrak motion-analysis system) to follow the movement of the artist's pencil. This device records the three-dimensional (3D) position of a lightweight marker attached to the artist's hand or pencil [7]. While these eye and hand movements were being recorded, the drawing's progress was filmed continuously with a close-up video camera.

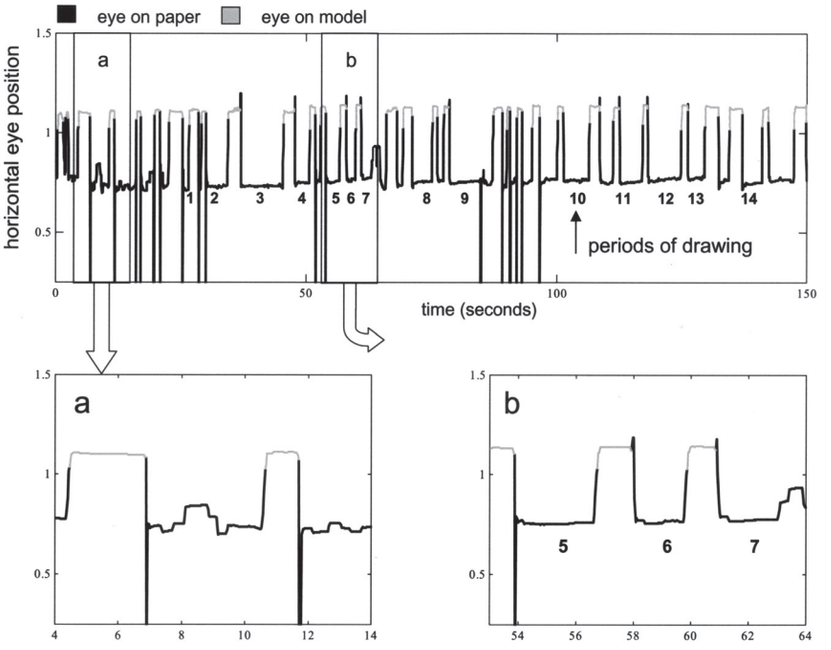


Fig. 2. Nick's portrait: the first 2.5 minutes. Horizontal position of the artist's eye against time, color-coded light grey when the eye fixated the model and black at all other times. The descending vertical lines are blinks, which are commonly made at the same time as large saccadic eye movements. (top and bottom left) The initial visualization period is shown in panel a, when the artist explored the blank paper with a rapid series of fixations. Compare the long fixations on the model's face with the brief fixations made to positions on the paper. (top and bottom right) Areas marked 5, 6 and 7 denote the drawing of a continuous line on the paper. The fixations on the model's face are rhythmic and of nearly equal duration.

EXPERIMENTAL PROCEDURE

A prime consideration throughout the project was to obtain data about an artist at work, rather than from an artist performing scientific tests. The methodology was therefore as follows:

1. Selecting a model: The artist, wearing the eyetracker, sat facing an empty chair, and was presented one by one with four male sitters. The duration and location of his initial fixations during the first few seconds were recorded in order to establish what he was looking for in a prospective model.

2. Brief sketches: The artist wished to make brief sketches of his candidate models to help him in his selection. He drew in ink in a small sketchpad held in his left hand, each sketch lasting 1–2 minutes.

3. The main portrait: The eyetracking system was set up to record the artist's right eye as he sat with a near-vertical drawing pad positioned on an easel about 45 cm in front and to the left of him. The model sat just to the right of the drawing pad, at the same distance, to minimize parallax errors in the video recordings made from the scene camera. The eyetracker was calibrated and used for about 15 minutes each hour, and the artist then worked normally without the eyetracker for the next 30–40 minutes, while model and artist rested for the remaining 10–15 minutes per hour. Thus, five recordings were made, spanning the entire portrait-drawing process. For the third and fifth session, we placed a motion-tracking monitor on the back of the artist's hand to record the position of the pencil within an accuracy [8] of about 10 mm and with a resolution of about 1 mm. This provided records of the spatial location of major hand movements and also of the timing of all hand movements.

4. Secondary portrait: The following day, three short portraits were performed, intended to take about 10 minutes, so that the eyetracker could be worn throughout each. The motion tracker was attached directly onto the shaft of the artist's pencil, increasing the spatial accuracy of the recording of the pencil tip to about 2 mm, with a resolution of 1 mm.

5. Comparison studies with untrained subjects: Some time after the detailed study, the artist and three untrained subjects made a series of very brief sketches. Each subject sketched from a black-and-white photocopy of a face [9] and was restricted to 1 minute per sketch. Both eye-gaze and pencil positions were recorded.

RESULTS

Selecting a Model

As each model candidate entered the camera's field of view and sat down, Ocean had already fixated on the person's left eye. He then made a number of rapid fixations, each lasting an average of 0.4 seconds, until his eye came to rest temporarily, for about 1 second. With the last candidate, subsequently selected as the model for the main portrait, these first few fixations were essentially confined to the person's eyes [10]. This high rate of fixations, about 140 per minute, and concentration with the subjects' eyes, are typical of eye movements reported by others [11].

Brief Sketches

Fixation rate and duration over the four sketches were remarkably consistent (Table 1). Overall average fixation duration was 1 second, and the rate just under 22 fixations/minute.

The Main Portrait

The eyetracker data can be usefully viewed as a time series to emphasize the temporal pattern of Ocean's eye movements (Fig. 2). We used the spatial location of the eye's gaze to color-code the time series, with segments in light grey denoting the periods Ocean was looking at the model (Nick), and in black, at the paper. Blinks, which hide the eye's pupil from the eyetracker camera, appear as vertical lines.

Ocean's eye movements adopted a regular rhythm from the beginning of Nick's portrait. For the first 35 seconds

Table 1. Ocean's eye fixation on the four candidate models during brief pen sketches.

Candidate No.	Total Duration of Drawing (Minutes)	No. of Fixations on Model	Average Fixation Duration (Sec)	Fixations per Min
1	1.35	29	1.05	21.5
2	1.35	31	1.10	22.6
3	1.98	41	0.98	20.7
4	2.16	47	0.82	21.8
Average 1–4			0.99	21.6

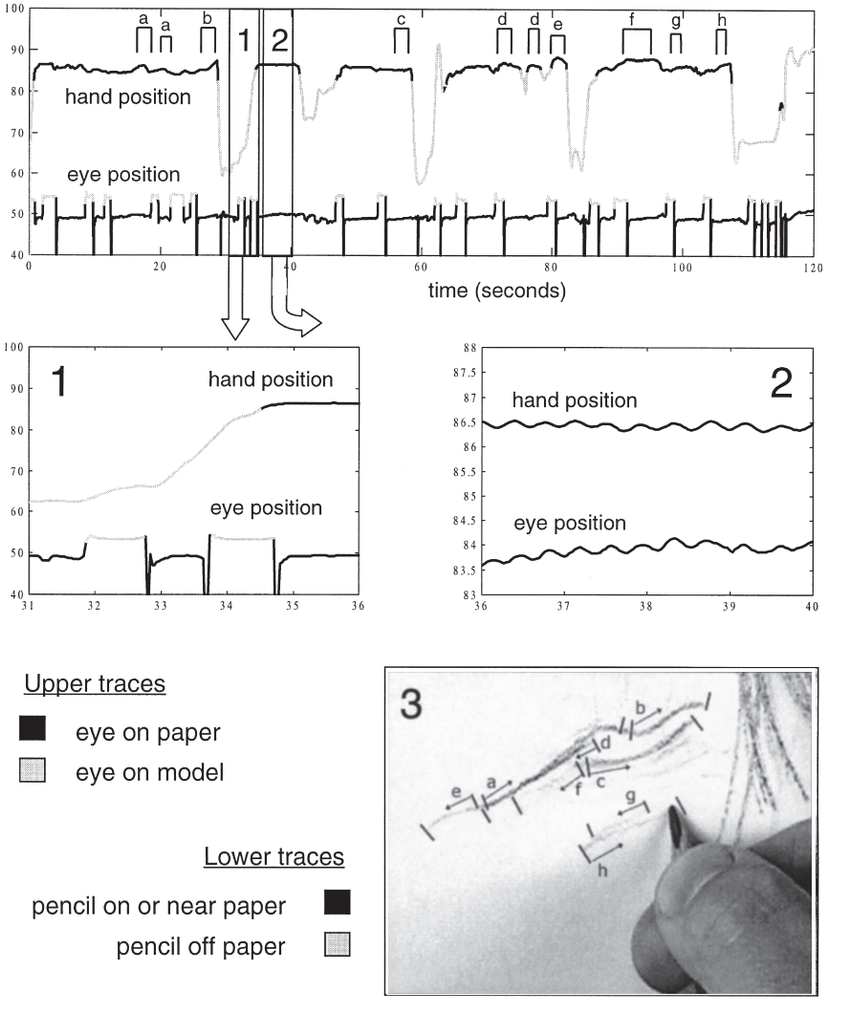
(Fig. 2a), he scanned the blank paper, occasionally referring back to the model, suggesting a visualization process. He then started drawing Nick's right eye [12], falling into a pattern of regular fixations on the model's face, each lasting 0.6–1.0 seconds, at a rate of about 12 per minute. One of the first continuous lines he drew (at 55 seconds) was a 4.5-cm contour of the model's eyebrow (segments marked 5, 6, 7 in Fig. 2b). While drawing this line, he stopped twice to glance back at the model, suggesting that his eye was capturing about 1.5 cm of detail per fixation. The drawing of the right eye proceeded for about 1 hour with the accumulation of such small marks.

Some subtle variations of this basic pattern appeared. For example, there were long fixations on the model at the start, during the first minute. An hour later, as Ocean drew the hair, there were rapid sequences of alternation between the subject and the paper. In the third hour, as he drew the lips, there were regular and spaced sequences. These differences suggest that there may be a consistent relationship between the complexity of the visual object being viewed and the viewing pattern. In particular, when capturing the sweep of the hair, Ocean made rapid comparisons of the model and the paper. As he added detail to the already partly drawn lips, a regular process of visual capture followed by drawing took place. The eye frequently returned to the same location on the model [13], at a rate that would indicate visual memory was refreshed about every 5 seconds.

We analyzed in detail Ocean's hand movements while he drew the model's lips and observed two interleaved movement cycles (Fig. 3). The first had a period of about 20 seconds: Ocean raised his hand from his lap close to the paper and drew and/or practiced, then lowered his hand again to his lap. In the second, with a period of about 5 seconds, he fixated on one detail on the model and then on one or more positions on the paper as he drew that detail. The precise timing of these movements requires more exploration, but this strategy likely provided the most recent visual input prior to hand movement.

Ocean's drawing was frequently accompanied by repeated practice strokes (Fig. 3). The pencil would move several times just above the paper's surface, followed precisely by Ocean's eyes, in a smooth movement [14]. Occasionally, the eyes would rapidly look away to fixate upon the corresponding detail on the model, or upon another part of the drawing, before returning to follow the pencil tip. Practice movements are seen in many tasks and sports requiring skilled movement and serve to refresh a short term "motor memory" of how the body moves [15]. In other instances, the "practice" resulted in very faint pencil marks on the paper, perhaps to aid in deciding on the exact form of the final line. The difference in pencil position between these two movement types, practice and drawing, were so slight (probably less than 1 mm from the paper surface) that our tracking technique could not separate them, and close-up video was required for their study.

Fig. 3. Ocean's eye and hand movements while drawing Nick's lips. (top and middle left) The synchronization of eye and hand movement, with a fixation on the model just as the pencil approaches the paper. (top and middle right) A period of rehearsal, with rapid cyclic pencil motion and corresponding smooth movements of the eye. (bottom right) Eight separate pencil strokes (a to h) were used, most of which were preceded by practice movements of the hand as shown on the graph.



Secondary Portraits

The intermittent recorded test sessions imposed an unnatural break to the artist's normal routine. We therefore agreed that he would produce a portrait within a shorter period, allowing us to monitor eye and hand movement throughout. Figure 4 shows the complete record of eye and hand movement during an 11.5-minute pencil drawing. One can see the very rhythmic sequence of eye movements between the paper and the model, while the upper record shows a pattern of hand movement similar to that seen in Fig. 3. The only significant difference was that the rest periods of the hand were less frequent, Ocean's hand dropping about once per minute. This may have reflected increased time pressure compared with the previous, longer portrait. In the eye-movement trace, the steady pattern of fixations on the model is again clear, with an average rate of 13 per minute, although for brief periods, e.g. at 5.3 minutes and 8 minutes, the rate increased. As before, it seems likely that this very rapid comparison of model and drawing was made in order to assess accurately the spatial arrangement, as each period preceded the drawing of a new feature (the right eye at 5.3 minutes, the lips at 8 minutes). The slower and steadier sequences that were seen occurred while Ocean drew the finer details of each feature.

Figure 5 shows the completed drawing and the corresponding spatial record of the pencil-tip movements. The differences between the black lines and the final drawing reflect practice hand movements that were not committed to paper.

Comparison with Untrained Subjects

Preliminary comparisons were made between Ocean and three novices. We imposed a time limit of 1 minute per sketch while they copied photographed faces. Ocean's fixation duration remained at 0.6–1.0 seconds, typical of that recorded previously. The novices' durations were about half as long. Furthermore, Ocean's fixations were always single, whereas the novices' were generally multiple. Ocean locked his gaze onto one position, apparently taking in a single detail, while the novices fixated on two or more positions, sometimes quite separate. The briefer and less consistent fixation durations of the novices were more typical of everyday eye movements and more typical of Ocean's fixation pattern when not drawing or painting.

It seems possible according to this data that a graded pattern of eye movement correlates with drawing skill. The most fluid and accurate drawing by our three novices was made with the most consistent, longest fixations on the model; the least accurate, with the least consistent eye movements. However, more tests are needed to confirm this.

Table 2. Ocean's average fixation timings while drawing a portrait.

	Portrait Duration	Fixation Duration (Sec)	Fixations per Min
Double-Portrait Sketch (pencil)	12 min	0.9	13
Brief Sketches (pen)	2 min	1.0	22
Nick—Main Portrait (pencil)	2 min	1.0	22
Luke 2—Secondary Portraits (pencil)	11.5 min	0.9 (st. dev. 0.47)	13
From Photo Sketches (Pencil)	1 min	0.86	26

DISCUSSION

Our study of Ocean at work has shown that his eye movements while drawing a portrait are different from his normal eye movements. While drawing, he made a sequence of regular single fixations on selected details of the model's face (Table 2).

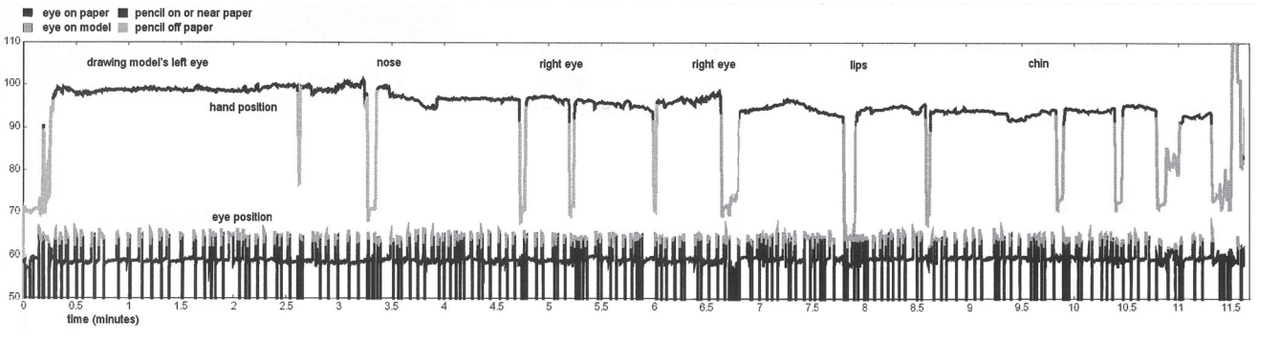
Between fixations on his model, Ocean would look at his drawing with shorter, more rapid fixations or, alternatively, with smooth movements that followed the pencil tip across the paper. Such eye-hand coordination was most dramatically illustrated by the practice sequences, when the pencil stroke was preceded by a rehearsing action just off the paper's surface. When changing his gaze from picture to model, or model to picture, Ocean's fixations were precisely targeted.

In contrast, untrained subjects did not show clear changes in eye movement when drawing; nor did they show precise fixation on individual details of the model.

How then does a skilled painter transform a vision of the external world into a picture on the canvas? The following five remarks help situate our observations of Ocean in the more general context of his way of working.

1. The capture of visual information detail by detail, rather than in a more holistic manner, is reflected in the way the drawing or painting is built up. Each detail and each element is of intrinsic importance. In Ocean's words: "The shape you are putting down is always abstract. . . . That next rhomboid is the side of the nose—or it is an abstract shape. Each bit of the picture has to be able to exist in its own right" [16].

Fig. 4. The complete recording of eye and hand movement when drawing *Luke 2*. The upper graph is the pencil position (actually a calculation of motion through 3D space), color-coded black when the pencil was within 1 cm of the paper and grey otherwise. The eye movements made during this 2-minute interval are shown as well (lower graph). The great regularity of Ocean's eye movements and the periodic pauses in his drawing are apparent.



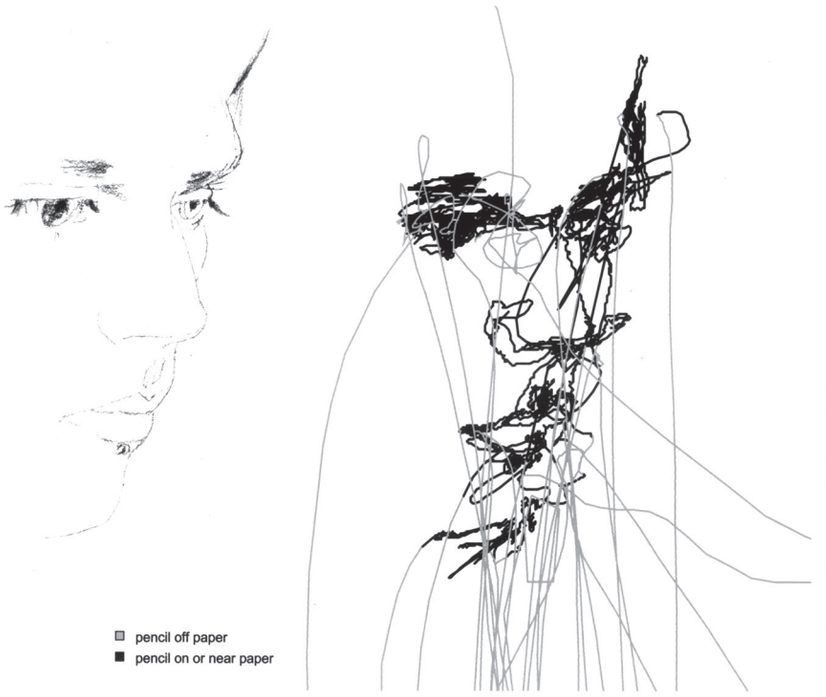


Fig. 5. (left) The portrait *Luke 2.* (right) A computer reconstruction of the pencil motion performed during drawing. Black lines indicate when the pencil was within 1 cm of the paper; grey lines indicate transfer of the pencil to and from the paper surface.

2. The artist's actions are essentially driven by the picture's progress—they are goal oriented rather than, as in his first encounter with his candidate models, stimulus controlled. Each glance at the model is meant to develop whatever he is drawing at the time. Such behavior is quite different from the normal way of viewing a face or a painting. Hence, perceptual and cognitive studies of finished artwork will not necessarily be relevant to the production of pictures.

3. The artist's eye and eye-hand skills are definable in terms of physiological parameters: fixation stability, fixation duration, targeting efficiency, etc. As these patterns were not found in our untrained subjects, one may assume, at this stage at least, that they are acquired through training and practice. Furthermore, with Ocean, they reflect his precision: "If the line lands a millimeter to the right or a millimeter to the left, it changes the weight, in some way, of the shape that it is describing. So when that line lands, you just want it to land in the right position, whatever that is!"

4. Very few lines in Ocean's portraits represent actual lines on the face. Most are subtle demarcations between areas of differing light intensity, texture and color. Not only are their precise locations on the model's face subjective to each viewer, but for the artist, they also depend on what he wants to do with them. Ocean remarked: "I'm sure of what I am seeing, I'm not quite sure what I am going to do about it. So I make a decision. The final result is made up of a great many decisions." The artist's skills allow him to draw with precision whatever line he chooses; the choice of line is determined by other factors.

5. The last observation centers on this choice: undoubtedly Ocean's reaction is dominated by the visual input to his retina. "At any given moment I will start from what I can see from where I am. I try to achieve a likeness. But what I want is a likeness to the reaction I have to something I can see." When he is doing a portrait, his vision concentrates nearly exclusively on the model and the canvas. It is this vision that we have investigated with the eyetracker.

Acknowledgment

The Wellcome Trust provided support for Miall's research, and a Sci-Art grant funded the project.

References and Notes

1. Reviews of existing literature may be found in P.J. Locher, "The Contribution of Eye-Movement Research to an Understanding of the Nature of Pictorial Balance Perception: A Review of the Literature," *Journal of the International Association of Empirical Studies* **14**, No. 2, 143–163 (1996); C.F. Nodine, P.J. Locher and E.A. Krupinski, "The Role of Formal Art Training on Perception and Aesthetic Judgment of Art Compositions," *Leonardo* **26**, No. 3, 219–227 (1993); R.L. Solso, *Cognition and the Visual Arts* (Cambridge, MA: MIT Press, 1994) p. 294.

2. Recent contributions include J. Fish and S. Scrivener, "Amplifying the Mind's Eye," *Leonardo* **23**, No. 1, 117–126 (1990); V.J. Konecni, "Portraiture: An Experimental Study of the Creative Process," *Leonardo* **24**, No. 3, 325–328 (1991); C. Frith and J. Law, "Cognitive and Physiological Processes Underlying Drawing Skills," *Leonardo* **28**, No. 3, 203–205 (1995); D.J. Cohen and S. Bennett, "Why Can't Most People Draw What They See?" *Journal of Experimental Psychology: Human Perception and Performance* **23**, No. 3, 609–621 (1997).

3. See accompanying article by R.L. Solso, "Cerebral Activities in an Expert versus a Novice Artist: An fMRI Study," *Leonardo* **34**, No. 1, 29–32 (2001).

4. J. Tchalenko, "The Making of *Double-Portrait,*" (London: Dulwich Picture Gallery, 1991) p. 4.

5. To an accuracy of 1/25 second, although the start and end of each eye movement were difficult to determine with precision.

6. Strictly speaking, we could only be sure at this stage that the artist was looking at his model, an action that we termed "glance." However, subsequent eyetracking showed that, virtually without exception, each of Ocean's glances was made up of a single fixation.

7. With Ocean, pencil, hand and often also his arm move as a single unit. Thus, the spatial location of the pencil tip can be determined from a marker placed on the back of his hand, as there is little movement between pencil and hand.

8. See glossary for explanation.

9. P. Ekman, *Emotion in the Human Face: Guidelines for Research and an Integration of Findings* (Oxford and New York: Pergamon, 1972).

10. A.L. Yarbus, *Eye Movements and Vision* (New York: Plenum Press, 1967).

11. Yarbus [10]; R.H.S. Carpenter, *Movements of the Eyes* (London: Pion Press, 1988); J.M. Henderson and A. Hollingworth, "High-Level Scene Perception," *Annual Review of Psychology* **50** (1999) pp. 243–271.

12. Ocean nearly always starts a portrait with drawing one of his subject's eyes, working outward to the rest of the face.

13. The eye's fixation point can be estimated to about 2° under these conditions. The fovea, the region of highest spatial acuity on the retina, is about 0.5° in diameter. Hence we cannot be certain that the eye was actually fixating the exact detail twice, but this seems likely, given drawing of the same part often followed each fixation.

14. The human eye makes five main types of eye movement. We mainly considered the rapid gaze shifts known as saccades typical of voluntary eye movement across a scene. The eye can also smoothly track a moving target, to maintain the target image steady on the retina. See R. Dodge, *American Journal of Physiology* **8** (1903) pp. 307–329. In the cases observed here, we believe that the smooth tracking may be a combination of smooth pursuit of the moving pencil and smooth eye movement compensating for small head oscillations (less than 0.6° maximum) synchronous with the hand movements.

15. J.A.S. Kelso, ed., *Human Motor Behavior* (Hillsdale, NJ, and London: Lawrence Erlbaum, 1982); R.A. Schmidt, *Motor Learning and Performance: From Principles to Practice* (Champaign, IL: Human Kinetics Books, 1991).

16. These quotations are from interviews with Ocean to appear in *The Way of a Painter* by John Tchalenko (in preparation).

Glossary

eyetracker—a head-mounted device used to record eye movement by providing a close-up video image of the pupil of one eye.

Fastrak—a motion analysis system, comprising a very weak electromagnetic transmitter mounted on a table top and a small lightweight receiver mounted

on a moving object, capable of recording the position and angle of the object within a sphere with a radius of about 90 cm.

fixation—the eye moves most commonly in brief jumps (saccades), each lasting about 100 milliseconds. In between, the eye steadily views a single gaze position (or if the target is moving, a single object). This act of viewing is referred to here as fixation.

gaze position—the position on the visual scene viewed during a fixation. In these experiments, we consider gaze position to include a single visual detail, although we cannot assess by eye-movement measurement alone how much peripheral visual input is also captured.

resolution—the smallest observable movement of the eye; this is smaller than the spatial accuracy, as only the relative movement of the gaze position, and not its true position, is measured.

saccade—rapid motion of the eye from one position to another, usually lasting between 50 and 150 milliseconds and typically occurring 2–3 times per second.

spatial accuracy—the accuracy with which gaze position can be estimated, with respect to the actual gaze position.

Chris Miall studied zoology as an undergraduate and graduate student at Imperial College, London. He has since worked as a research scientist in the study of neural control at Oxford University and various other institutions. Since 1994 he has been a Senior Research Fellow for the Wellcome Trust, and he is a University Reader in Neuroscience. His research focuses on the role of the cerebellum in the guidance of movement.

John Tchalenko studied geology and civil engineering and has lectured in seismotectonics at Imperial College of Science in London, where his research specialized in Near Eastern earthquakes. He came to films in 1975 via the National Film and TV school and directed a number of broadcast films on science and art subjects. His collaboration with Humphrey Ocean started in 1991 with "Double Portrait," which preceded the present "Painter's Eye" project. At present he is head of the Drawing and Cognition research section at Camberwell College of Arts, London.

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