Art, Aesthetics, and the Brain

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Raphael Rosenberg and Christoph Klein

5.1 Gaze movements as a literary model in art history

Gaze movements have been an issue in the history of art long before they became a research topic in psychology. Early evidence dates back to the sixth century, when in 553 the Byzantine historian Procopius of Caesarea described how the interior space of the Hagia Sophia (Istanbul) overwhelms the beholder:

> each detail attracts the eye and draws it on irresistibly to itself. So the vision constantly shifts suddenly, for the beholder is utterly unable to select which particular detail he should admire more than all the others. But even so, though they turn their attention to every side and look with contracted brows upon every detail, observers are still unable to understand the skilful craftsmanship. (Procopius 1940, pp. 23–5)

In the course of early modern times, reflexions on gaze movements have significantly increased in writings about art, and they were repeatedly used to justify aesthetic qualities. In the 1460s the Florentine architect and sculptor Filarete explains the superiority of the round arch over the gothic pointed arch by referring to the eye movements it induces:

> It cannot be doubted that nothing which impedes the sight in any way is as beautiful as the one that leads the eye rather than restraining it. Such is the round arch. As you have noticed, your eye is not arrested in the least when you look at a half-circle arch . . . The pointed is not so, for the eye, or sight, pauses a little at the pointed part and does not run along as it does on the half circle. (Filarete 1972, pp. 230–1, translation by the authors)

Denis Diderot, the French philosopher who was also a founding father of art criticism, went significantly further. In 1767, comparing two altarpieces by the painters Gabriel François Doyen and Joseph-Marie Vien, he drew an explicit link between the composition of paintings and the gaze of the beholder. For Diderot, composition is an instruction to the eye, a path which the gaze follows in a certain order. He describes Vien's painting (Figure 5.1) as follows:

> Such is the path followed in perusing this composition, Religion, the angel, the saint, the women at his feet, the listeners in the background, and those in the left background, the two tall standing female figures, the elderly man leaning forward at their feet, and the two figures, one a man and the

> other a woman, seen from the back and placed squarely in the foreground, this path descending gently and meandering . . .; a line of liaison that clearly, crispy, and effortlessly links the composition's principal features. (Diderot 1995, p. 29)

For Diderot, Vien's painting is an example of a beautiful "line of liaison" whereas he finds Doyen's piece (Figure 5.2) very poor in this regard:

> In every composition there's a path, a line . . . If this line, which I call the line of liaison, bends, folds over onto itself, twists, is agitated, if its circumvolutions are diminutive, multiple, recti-linear, and angular, the composition will be ambiguous and obscure; the eye, wandering at random through a labyrinth, bewildered, will find it difficult to grasp the connections . . . If it is broken, the composition will have empty spots, holes . . . Doyen's Miracle of Saint Anthony's Fire is not above reproach in this respect: its line of liaison is fractured, bent, folded, and twisted. It is difficult to follow; sometimes it's ambiguous, or comes to a sudden halt, or requires considerable indulgence from the eye that's trying to follow its course. A well-ordered composition will always have but one true line of liaison; and it will serve as guide to anyone looking at it as well as to anyone attempting to describe it. (Diderot 1995, p. 152)

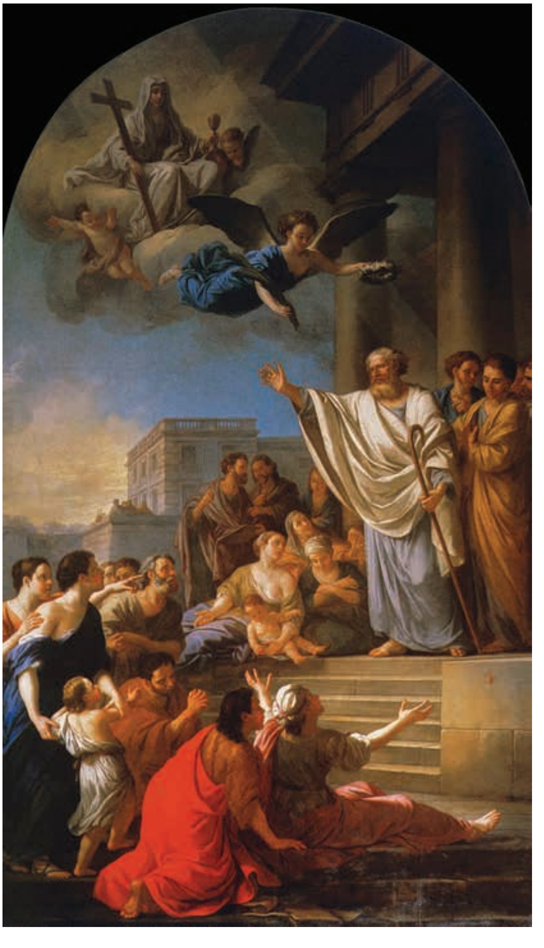


Figure 5.1 Joseph-Marie Vien, *St. Denis Preaching in Gaul*, 1767. © The Art Archive / Collection Dagli Orti.

Figure 5.2 Gabriel François Doyen, *The Miracle of Saint Anthony's Fire*, 1767.

As an academic discipline, art history was established in the middle of the nineteenth century; the language it used was based on much older writings about art. The idea of the movement of the eye as related to the aesthetic and the structure of the work of art was to remain an important paradigm of this new discipline. Some art historians thought that stylistic differences between artworks of different times and places were due to changes in the behavior of the eye. Thus in 1899, Heinrich Wölfflin, one of the most influential art historians in the early twentieth century, explains the difference between the Italian arts of the early Renaissance—that is, the fifteenth century—and the High Renaissance of the early sixteenth century by the eye's need to relax:

> The Quattrocento placed unbelievable demands on the eye. The viewer not only has the greatest difficulty in picking out individual physiognomies from the serried ranks of heads but the figures are only discernible in fragmentary form. . . . By contrast, what great ocular satisfaction there is to be derived from the compositions of Raphael with the many figures. (Wölfflin 1899, p. 292, translation by the authors)

In 1912, Wilhelm Waetzoldt, who later became director-general of the State Museums in Berlin until the Nazis removed him from his post, explained the differences between the Italian and the German/Dutch style in Renaissance art as having a basis in national differences in the eye's aptitudes:

> Italians have an architectural-plastic talent accustoming the eye to trace the form of things, to see each individual figure in space and to ascertain the physicality of a thing by scanning it with the eye. . . . The Italian vision isolates, the vision of Dutch people and Germans connects; the former is used to the mobility of gaze, the latter to the quiet-looking eye. (Waetzoldt 1912, p. 211ff., translation by the authors)

Perception remained a central topic in art history throughout the twentieth century. On the one hand, the idea of the eye following the composition of artworks was sustained. On this basis, the art historian Kurt Badt (1961), for instance, developed a general method for the interpretation of paintings, insisting that the path of composition normally begins—and should begin—at the lower left-hand corner of pictures (Rosenberg 2014). On the other hand a more general, though sometimes rather metaphorical discussion about "cultures" of perception, also addressed as "scopic regimes," figured prominently not only in art history but also in visual culture studies, a new discipline which emerged from this very discussion in the 1990s (Foster 1988; Volkenandt 2011).

In speculating about the eye movements of virtual beholders, art critics and art historians touched upon a field that would later evolve as a central method in psychology: the recording of gaze movements to investigate cognitive processes. Psychological advances were made possible by the description and by recordings of the saccadic nature of eye movements by ophthalmologists since the end of the nineteenth century (see section 5.2), but art historians did not take note of it for over 100 years (first discussions appeared in Frangenberg 1990, p. 144ff; Baxandall 1994, p. 413; Clausberg 1999; Rosenberg 2000, p. 49ff; Giuliani 2003, p. 27ff.).

In the following sections we will introduce the measurement of gaze movements as a prominent psychological technique and outline its neural bases and relationships with visual attention before reviewing what we have learned so far about eye movements of the beholders of paintings from experiments.

5.2 Analysis of gaze movements as a psychological method

5.2.1 Overview

Gaze movements are basically alternations between periods of the eyes remaining relatively stationary, which we call "fixations," and shorter periods of greater mobility, which we call "saccades" (from the French word "saccade" meaning "jerk") (Figure 5.3). This was described for the first time in 1879 by Javal and Lamare (Javal 1879).

Two decades later, Erdmann and Dodge reported the first successful attempt to record and measure eye movements empirically (Erdmann and Dodge 1898). Not only did this pioneering technological work lay the foundations for eye-movement research in clinical populations (Klein and Ettinger 2008), but it also opened the field for experimental

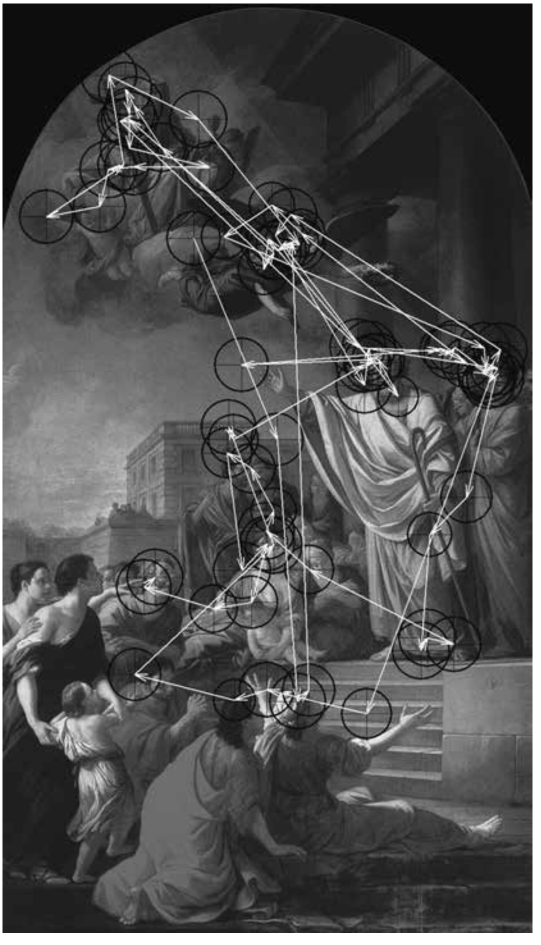


Figure 5.3 Saccades (white arrows) and fixations (black circles) of a beholder whilst viewing Vien's painting (*St. Denis Preaching in Gaul*, 1767) for 20 s. Adapted version: © Laboratory for Cognitive Research in Art History, University of Vienna.

psychological eye-movement research (Wade and Tatler 2005). Nowadays, the study of gaze movements figures prominently in basic and applied psychological research. In basic research, gaze movement analyses have been used to study interactions between covert and overt attention processes (e.g. Henderson et al. 1989; Hoffman and Subramaniam 1995), reading (Henderson and Fereira 1993), problem-solving processes (Grant and Spivey 2003; Knoblich et al. 2009), exploration of geometric patterns (Manor et al. 1995; Noton and Stark 1971c), the study of faces (Mertens et al. 1993), film watching (Smith 2014), visual processing of media (Bucher and Schumacher 2012), the analysis of visual scenes (Rayner et al. 2009), and in paintings. In applied research, gaze movements have been used to study, for example, product designs (Carbon et al. 2006), and print advertisements (Pieters et al. 1999), to construct human–computer interfaces (Jacob and Karn 2003), to investigate processing of social situations in autistic patients (Klin et al. 2009) and problem-solving strategies in patients with Parkinson's disease (Hodgson et al. 1999), and first-episode schizophrenics (Huddy et al. 2009).

5.2.2 Measurement of gaze movements as a distinguished method in psychology

There are at least three reasons for the popularity of eye movement recordings in psychological research: importance, immediacy, and versatility. Gaze movements are *important* to investigate because the ocular-motor system is doubtlessly the most used system among the sensory-motor systems in primates, supported by an extensively distributed functional neural system that is currently better understood than any other functional system of the primate brain. Due to the anatomy of the eye, this system's effects can be investigated with an unmatched degree of *immediacy*, both psychologically and technically. As there is only one small spot of highest visual acuity on the retina, the fovea centralis, both the exploration of the visual world and our responses to its changes require our gaze to move as a series of fixations and saccades which, together, provide the best available model of the structure of human consciousness unfolding in space and time. The final virtue of eye movement studies is the *versatility* of their application in all kinds of basic as well as applied scientific settings—from everyday situations (e.g. Hayhoe and Ballard 2005) to the narrow setting of a funcational magnetic resonance imaging (fMRI) scanner—and experimental paradigms.

5.2.3 Fixations and saccades

The analysis of gaze movements crucially hinges upon (a) the definition of fixations and saccades, and (b) the method of their grouping. We will explain the definitions in the following, and discuss methods of grouping in section 5.4.

Regarding the definition of fixations, if we assume that there is a *continuum* between "*fixation*," considered as periods of relatively stationary gaze that are characterized by the presence of micro-saccades (or "fixation saccades"; plus drifts), and "*exploration*," considered as periods of relative gaze mobility that are characterized by the presence of larger-amplitude saccades (and drifts) (Otero-Millan et al. 2013), the definition of fixations in terms of degrees of displacement of the eye is to some degree arbitrary. Similarly ambiguous is the question as to what minimum duration a so-defined fixation should have, as this parameter is likely to be different for different kinds of tasks and different individuals.

Accordingly, various definitions of fixations have been suggested in different domains of the literature, but these have been rarely compared empirically (see Manor and Gordon 2003). Typically, periods of relative gaze stationarity of at least 200 ms are considered as fixations. However, this definition has been based on early reading studies and may thus be inappropriate for other visual tasks that use visual stimuli that are more complex or less complex than words. Extracting the gist of a complex scene, for instance, takes less time (40–100 ms) than analysing it (with minimum fixation durations of 150 ms; Rayner et al. 2009). Fixations during reading also take at least 140 ms according to McConkie and colleagues (1992; but see Liechy et al. 2003). Westheimer (1954; but see Manor and Gordon 2003) reported intervals between successive saccades of 150 ms. Similar values, ranging between 100 ms and 200 ms have been reported in later studies (van Diepen et al. 1995; Harris et al. 1988; but see Manor and Gordon 2003). Russo and Rosen (1975) used minimum fixation durations of 200 ms to investigate gaze movement patterns during a reading and selection task. Even longer fixation durations, say, of 320 ms for the analysis of geometric stimuli (Manor et al. 1995) have been reported as well. This latter figure corresponds well with the average fixation duration of about 320 ms which we found for the participants of our study, irrespective of the painting they viewed (unpublished work).

Fixation durations, however, not only differ between situations but also between individuals, and within individuals. Furthermore, speaking about the painting reduced fixation durations by about 40–50 ms (Klein et al. 2014). And inter-individual fixation durations varied greatly between 200 ms and 800 ms, with a preference for 250–400 ms (Mertens et al. 1993).

One of the few studies that empirically investigated the impact of different fixation definitions on gaze movement parameters was published by Manor and Gordon (2003), who compared different fixation thresholds. Comparing 200 ms and 100 ms thresholds, this study reported significant increases in the number of fixations, total fixation duration, and scan path length (defined as a continuous line drawn through consecutive points of fixation), as well as significant decreases in average fixation duration for geometric and face stimuli. Particularly noteworthy here is the association of the shorter fixation threshold with increased scan path lengths, underlining the perceptual–cognitive significance of this relatively short (100 ms) fixation threshold. Also, schizophrenic patients could be more accurately discriminated on the basis of 100 ms as opposed to 200 ms fixation thresholds in showing less fixations and shorter scan paths, as well as longer overall fixation durations. Fixation parameters may differ according to stimulus types. Manor and Gordon (2003) compared face stimuli and geometric figures of the Rey–Osterrieth complex figure type and found more numerous and shorter fixations for face stimuli, independent of fixation threshold (100 ms or 200 ms).

Assuming again that fixation-related saccades and exploration-related saccades lie on a continuum and thus follow the same “main sequence” (Otero-Millan et al. 2008); that is, the positive function relating the amplitude of saccades to their peak velocities (which holds for saccades 0.03–50° in amplitude: Becker 1989), it is clear that the amplitude of saccades that are typically observed whilst participants are presented with various kinds of eye movement tasks on a computer screen are easily determined by their velocity curves and an arbitrary or calibration-based onset/offset criterion (e.g. 20° per s or 20 per cent of the amplitude of the velocity curve; Klein and Foerster 2001).

In such situations, saccades are easily recognizable as stepwise, discontinuous eye movements. It has been estimated that humans execute about 200 000 saccades per day (but see Fischer 1999). During these ballistic eye movements the eyeball reaches peak velocities of more than 400° per second (Fischer 1987; cf. Manor and Gordon 2003). Saccades are characterized by abrupt eye movement onsets with accelerations of up to 30 000°/s^2, peak velocities of 400–600°/s, and an almost instantaneous termination of the movement (Becker 1989). While at least seven different classes of saccades can be distinguished (see Becker 1989), *re-fixation saccades*, directed at objects that are selected beforehand from the environment, are of primary interest here. Such re-fixation saccades are frequently inaccurate and do not hit their target accurately; as a consequence, corrective eye movements, either glissades or corrective saccades, follow. The amplitude of the primary saccade may be too small ("undershoot") or too large ("overshoot"). Undershoots prevail in the execution of large amplitude saccades (Fioravanti et al. 1995) and are followed by secondary "corrective" saccades as the second part of a pre-programmed two-step sequence (Becker and Fuchs 1969).

5.2.4 Physiological and neural basis of fixations and saccades

The visual system of primates has been investigated very intensively. Light enters the eye through the pupil and reaches two types of photo-receptors on the retina, rods processing dim light and cones processing bright light and colors. These photoreceptors accomplish a transduction that translates light information from a spotlight into an electric signal. The central fovea, a roughly 1.5 mm small area located about 5° temporally to the visual axis, contains the highest density of cones and thus enables the most precise viewing. The axons of about a million ganglion cells leave the eye through the blind spot, form the optic disc, and transmit their neuronal information via the optic nerve, passing the optic chiasm and the optic tract to reach the lateral geniculate nucleus of the thalamus and from there the primary visual cortex (V1) and further the visual association cortices (V2–V5). From these association cortices the visual information spreads out to be processed by a complex system of cortical and sub-cortical areas. It is important to note that the central fovea covers only less than 1 per cent of the retinal area but projects to a large portion of the visual cortex to process visual information coming from the central 2° of the visual field. These mere anatomic conditions highlight two important functional aspects of the visual attention—its anatomically "embodied" selective nature and its close link with the continual alternation between fixations and saccades to (re)construct the visual outer world.

The brain structures involved in "fixations" and "saccades" overlap to a large degree. This overlap can be expected by *a priori* reasoning under the aforementioned assumption of a continuum between fixation-related and exploration-related saccades. These structures include: (a) the frontal eye fields (Bruce and Goldberg 1985; Bruce et al. 1985); (b) the supplementary eye field (Bon and Lucchetti 1990; Schall 1991); (c) parts of the parietal cortex (Robinson et al. 1978; Andersen 1989); (d) the substantia nigra of the basal ganglia (Hikosaka and Wurtz 1983); (e) the superior colliculus (Dorris and Munoz 1998; Schiller and Stryker 1972); and (f) regions in the brainstem (Paré and Guitton 1994; Bruce 1990).

While the functional system involved in gaze movements during the contemplation of visual art is already complex, it is by no means exhaustive with respect to the complexity of processes that are supposed (Leder et al. 2004) and can be experienced subjectively during the contemplation of paintings.

5.3 Visual attention and gaze movements

The (functional) anatomic and neural features of the visual system outlined in section 5.2 not only underline the fact that the visual system is a system of information selection; they also indicate that visual attention unfolds in space and time as a continual alternation between fixations and saccades (or "fixation-related" and "exploration-related" saccades), which we will henceforth call "gaze movements." Decades of experimental research with human and non-human primates have scrutinized these intricate relationships between visual attention and gaze movements (recently reviewed in Kowler 2011) in order to address—among others—two questions of fundamental importance: how do "top-down" and "bottom-up" factors interact; and what is the relative importance of low-level stimulus features (in particular, contrast, color, and motion) as opposed to higher-level stimulus structures (in particular, objects or gist; Einhaeuser et al. 2008)?

With regard to the importance of low-level features, Koch and Ullman (1985) have suggested that locations within the visual field that exhibit relatively high physical salience are more likely to be attended and fixated. According to these authors, visual scenes contain spatial distributions of local contrasts of luminance, color, or movement that can be described in "saliency maps" and are processed in early stages of visual information processing. On the one hand, the concept of saliency maps is certainly theoretically intriguing and straightforward in predicting the locations of fixations better than models that posit random fixation locations (Foulsham and Underwood 2008). On the other hand, empirical research has shown that many further factors co-determine gaze positions and that these factors are more "top-down" than "bottom-up." Such factors include strategic decisions to optimize task performance such as looking at locations that maximize the probability of finding a searched target (Najemnik and Geisler 2005), or looking near the center position in a scene to identify large portions of the scene with this single optimal viewing position (Tatler 2007). Another top-down factor is specific interests that direct the gaze to relevant areas of the visual field (e.g. looking at eyes and heads in social scenes to extract relevant social information; Birmingham et al. 2009). Similarly, interesting objects may attract the allocation of attention and fixations better than the perceptual saliency of an area of the visual field (Einhaeuser et al. 2008). Also, specific tasks can strongly impact which information participants select when looking at visual scenes; this includes the contemplation of paintings as well and will be discussed in the following section.

Such bottom-up and top-down factors, rather than being mutually exclusive, are likely to interact. This was demonstrated, for instance, in Cerf and colleagues' (2008) study, which reported an improved prediction of gaze positions when the combined influences of top-down face preference and bottom-up low-level saliency were considered. These examples thus show that visual attention is controlled both by exogenous bottom-up processes of perceptual saliency and endogenous top-down processes (Chica et al. 2013).

That visual attention unfolds in space and time suggests that it is the *sequencing of saccades* during the exploration of visual scenes (rather than an individual fixation or an individual saccade) that requires scientific investigation. In this regard, Kowler (2011) has pointed to two principles that seem to rule the sequential selection of saccadic goals. According to the "winner-takes-all" principle, the area of the visual field that momentarily exhibits the highest "strength" (e.g. saliency, interest value) attracts visual attention. According to the "inhibition of return" principle, however, the selected area quickly (within a few hundred milliseconds) loses its "strength" to other areas to be fixated as the new "winners." It is important to note that during such sequences of saccades to different fixation locations, the proper eye movements as manifestations of overt visual attention are *preceded* by movements of covert visual attention to the location that is to be fixated next (Henderson et al. 1989). While the movements of covert and overt visual attention are temporally staggered, they are spatially isomorphic as it has been shown that it is impossible to orient attention (covertly) to one location while moving the eyes to another (Hoffman and Subramaniam 1995).

Gaze movements as the sequence of fixations and saccades to new locations generate scan paths across a stimulus of interest (Liechty et al. 2003). Such scan paths were first described by Noton and Stark (1971a, 1971b, 1971c), who showed that when participants looked at visual patterns their gazes repeatedly created a fixed series of fixation locations, the “scan path,” that was characteristic for an individual participant. Noton and Stark also found that different scan paths were created by different individuals for the same pattern, and different scan paths by the same individual for different patterns. Interestingly, these scan paths remained consistent across different presentations of the same stimulus to the same participant and were even replicated when a previously scanned stimulus was removed and had to be imagined. The apparent existence of an ocular-motor “memory” of an individual stimulus certainly stands as among the most compelling evidence of top-down factors in gaze movements.

Gaze movements as alternations of fixations and saccades seem to be governed by two different states of visual attention, according to Liechty and colleagues (2003). During states of *local visual attention* and under the presumed control of the inferior temporal cortex, information is extracted from specific and proximal locations by means of short saccades. Conversely, during states of global visual attention presumably influenced by the posterior parietal cortex, long saccades are employed to integrate information from distal locations. According to Liechty and colleagues (2003), the interaction between temporal/local and parietal/global states is controlled by the prefrontal cortex.

To summarize, the fact that only a very small area of the retina provides the best visual acuity requires visual attention to unfold as gaze movements. The dynamics of gaze movements are co-determined by perceptual bottom-up factors as well as cognitive or motivational top-down influences, governed by principles that regulate how a fixation location is selected and then abandoned as a new location is chosen, and may switch between local and global states of visual attention.

5.4 Gaze movements during the beholding of paintings

5.4.1 History of research

What do we do when we behold works of visual arts? Given the central role of the ocular system in this process and in the light of the emphasis of gaze movements in literature on art (section 5.1), eye tracking is logically among the foremost methods used to investigate this field. However, although the first comprehensive research dates back to the 1930s, the number of investigations into this area has remained rather limited.

The psychologist Guy T. Buswell (1891–1994) accomplished the first in-depth studies on how people look at paintings and published the only book to-date about eye tracking and art perception (Buswell 1935). He recorded gaze movements of children and adults, of art experts and lay persons, of American and "Oriental" subjects looking at reproductions of works of art (paintings, drawings, prints, sculptures, buildings, applied arts) various in cultural origin, color, design, and balance, and the amount of detail incorporated. He included silhouettes and pictures with outline drawings as well as partly unfinished paintings. Compared to present day eye trackers, Buswell's device was cumbersome for the experimental subjects and the data it provided were extremely time-consuming to analyse. However, he did manage to collect a total of 1877 records from 200 different individuals looking at different pictures for several tens of seconds at a rate of 30 measurements per second.

Buswell thoroughly addressed most of the questions that research in this area eversince investigated. His main chapters—"The Duration of Fixation Pauses," "Variations in Perception Related to Characteristics of the Picture," "Variations in Perception Related to Characteristics of Individuals," and "Variations in Perception Due to Directions for Looking at Pictures"— follow a systematic order that we have adopted for the headings of the present section. Buswell and his collaborators at the University of Chicago were technically innovative, thoughtful in the design of their studies, and very rigorous in their methodologies. However, their overall conclusions are rather sobering. A contemporary reviewer noticed in the *Burlington Magazine*: "Our admiration for the ingenuity of Professor Buswell's apparatus and the heroic laboriousness of his experiments and calculations may be a little tempered by our disappointment at noticing that nothing of the slightest importance to the sciences of aesthetics or psychology seems to result from this research" (Thouless 1936, p. 58). In retrospect one may say that Buswell's rather flawed general results were due to technical limitations. Buswell (1935, p. 90) would have loved to investigate longer periods of beholding, especially with experts, but for technical reasons this was not feasible. In addition, without electronic data processing his capacity for a comparative analysis of the huge amount of recordings was very restricted. Longer measurements of gaze movements when viewing images were first carried out by the Russian psychologist Alfred L. Yarbus (1914–1986). Some of the stimuli used by Yarbus were works of art. However, the topic of his seminal book was "Eye Movements and Vision" in a broader sense. He did not focus solely on art as Buswell did.

Due to the very nature of art, the essence of which withstands any bold attempts at manipulation without being destroyed, and to the difficulty of offering aesthetic experiences in the cool atmosphere of a laboratory, scant proper experimental research has been accomplished regarding viewing visual art. Approaches that do not manipulate the painting to be viewed and which measure paintings in their original contexts are the most appropriate, but most studies were governed by the technical feasibility of eye trackers. Only a few studies have as yet been conducted in museums rather than in labs, and the limitations imposed on the subjects by wearing eye trackers are not negligible (Heidenreich and Turano 2011; Kapoula and Lestocart 2006). Worth bearing in mind too is that the time taken to look at artworks used to be quite short. The average time taken in most experimental settings was less than the mean time of 27.2 and median of 17.0 seconds, a period which general visitors were found to spend looking at paintings at the Metropolitan

Museum (Smith and Smith 2001), and was much less than the time art experts would consider as sufficient to have an aesthetic experience (Massaro and colleagues (2012) is a recent example using a viewing time of 3 s). We assume that it can take several minutes to enjoy a work of art fully and to experience the aesthetic values of a painting that one does not know. The viewing time of experts such as artists or art historians, especially when speaking in groups with each other, can often last for several minutes, sometimes more than an hour, including alternating phases of silent contemplation and discussions about the artwork under consideration. In an interdisciplinary project between departments of art history and psychology we sought to overcome these limitations as far as technically possible. In a first study at the University of Heidelberg we recorded the gaze movements of 99 participants who were presented four facsimiles of paintings, looking at each for 15 minutes. The paintings had been reproduced in (almost) original size with the best photographic techniques currently available, were mounted with appropriate frames, and hung on the wall of an otherwise "neutral" room that, in terms of art exhibitions, would be defined as a "white cube." We used a head-mounted eye tracker with an electromagnetic-positioning system (SMI® IViewX HED-HT) that allows the participant to move within a radius of about 120 cm (Klein et al. 2014). In a later series of recordings at the University of Vienna, subjects looked at high-quality digital reproductions of paintings on a high-resolution screen (Apple® 30" 2560 × 1600 pixel) at a distance of about 90 cm, each for two minutes. Their gaze movements were recorded without any physical contact between subjects and the device (remote eye tracker SMI® IViewX RED 120). From the binocular recordings we processed the data recorded of the dominant eye of every subject (Brinkmann et al. 2014).

5.4.2 Variations of gaze movements during the time lapse of beholding

Eye tracking enables a precise description of the time lapse during the viewing of paintings, and this was always a central issue in eye-tracking studies about art. One of the chief findings of Buswell (1935) was that the duration of fixations tends to increase during the course of viewing. He differentiates two "general patterns of perception" within the first 10–15 seconds—a first phase of general survey with shorter fixations followed by a phase of more detailed study with longer fixation durations and (shorter) saccades concentrated over small areas of the picture. The major distinction between these patterns of perception has been confirmed and elaborated several times, among others by Berlyne (1971), Antes (1974), and more recently by Liechty and colleagues (2003) (see section 5.3), Locher (2006), and Locher and colleagues (2007) in the light of cognitive theories. Molnar (1981) accepted this distinction as well but tried to also distinguish a third "kind of exploration" with distinct patterns of the duration of fixations and of the length of saccades. He thought that these patterns also depend on the complexity and style of the painting, but he failed to give sufficient experimental evidence for his supposition. Our own studies, which for the first time consider much longer periods of time, endorse Buswell's findings and underline that there is a significant inter-individual variability in the duration of fixations, in the length of saccades, and in the sequence of different patterns of perception. The most significant average changes to the duration of fixations and the length of saccades occur in the first seconds of viewing. However, repeated alternations of patterns of perception, oscillating between general survey and detail study continue for at least 15 minutes. Within the first few seconds, the average duration of fixations significantly increases. In the following minutes the slope of the curve becomes rather flat but the increase in duration of fixations endures. We interpret this as indicating a deeper perception that can be arguably related to aesthetic experience. This would confirm a study by Molnar and Ratsikas (1987), where a group of beholders that were asked to judge the aesthetic qualities of the picture had clearly longer fixations than another group of beholders who were simply asked to describe what they saw.

5.4.3 Variations of gaze movements related to paintings

Buswell (1935) demonstrated that gaze movements meet common assumptions made in art literature (such as those reported in section 5.1) only in some respects. His numerous eye-tracking graphs make clear that the eye hardly ever moves systematically along a composition line from one end to the other. Nevertheless, Buswell's work provided important indications as to the relationships between gaze movements and pictures. He showed that every picture has specific centers of interest that attract a higher density of fixations than other areas (Buswell 1935, pp. 18–24). Regarding gaze movements, his results were very restricted and his analyses limited to the two initial saccades and to three images showing mainly vertical lines (interior of a gothic church), mainly horizontal lines (Library of the Oriental Institute of the University of Chicago), and lines following the direction of a wave (Hokusai, *The Wave*). He states that his results were "quite in accord" with the general assumption "that the eye will follow the direction of the principal lines in a picture" (Buswell 1935, pp. 79 and 82). Yarbus (1967, pp. 171–96) published single recordings of subjects viewing reproductions of landscape paintings for up to 30 minutes. Probably due to technical reasons, those visualizations only show a portion of the total fixations and saccades. However, they are revealing since they make clear that while beholding the same painting for many minutes the subject's eyes repeat the same movements—Yarbus talks about individually specific "cyclical patterns." Molnar (1981, 1992) came to similar conclusions, and described these visualizations using statistical methods as follows: the transition probability between the areas of interest of two paintings (by Titian and Manet) reached a stable state after just 20 or 25 saccades. Like the "scan paths" described by Noton and Stark (1971a, 1971b, 1971c, and see section 5.3; but see Mannan et al. 1997; Krieger et al. 2000), those findings were related to single spectators.

In our studies (Rosenberg et al. 2008; Engelbrecht et al. 2010; Brinkmann et al. 2014; Klein et al. 2014; Rosenberg 2014) we have meanwhile shown 57 paintings from different epochs (fifteenth to the twentieth centuries) and different genres (history paintings, portraits, landscapes, still life, abstract art). The viewing time was either 2 or 15 minutes and the number of participants varied between 10 and 99. Taken together, our studies confirm Buswell's conclusion that most paintings have specific centers of interest with significantly higher densities of fixations (Figure 5.4). This is hardly the case for paintings such as

(a) (b)

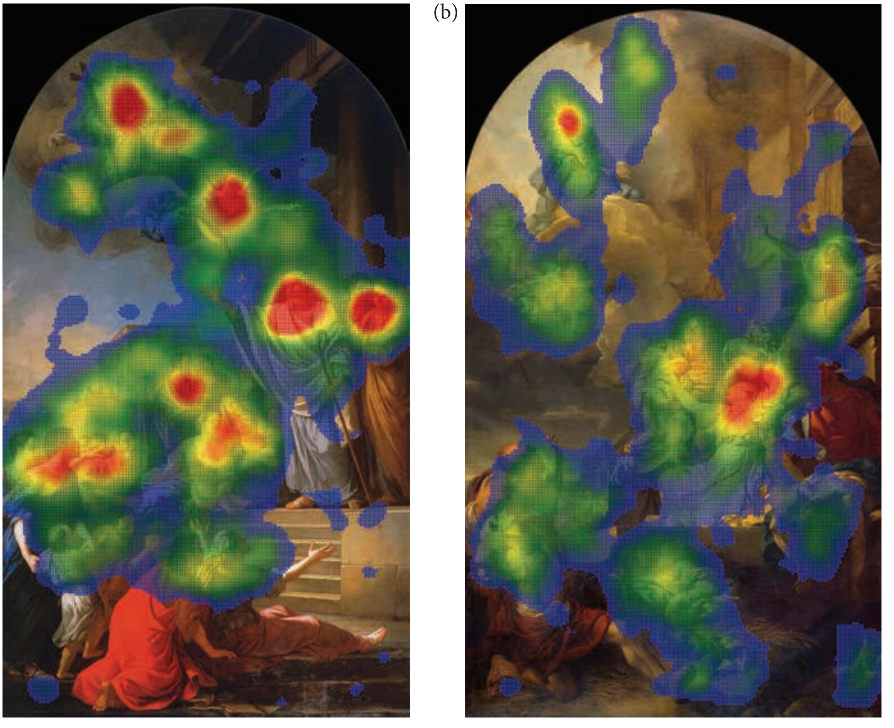


Figure 5.4 Heat maps of fixations of 40 viewers (20 art experts and 20 non-experts) looking at Vien's (a, *St. Denis Preaching in Gaul*, 1767) and Doyen's (b, *The Miracle of Saint Anthony's Fire*, 1767) paintings for 2 mins each. Adapted versions © Laboratory for Cognitive Research in Art History, University of Vienna.

Jackson Pollock's drippings (Figure 5.5), however, where the artist intentionally avoided a hierarchical composition, and denied as much as possible any distinction between figure and ground, resulting in no single zone with enough fixations to be red in the heat map.

For a significant number of paintings and despite major differences between subjects, not only fixations but also saccades build patterns that are specific to each painting: Beholders tend to reiterate particular paths with their eyes. This is evident when the saccades of different viewers are superimposed (see Figure 5.6a and 5.6b, with a reduction to 10 per cent of all saccades to reduce confusion). Hence we conclude that the "cyclical patterns" observed by Yarbus (1967) do not only occur for single subjects but are very similar for different subjects viewing the same painting as long as they do so for longer stretches of time.

We have developed different methods to determine whether and how saccades repeat specific paths: "Frequent cluster transitions" show the spots (clusters) with the highest density of fixations and the often-repeated saccadic transitions. We thereby define clusters of fixations as circular regions of a given diameter (here 90 pixels) containing more than a certain amount of fixations as per minute rate (for an alternative definition of fixation clusters see also Santella and DeCarlo 2004). An algorithm calculates the

(a)

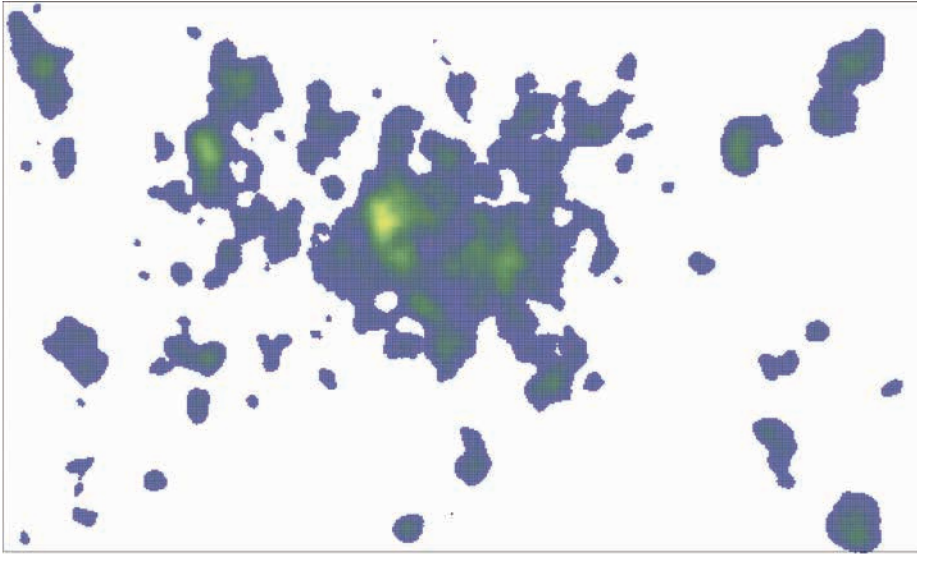

(b)


Figure 5.5 (a) Jackson Pollock's *Convergence*, 1952, and (b) heat map of fixations of 40 viewers (20 art experts and 20 non-experts) viewing this painting for 2 mins each. Albright Knox Art Gallery/Art Resource, NY/Scala, Florence. © The Pollock-Krasner Foundation ARS, NY and DACS, London 2015. Part (b) © Laboratory for Cognitive Research in Art History, University of Vienna.

amount of saccadic transitions between the fixations of those clusters. In Figure 5.7a and 5.7b we visualize all transitions repeated at least 0.5 times per minute. The width of the lines between the clusters encodes the frequency of saccades, with more frequent transitions resulting in greater width. Color can be used to encode the direction of saccades.

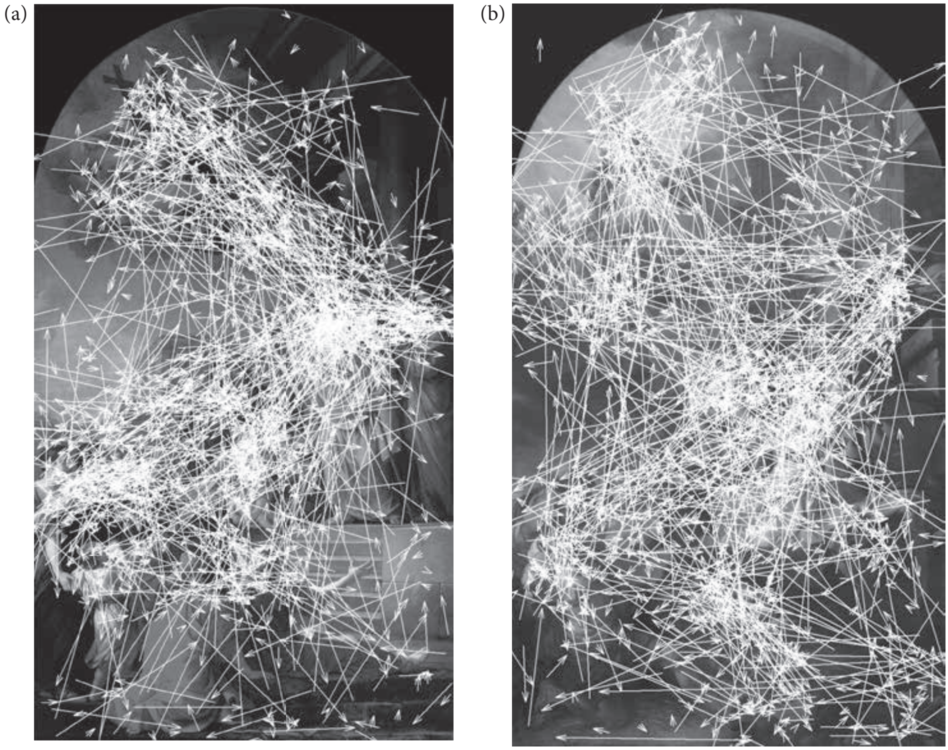


Figure 5.6 10 per cent of all saccades of 40 viewers (20 art experts and 20 non-experts) beholding Vien's (a) and Doyen's (b) paintings for 2 mins each. Adapted versions: © Laboratory for Cognitive Research in Art History, University of Vienna.

The visualizations of gaze movements (see Figures 5.3, 5.6a and 5.6b) show that Diderot's analyses (section 5.1)—as well as similar claims recurring in the art historical literature—do not match the real dynamic of the eye. The gaze jumps from fixation to fixation, moving forth and back. Eyes do not follow any line of composition in a continuous manner, nor do beholders scan paintings from top to bottom or left to right continuously. In addition, the general assumption of art historians (Badt 1961; Wölfflin 1941) that viewers' eyes predominantly move from left to right—as when reading—when looking at European paintings is empirically incorrect since the average direction of saccades between most clusters of fixations tends to be balanced in all the paintings we have studied to date.

However, the analysis of average eye movements, both for fixations (Figure 5.4a and 5.4b) and saccades (Figure 5.7a and 5.7b), reveals that several aspects of Diderot's text are indeed correct: viewers concentrate much longer on certain parts of Vien's painting (greater amount of red areas in the heat map), whereas their fixations are more scattered when looking at Doyen's piece. This corresponds with Diderot's description of the differences between those altarpieces. His description of a line of composition in Vien's altarpiece is correct as long as we consider the frequently repeated saccades and not the actual

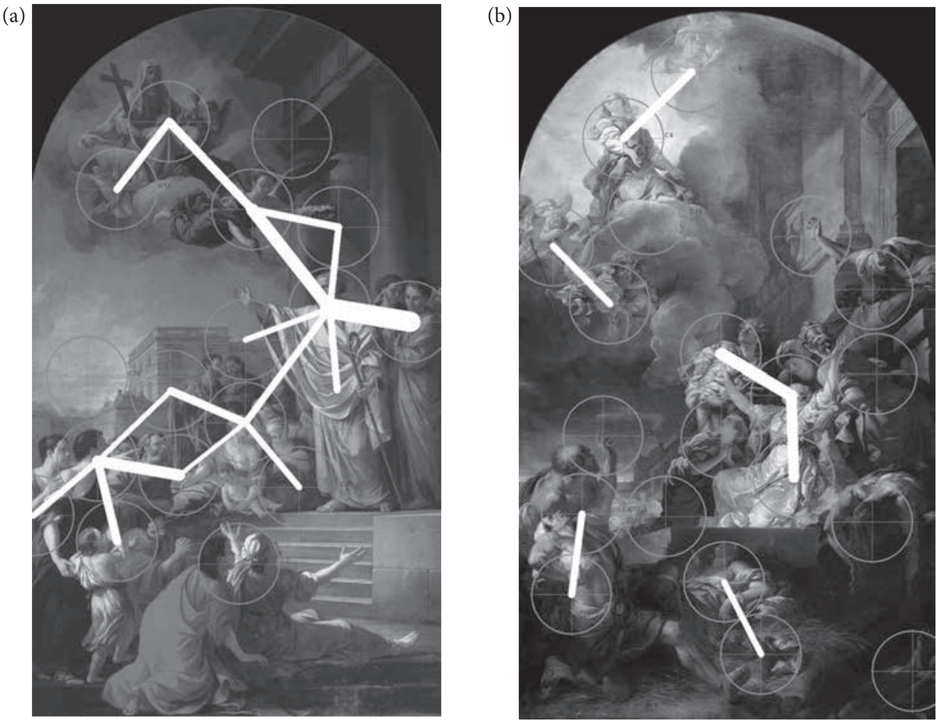


Figure 5.7 Frequent saccadic transitions between fixations clusters for Vien's (a) and Doyen's (b) paintings (average of 40 viewers, 20 art experts and 20 non-experts, whilst viewing for 2 mins each). Adapted versions: © Laboratory for Cognitive Research in Art History, University of Vienna.

course of the movement of the eye. The line he describes matches the graph of the most frequent saccadic transitions between clusters of fixations (Figure 5.7a). Correspondingly, it is clear that the saccadic movements executed when viewing Doyen's painting (Figure 5.7b) connect the figures within the four groups, but they do not connect those groups with each other quite as much. In contrast, fixations are almost equally distributed when looking at Pollock's canvas (Figure 5.4), and this corresponds to the "allover", a term commonly used to describe his canvases covered with paint from edge to edge, without preferences.

Another method to illustrate and evaluate the paths repeated by the beholder's eyes is the visualization of "similar saccades". We developed an algorithm merging all saccades that are more or less close to each other and run more or less in parallel to each other. This method is useful for paintings that do not have clear centers of interest like human figures and especially faces; for example, landscapes, abstract images, etc. (Figure 5.8a and 5.8b).

We have chosen the altarpieces by Vien and Doyen because Diderot's description of (hypothetical) eye movements during the contemplation of these paintings is prominent in the history of art literature. However, those altarpieces stand for a wide range of paintings where the fixations and saccades of almost all beholders repeat

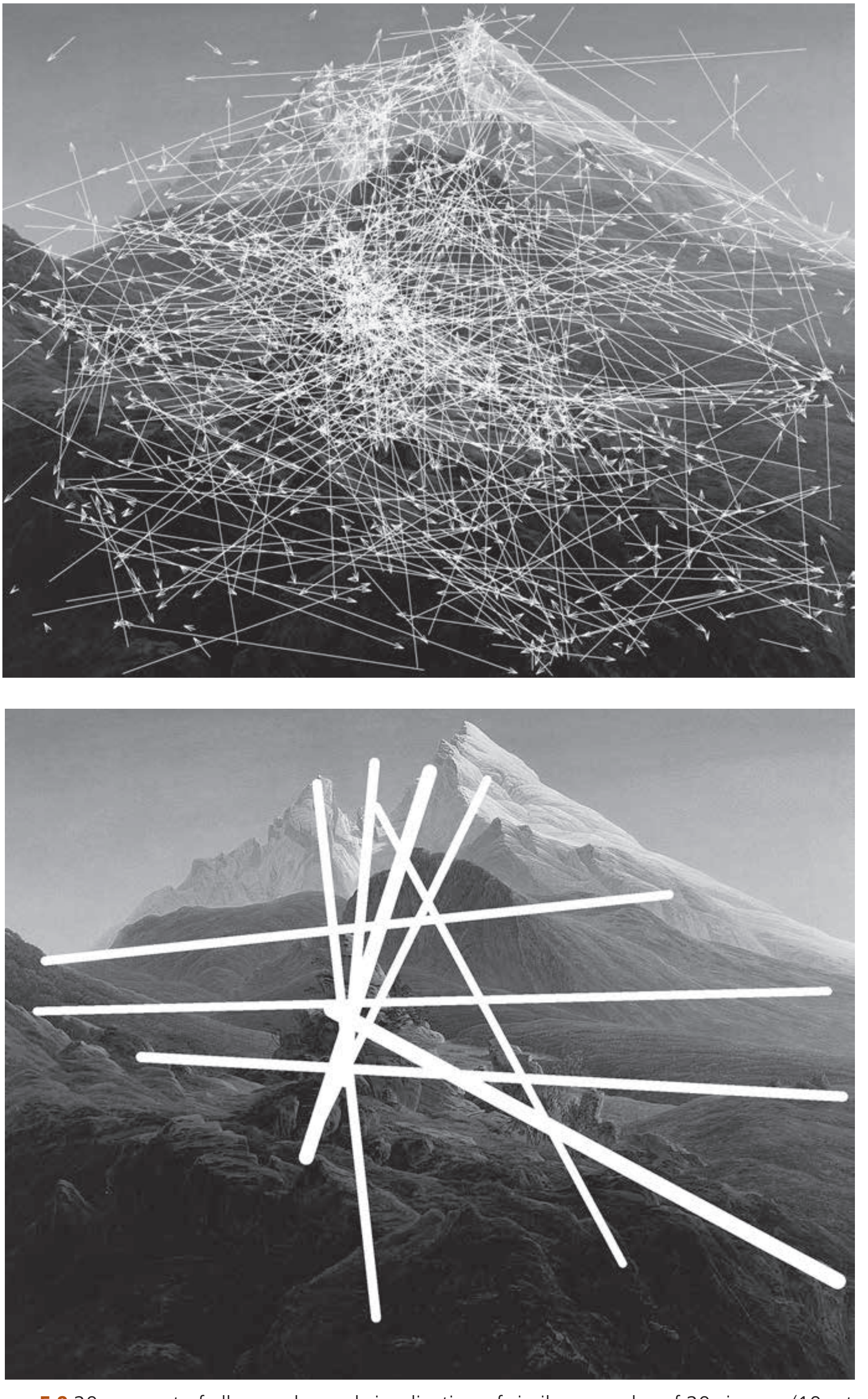


Figure 5.8 20 per cent of all saccades and visualization of similar saccades of 20 viewers (10 art experts and 10 non-experts) whilst looking at C.D. Friedrich, *Der Watzmann*, 1824/25, for 2 mins each.

patterns that are specific to the composition of each painting. Those patterns often match the analysis of the paintings given by art critics over the centuries, and they are very similar to diagrams of composition of those paintings, as they have been sketched by artists and art historians since the second half of the eighteenth century (Rosenberg 2008). We thus conclude that the eyes of beholders do indeed often reconstruct the structure of paintings, and that the repetitions of the structures of works of art with our eyes might be a basis for aesthetic experience. As with Diderot's text, subjective analysis seems often a kind of general summary of real-life gaze movements; an abstraction of factual gaze movements highly influenced by cognitive processes, such as the awareness about the content (iconography) of the painting. Knowledge about the content and the history represented in a painting affects the order in which we arrange the pieces of this painting in our minds and hence the order in which we describe it, regardless of the fact that our eyes perceive these parts again and again in alternating sequences.

However, for some types of paintings the patterns of gaze movements do not mirror their structure. This is particularly the case for paintings where faces are dominant, as in portraits, since the beholder's eyes mainly concentrate on eyes, nose, and mouth, and very few other details (Figure 5.9), although any art critic and most art viewers will normally describe many more aspects of the painting than those facial details. Another limitation is given by the fact that gaze patterns only appear if the painting has points of reference, saliencies in regard to form and or content. This is less the case for abstract than for

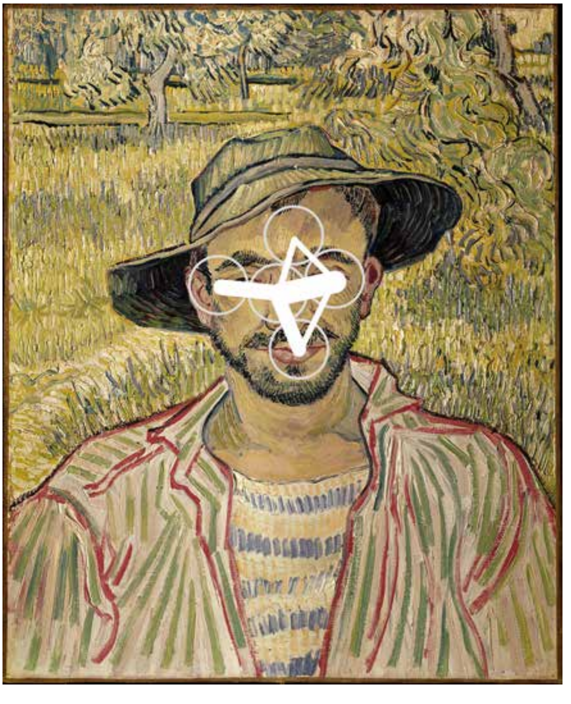


Figure 5.9 Frequent saccadic transitions between fixation clusters of 40 viewers (20 art experts and 20 non-experts) of Vincent van Gogh, *Portrait of a Peasant*, 1889, whilst beholding for 2 mins each.

representational art (Brinkmann et al. 2014), and of course even less for color-field or even monochrome paintings where fixations and saccades do not form any patterns.

5.4.4 Variations of gaze movements related to beholders

There is literally no psychologically relevant feature in which individuals do *not* differ greatly. Given the complexity and general openness of art to varying interpretations (Eco 1962), individual differences can be assumed to be particularly relevant with regard to the way people look at paintings. Indeed, pronounced individual differences in gaze movement patterns while looking at paintings had already been noticed by Buswell (1935). Three decades later, Yarbus (1967, p. 192) concluded that "individual observers differ in the way they think and, therefore, differ also to some extent in the way they look at things." Locher (1996) analysed individual subjects' fixation distributions and reported individual differences in identifying the visual center of a picture (an individual's mean eye position).

In one of our studies (Klein et al. 2014), given its large sample size and long recording duration, we also looked at various eye movement parameters, grouped according to factor analysis into saccades, fixations, and transitions between fixations clusters. We found individual differences in all of these factors to be highly stable across the viewing time of 10 minutes (unpublished work); these individual differences were, furthermore, somewhat consistent across the four paintings of this study. Overall, our results thus suggest that individual differences in elementary facets of gaze movement control during the contemplation of paintings are stable across stretches of several minutes and are consistent across different types of painting. Hence, we can assume major personality-related contributions, the nature of which is yet to be determined, to the way people look at paintings.

Beyond inter-individual variances, group-specific differences are one of the most interesting topics of eye-tracking research about the perception of images—both for psychology and art history. Buswell (1935) asked about differences due to expertise and culture but he was not able to discern any. Kristjanson and Antes (1989) reported differences in gaze movement patterns between artists and non-artists that seemed to correlate with the familiarity of the paintings. Artists showed longer fixations during the contemplation of known paintings and shorter ones with unknown paintings, whilst the opposite held for non-artists. The importance of art expertise for the way people look at paintings has also been emphasized by Nodine and colleagues (1993). They presented original and manipulated paintings for 12 seconds to artists and non-artists and found that untrained viewers failed to recognize the perceptual organizing function of pictorial elements. Furthermore, Zangemeister and colleagues (1995) compared the gaze movements of art experts and laypersons when viewing representational or abstract paintings. While fixation durations did not differentiate paintings or participant groups, art experts were found to explore paintings with longer saccades than non-experts. This group difference was more pronounced for abstract as compared to representational paintings. Vogt and Magnussen (2007) as well as Pihko and colleagues (2011) also describe differences in viewing strategies influenced by expertise.

In our studies, for the first time we compared experts (students of art history above degree level) and non-experts (students from the same university not interested in art) for viewing periods longer than one minute per painting. We could not detect any differences between the two groups for non-complex paintings. By contrast, we found that for complex paintings these groups differed in their eye movement patterns, but only at the beginning of the contemplation for periods of time of several tens of seconds (Rosenberg 2014). In the case of Vien's altarpiece, for instance, such group differences lasted for approximately 30 seconds (Figure 5.10). One possible explanation is that non-experts might need more time to understand the structure—the intrinsic meaning of the painting—conversely, experts are faster in mapping the structure of a painting, in particular when it is complex.

Given the fact that historical changes can be described as cultural changes, a crucial question for art historians is whether and to what extent the cultural imprint may influence looking at artworks. Art historians have discussed whether stylistic changes in art might be due to changes of cognitive modes (Baxandall 1972), and whether the perception of artworks has changed during centuries (Rosenberg 2000). We are currently carrying out a project on the "cultural eye" (by doctoral student Hanna Brinkmann) focusing on

(a) (b)

Figure 5.10 Frequent saccadic transitions between fixations clusters of 20 art experts (a), and 20 non-experts (b) whilst looking at Vien's painting for 30 s each. Adapted versions: © Laboratory for Cognitive Research in Art History, University of Vienna.

differences between Japanese and Austrian beholders. In a preliminary study with 6 Japanese and 6 Austrian test people looking at ten paintings for two minutes each, we found significant differences. The Japanese concentrated on the background of the paintings (compare Boland et al. 2008; Nisbett et al. 2001; Nisbett 2003), and made fewer horizontal and more vertical saccades, compared to the Austrian individuals (Figure 5.10). This might be due to reading habits. Finally, the Japanese executed longer fixations. This could be due to the fact that all paintings in this test were European, hence might have been unfamiliar to the Japanese viewers.

5.4.5 Variations of gaze movements related to task and context

Buswell (1935, pp. 136–41, 144) demonstrated that the "directions given prior to looking at pictures have a marked influence upon the character of perception." Yarbus recorded the eye movements of a beholder viewing the reproduction of a painting by I. Repin, with seven different instructions such as "give the ages of the people," or "remember the position of the people and objects in the room." The page illustrating those recordings (Yarbus 1967, p. 174) has been quoted regularly, and the experiment was replicated with 17 observers (DeAngelus and Pelz 2009). There can be no doubt that the variation of task has a stronger influence on gaze movements than differences between beholders, and it is interesting to use paintings to test such differences and hence demonstrate the top-down control of gaze movements. However, instructions as used in the Yarbus experiment are alien to the purpose of paintings as works of art and to the normal conditions of their beholding. More relevant to the understanding of aesthetic processes is an experiment conducted by Molnar and Ratsikas (1987). They compared gaze movements of participants looking at

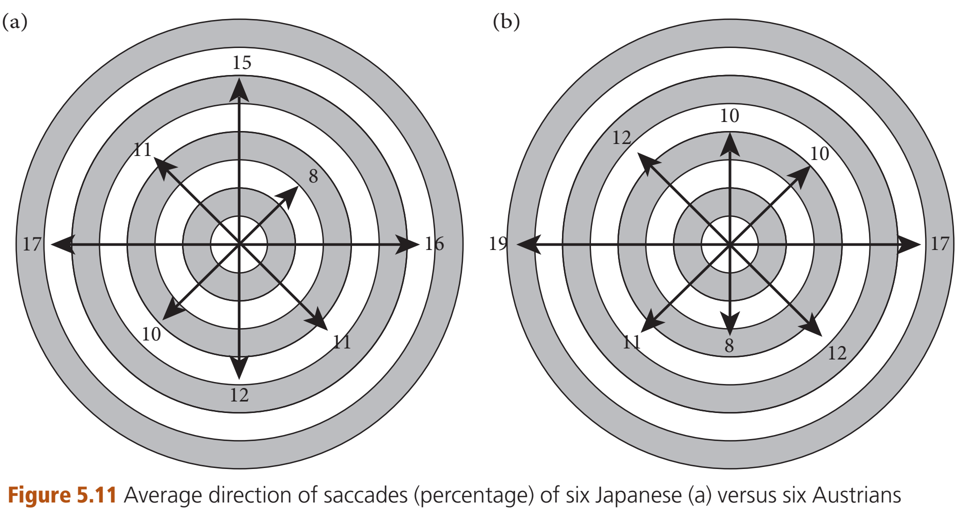


Figure 5.11 Average direction of saccades (percentage) of six Japanese (a) versus six Austrians (b) non-experts test individuals looking at C.D. Friedrich, *Der Watzmann* (see Figure 5.8), for 2 mins each (eight segments of 45°, arrows are segment bisectors). © Laboratory for Cognitive Research in Art History, University of Vienna.

reproductions of paintings knowing that they were expected to report verbally later on either the semantic content of the paintings or their aesthetic qualities. The group with the aesthetic instruction had significantly longer fixations.

Until the eighteenth century, paintings normally did not have titles. Yet, in the course of the nineteenth century, titles became an integral part of works of visual art. Viewers nowadays often look at a painting after they have read its title. The title might hence be regarded as an element which guides the eye of the spectator, and artists and art historians are thus aware of the importance of titles for the spectator (Welchman 1997). Kapoula and colleagues (2009) demonstrated that at least in the case of Fernand Léger's Cubist paintings, which include rather unclear motifs, knowledge of different titles has a significant influence on gaze movements.

A normal "task" for the spectator of art is to speak about the observed works. Since the Italian Renaissance, talking about artworks in front of them was a common practice not only among artists but also among the growing group of interested laypersons: connoisseurs and, later, art historians. There are extensive sources on discourses and descriptions of paintings that were originally spoken in front of the works of art (Welzel 1997), and the practice of describing works of art remains fundamental in museums and art history courses. In order to understand whether and how speaking about the work influences the processing of beholding we designed a study in which participants contemplated paintings, selected to cover different genres, for 10 minutes, followed either by a period of up to 5 minutes during which participants were required to answer several open questions regarding the painting or by a period of 5 minutes of continued silent viewing. The results suggest how striking an effect speaking has on the way people look at paintings: consistent with a shift towards the global state of attention (that is, not focusing on details; see section 5.3), participants employed shorter fixations and longer saccades while they were speaking compared to silent beholding. In addition, the number of transitions between clusters of fixations significantly increased. We therefore suggest that speaking about known visual artworks activates a mnemonic representation of a particular painting, built up during the previous period of viewing that guides gaze movement control during a global state of attention and in partial disregard as to the details (Klein et al. 2014).

We also assume that context affects the reception of art in general and gaze movements of spectators in particular. As long as eye trackers could be used only in laboratories, it was not possible to test contextual influences. Thanks to new devices which enable eye tracking of mobile spectators, some studies have begun to investigate the influence of the context where paintings are exhibited (Brieber et al. 2014).

5.5 Conclusion and directions for future research

The mutual interest between art history and psychology can be traced back through over a century of research. Fechner (1876), one of the founding fathers of psychology, was also a pioneer of experimental investigation of aesthetics just as Wölfflin (1886) and Riegl (1901), two leading figures in art history during their own lives, developed psychological approaches in order to gain a basic understanding of the historical evolution of art. Since the 1950s publications of the psychologist Rudolf Arnheim were read by artists and art historians, as those by the art historian Ernst Gombrich were by psychologists. In terms of major recent developments in psychophysiology, eye tracking is probably the most promising technique, opening new horizons for collaborative research on the psychology of visual arts. The scope of this collaborative research is as broad and versatile as the many disciplines involved. It requires decisions about what should be some fundamental questions and it offers the possibility of addressing a range of relevant topics.

Among the fundamental questions are the following. First, what is the nature of the setting in which the appreciation of art is to be studied? While the vast majority of the limited number of studies in the psychology of visual arts have been conducted in the laboratory, ambulatory assessment nowadays uses versatile equipment which can be used to study the viewing and appreciation of art in environments that are more valid than the laboratory, such as museum, gallery, or the home. These studies would not be confined to subjective reports (e.g. using mobile devices which could be used to prompt responses, such as cell phones) or the measurement of gaze movements. They could investigate a wealth of psychophysiological processes supposedly associated with the appreciation of art (e.g. pupil diameter, electro-encephalography, heart rate, skin conductance response). Here, as in all domains of ambulatory assessment, the gain in ecological validity comes at the expense of "softened" cause–effect relationships ("internal validity") which still can be ascertained best in the laboratory. Secondly, what kind of co-variation should be investigated? Should it be "natural" co-variation such as the variation of aesthetic judgments across the paintings exhibited in a gallery, or "experimental" co-variation such as the changes in brain responses to a painting as a consequence of varying beholding instructions? Here, the fundamental question is whether to vary or manipulate the painting or the beholder (or both). Varying paintings—for example, by comparing abstract versus representational paintings or by comparing paintings from different epochs—leaves the object of study "intact" but renders the analysis of its effects ambiguous due to the many differences between paintings. Conversely, manipulating paintings—for example, by applying graphical filters to alter colors, contours, and the like, or relocating its elements to alter symmetry or composition—may yield at best clear "cause and effect relationships," but possibly ones that border on art-historical irrelevance due to the "artificial" nature of the manipulation. Varying (by selection) or "manipulating" (by instruction) the beholder, by contrast, tells us little about how a piece of art influences our perception of it. This individual-centered approach instead emphasizes the subject of the process of constructing "beauty in the eye of the beholder" and offers a variety of different approaches such as the following. We can study the impact of individual-related variables such as the degree of art expertise, age, gender, and cultural background (cross-cultural and sub-cultural) as well as their interaction by keeping the object artwork constant. This approach can be easily combined both with the art-centered approaches outlined earlier and with individual-centered manipulations of viewing instructions. Such instructions can focus on aspects of the paintings (e.g. its colorfulness, contents, etc.) or the processes in the beholder (e.g. remembering, evaluating, etc.), or both. All these approaches have been employed in the pertinent literature so far, albeit often not in combination with the recording of gaze movements. Due their close coupling with visual attention, detailed in section 5.3, gaze movements should be more systematically recorded in these endeavours.

Irrespective of the selection of approaches chosen, there are a number of topics that should be addressed in future research of a psychology of visual art. First, given the importance of hypothetical eye movements for the analysis of visual art (see section 5.1), more empirical work using gaze movement recordings is required to revise and possibly to re-evaluate and extend this kind of theorizing on the basis of firm empirical data. Secondly, given the inherently subjective nature of aesthetic experience and the openness of any kind of art, the systematic study of "personality" (in the broadest sense of the term) factors in looking at artworks is of utmost importance for this field of research. This does not only refer to the influences of gender, age, expertise, general education, general intelligence, or culture (with its pertinence for historical studies, see section 5.4.4), but it also touches upon the influences of "situational" factors (gallery versus lab), or the stability of individual differences. Thirdly, the observed gaze movement patterns should be validated against psychologically meaningful parameters (e.g. does fixation duration predict encoding success? Is the understanding of an artwork's complexity related to the complexity of the gaze movement patterns?). Fourthly, assuming that art is essential to the education systems of many cultures, how can we utilize the measurement of gaze movements during art contemplation to foster the understanding of art at different ages across the life span? Furthermore, eye-tracking studies have been used already in the field of conservation. Maisey and colleagues (2011) measured the reaction of beholders to discover how to re-integrate a highly damaged painting by John Martin at Tate Britain. We assume that in the future eye tracking will have significant implications in decisions about art display (museum and exhibition design) and for art-educational programs. Fifthly, while almost all research on the psychology of visual art has focused on the perception of art, experimental research on art production (as Miall and Tchalenko 2001) still remains a greater challenge. However, it is conceivable that even in this field eye tracking—for instance of a painter at work—will give us clues in the future about the nature of the creative act.

Acknowledgments

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