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Misperception, illusion and epistemological optimism: vision studies in early nineteenth-century Britain and Germany

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Abstract. This article compares investigations of the process of vision that were made in early nineteenth-century Britain and the German lands. It is argued that vision studies differed significantly east and west of the North Sea. Most of the German investigators had a medical background and many of them had a firm grasp of contemporary philosophy. In contrast, the British studies on vision emerged from the context of optics. This difference manifested itself in the conceptual tools for the analysis of vision, deception and illusion and shaped the experiments on visual phenomena that were carried out. Nevertheless, both in Britain and in the German lands vision studies were driven by the same impetus, by epistemological concerns with the nature and reliability of knowledge acquisition in experience. The general epistemological conclusions drawn from researches on vision and deception were optimistic. Precisely because mechanisms of deception and illusion could be uncovered, the possibility of acquiring empirical knowledge could be secured.

Vision studies were a blossoming field of research in the early nineteenth century. In Britain several investigators were fascinated by optical toys of all kinds, such as kaleidoscopes, thaumatropes and microphotographs. In the German lands many scholars explored the peculiar nature of subjective sensations. In recent years several historians and philosophers of science have commented on this increased interest in vision studies. They have described in detail the technologies of vision in Victorian culture[1] as well as the rise of sensory physiology in the German lands.[2]

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1 For an overview of early nineteenth-century research on optical toys see N. Wade, 'Philosophical instruments and toys: optical devices extending the art of seeing', *Journal of the History of the Neurosciences* (2004), **13**, 102–24. On Brewster's investigations of the kaleidoscope and other optical devices see M. Kemp, '"Philosophy in sport" and the "sacred precincts": Sir David Brewster on the kaleidoscope and stereoscope', in *Muse and Reason: The Relation of Arts and Sciences 1650–1850* (ed. B. Castel *et al.*), Kingston, 1994; R. J. Silverman, 'The stereoscope and photographic depiction in the 19th century', *Technology and Culture* (1993), **34**, 729–56; A. Morrison-Low, 'Brewster and scientific instruments', in '*Martyr of Science*'*: Sir David Brewster 1781–1868* (ed. A. Morrison-Low and J. R. Christie), Edinburgh, 1984, 59–65. On visual imagination in Victorian culture see K. Flint, *The Victorians and the Visual Imagination*, Cambridge, 2000; and M. Benjamin, 'Sliding scales: microphotography and the Victorian obsession with the minuscule', in *Cultural*

Comparative studies, however, are lacking. Only a few scholars look at both sides of the North Sea. Those who do, make rather sweeping claims. Inspired by Michel Foucault's writings, they regard the manifold early nineteenth-century vision studies as one grand transformation which eventually produced the 'modern observer'.[3] This paper exposes significant differences between researches on vision east and west of the North Sea. Most of the German investigators were trained as physicians. Many of them were well acquainted with contemporary natural philosophy. In contrast, the British studies on vision emerged from the context of optics. This difference manifested itself not only in the conceptual tools for the analysis of vision, deception and illusion but also in the experiments on vision that were carried out. Yet both in Britain and in the German lands scholars had similar epistemological concerns. They aimed to establish the nature and reliability of knowledge acquisition in experience. It is argued that the

Babbage: Technology, Time and Invention (ed. F. Spufford and J. Uglow), London, 1996, 99–122. Optical toys are often considered as part of the prehistory of cinema, as in S. Neale, *Cinema and Technology: Image, Sound, Colour*, Bloomington, 1985; M. Chanan, *The Dream that Kicks: The Prehistory and Early Years of Cinema in Britain*, London, 1980; A. Knight, *The Liveliest Art: A Panoramic History of the Movies*, New York, 1959; for a very early example see H. V. Hopwood, *Living Pictures: Their History, Photo-Production and Practical Working*, London, 1899.

2 The sudden interest in the German project of 'subjective sensory physiology' that developed in the mid-1990s can be explained with the upsurge of research on Hermann von Helmholtz on the occasion of the centennial of his death in 1994. Much of the work on early nineteenth-century sensory physiology arose from the interest in the 'prehistory' of Helmholtz's physiological optics. This 'prehistory' is treated in M. Heidelberger, 'Innen und Außen der Wahrnehmung. Zwei Auffassungen des 19. Jahrhunderts (und was daraus wurde)' in *Video ergo sum. Repräsentationen nach innen und außen zwischen Kunst- und Neurowissenschaften* (ed. O. Breidbach and K. Clausberg), Hamburg, 1999, 147–57; M. Heidelberger, 'Beziehungen zwischen Sinnesphysiologie und Philosophie im 19. Jahrhundert' in *Philosophie und Wissenschaften. Formen und Prozesse ihrer Interaktion* (ed. H. J. Sandkühler), Frankfurt am Main, 1997, 37–58; R. S. Turner, *In the Eye's Mind: Vision and the Helmholtz–Hering Controversy*, Princeton, 1994; T. Lenoir, 'The eye as a mathematician: clinical practice, instrumentation, and Helmholtz's construction of an empiricist theory of vision', in *Hermann von Helmholtz and the Foundations of Nineteenth-Century Science* (ed. D. Cahan), Berkeley, 1993, 109–53; T. Lenoir, 'Helmholtz, Müller und die Erziehung der Sinne', in *Johannes Müller und die Philosophie* (ed. M. Hagner and B. Wahrig-Schmidt), Berlin, 1992, 207–22; and G. Hatfield, *The Natural and the Normative: Theories of Spatial Perception from Kant to Helmholtz*, Cambridge, MA, 1990. Other historians and, occasionally, philosophers have considered physiological investigations in the context of recent revisions of Romantic science and philosophy. For the relation between sensory physiology and Romanticism see J. Müller-Tamm, 'Die "Empirie des Subjektiven" bei Jan Evangelista Purkinje: Zum Verhältnis von Sinnesphysiologie und Ästhetik im frühen 19. Jahrhundert', in *Wahrnehmung der Natur – Natur der Wahrnehmung. Studien zur Geschichte visueller Kultur um 1800* (ed. G. Dürbeck *et al.*), Dresden, 2001, 153–64; and D. L. Sepper, 'Goethe, colour, and the science of seeing', in *Romanticism and the Sciences* (ed. A. Cunningham and N. Jardine), Cambridge, 1990, 189–98. For the philosophical context of Purkinje's and Müller's works see M. Hagner, 'Psychophysiologie und Sinneserfahrung. Metamorphosen des Schwindels und der Aufmerksamkeit im 19. Jahrhundert', in *Aufmerksamkeiten* (ed. A. Assmann and J. Assmann), München, 2001, 241–63; M. Hagner, 'Sinnlichkeit und Sittlichkeit. Spinozas "Grenzenlose Uneigennützigkeit" und Johannes Müllers Entwurf einer Sinnesphysiologie', in *Johannes Müller und die Philosophie* (ed. M. Hagner and B. Wahrig-Schmidt), Berlin, 1992, 29–44; and, again, Hatfield, op. cit. On the compensatory role of sensory physiology for early nineteenth-century brain research see M. Hagner, *Homo cerebralis. Der Wandel vom Seelenorgan zum Gehirn*. Berlin, 1997, 238–46.

3 J. Crary, *Techniques of the Observer: On Vision and Modernity in the Nineteenth Century*, Cambridge and London, 1990; D. Pick, 'Stories of the eye', in *Rewriting the Self: Histories from the Renaissance to the Present* (ed. R. Porter), London, 1997, 186–99.

epistemological conclusions that were drawn from vision research were optimistic. Precisely because mechanisms of deception and illusion could be uncovered, the possibility of acquiring empirical knowledge could be secured.

Prussia: mediation of subject and object through the visual sense

Around 1800 many investigators, among them Goethe, Georg Steinbuch and Caspar Theobald Tourtual,[4] designed experiments to explore the nature of visual experience. Two people who took the lead in the rising sensory physiology in the German lands were the two anatomist–physiologists Jan Evangelista Purkinje, of Czech origin, and Johannes Müller. Both published extensively on the physiology of the senses. Purkinje's first contribution, his Prague doctoral dissertation, was published in 1819. The second imprint of this work was published in 1823, in the same year as his Breslau dissertation on the physiology of the eye and the skin, and the second part of his contributions to the physiology of the senses appeared in print only two years later.[5]

In 1826 Müller followed suit with two book-length studies on the sense of vision.[6] Müller himself presented these enquiries as an integral part of an ongoing research programme, linking his researches closely to Purkinje's investigations, in both theme and approach. The principal aim of all these endeavours was to examine the 'sensuality of seeing itself'.[7] The physiologists were not much concerned with the anatomy of the eye and the passage of light rays. Rather they aimed to understand the process of vision and the sensations as they are experienced by the subject. To do so, the physiologists conducted self-experiments, experiments on their own sense organs.

As a project of self-examination, sensory physiology fits well with other scholarly and artistic enterprises in the 'age of reflexion'. Andrew Cunningham and Nicholas Jardine use this to characterize the decades around 1800. They have emphasized the explicit interest in individual and cultural self-understanding that bound together diverse endeavours, such as subject-oriented poetics and aesthetics found, for example, in Schiller's *Aesthetic Education of Mankind*, Romantic historical critique in the wake of Herder, Henrik Steffens's developmental history of the Earth and numerous other projects. All attempted to answer the question of identity, whether as a nation, a society

4 J. W. von Goethe, *Zur Farbenlehre*, Weimar, 1987 (1810); G. Steinbuch, *Beytrag zur Physiologie der Sinne*, Nürnberg, 1811; C. T. Tourtual, *Die Sinne des Menschen in den Wechselbeziehungen ihres psychischen und organischen Lebens*, Münster, 1827.

5 J. E. Purkinje, *Beobachtungen und Versuche zur Physiologie der Sinne. Erstes Bändchen. Beiträge zur Kenntniss des Sehens in subjektiver Hinsicht*, 2nd edn., Prague, 1823; *idem, Abhandlung über die physiologische Untersuchung des Sehorgans und des Hautsystems,* Halle, 1823; *idem, Beobachtungen und Versuche zur Physiologie der Sinne. Neue Beiträge zur Kenntniss des Sehens in subjektiver Hinsicht*, Berlin, 1825.

6 J. Müller, *Zur vergleichenden Physiologie des Gesichtssinnes des Menschen und der Thiere nebst einem Versuch über die Bewegung der Augen und über den menschlichen Blick*, Leipzig, 1826; *idem, Ueber die phantastischen Gesichtserscheinungen. Eine physiologische Untersuchung mit einer physiologischen Urkunde des Aristoteles über den Traum, den Philosophen und Aerzten gewidmet*, München, 1967 (1826) (on which see Hagner, 'Sinnlichkeit und Sittlichkeit', op. cit. (2)).

7 J. Müller, *Zur vergleichenden Physiologie*, op. cit. (6), p. xiv.

or an individual.[8] Sensory physiology, the examination of how we see, falls squarely into the domain of this reflexive enterprise of self-understanding.

As a general framework for the characterization of the period around 1800, the notion of an 'age of reflexion' is apt. However, there is also more specific resonance between post-Kantian philosophy and the empirical study of vision. A key part of the Kantian project was the distinction between 'things in themselves' and 'appearances'. This dualism severed the experiencing subject from nature so that the true experience of nature was precluded. One major strand in the manifold philosophical works of that period was the endeavour to overcome this dualism and to show that knowledge of nature was possible, and how. Consider for example Schelling's explication of the identity of nature and mind:[9] Schelling sought to show that material nature and mind were different aspects of the same absolute in which they were both grounded. We can read the metaphysical claim of a fundamental unity between nature and mind as an attempt to assure the possibility of knowledge of the hidden forces and processes of nature that the Kantian approach rejects. Against the background of this metaphysical assumption, things in nature could be seen to have a symbolic significance. In this way, Schelling was able to explain how the subject's experience reached beyond appearances, grasping nature as the universal production of ideas.

Romantic *Naturphilosophie* such as Schelling's philosophy of nature inspired projects in the empirical sciences that can also be understood as attempts to cope with the apparent epistemic divide between nature and the experiencing subject. Johann Wilhelm Ritter's experimental exploration of the self is an instructive example. Stuart Strickland has shown how for Ritter, as for many other Romantic scientists, self-knowledge and the knowledge of nature each implied the other. Ritter conceived of his body at once as a laboratory instrument, as a metaphor for nature and as a sign of the experimenter's individual identity.[10] When Ritter explored the effects of electrical currents on his own body, nature and the self were on a par; the study of nature was expected to reveal the nature of the self and vice versa.

The physiologists who were active in the early decades of the nineteenth century were familiar with natural philosophy and the philosophical exploration of subject–object. For them, these philosophical programmes were both an inspiration and the intellectual background against which the science of physiology had to be outlined and developed as an independent enterprise. Like the majority of their physiologist colleagues, Purkinje and Müller were well acquainted with the contemporaneous philosophy of 'subject–object'. In 1835 Purkinje recalled that his early investigations had been inspired by the works of Goethe and the Romantic physiologist–philosopher Gruithuisen. Müller, who studied at the newly founded university of Bonn, was exposed to natural philosophy throughout his university

8 A. Cunningham and N. Jardine, 'The age of reflexion', in *Romanticism and the Sciences* (ed. A. Cunningham and N. Jardine), Cambridge, 1990, 1–9.

9 F. W. J. Schelling, *Ideas for a Philosophy of Nature*, Cambridge, 1988 (1803).

10 S. Strickland, 'The ideology of self-knowledge and the practice of self-experimentation', *Eighteenth-Century Studies* (1998), **31**, 453–71, 454–6.

education.[11] The rise of sensory physiology, the study of how we see, can be understood as another contribution to the project of overcoming the abyss between nature and the experiencing subject that Kantian philosophy had opened up, if with a different thrust. As illustrated below, Purkinje and Müller did not assume that nature and the self were on a par, and that the study of the self was therefore akin to the study of nature. Rather, they hoped to understand by empirical means how the subject experienced nature. They aimed to explore in experiments the very relation between objects and experiencing subjects.[12]

In their realization of this project, Purkinje and Müller also drew on contemporaneous medical theories of the animal body. Eighteenth-century physiologists, notably Albrecht von Haller, had begun to replace older mechanistic models of the body. The new models acknowledged that living beings have properties that cannot be reduced to mechanics, namely the irritability of the muscles and the sensitivity of the nerves.[13] It is this idea of specific organic functions that was taken up by the sensory physiologists. To explain the peculiar 'life' of the sense of vision, the sensory physiologists resorted to the notions of energy,[14] stimulus and response. The two domains of the organic and the inorganic were understood as connected through specific causal relations. The specificity of living matter was its state of continuous activity that changed only in intensity. Such a change could be brought about by physical or chemical causes. Organic matter responded to these causes in a form that was categorically different from the stimulus, for example in the form of an inflammation. Purkinje and Müller employed precisely

11 J. E. Purkinje, 'Beiträge zur Physiologie der menschlichen Sprache', in *idem*, *Opera Omnia*, 12 vols., Prague, 1973, xii, 47–88, 48. On Müller's philosophical background and university education see D. von Engelhardt, 'Müller und Hegel. Zum Verhältnis von Naturwissenschaft und Naturphilosophie im deutschen Idealismus', in *Johannes Müller und die Philosophie* (ed. M. Hagner and B. Wahrig-Schmidt), Berlin, 1992, 85–104; N. Tsouyopoulos, 'Schellings Naturphilosophie: Sünde oder Inspiration für den Reformer der Physiologie Johannes Müller?', in *Johannes Müller und die Philosophie* (ed. M. Hagner and B. Wahrig-Schmidt), Berlin, 1992, 65–83; and M. Müller, 'Über die philosophischen Anschauungen des Naturforschers Johannes Müller', *Archiv für Geschichte der Medizin* (1926), **18**, 130–50, 209–34, 328–50. On the search for a scientific physiology and the physiological exploration of 'subject–object' see B. Lohff, *Die Suche nach der Wissenschaftlichkeit der Physiologie in der Zeit der Romantik*, Stuttgart and New York, 1990. For the relation between physiology and Romantic philosophy see also T. Broman, *The Transformation of German Academic Medicine, 1750–1820*, Cambridge and New York, 1996.

12 Gerlof Verwey explicitly suggests that Müller's philosophy can be understood as a 'scientific complement' to the philosophy of German idealism but reads early nineteenth-century sensory physiology as an attempt to overcome the Cartesian dualism between mind and body, not the Kantian dualism between things in themselves and things for us; G. Verwey, 'Johannes Müller und das Leib-Seele-Verhältnis. Zur systematisch-philosophischen und philosophie- und wissenschaftshistorischen Ortung', in *Johannes Müller und die Philosophie* (ed. M. Hagner and B. Wahrig-Schmidt), Berlin, 1992, 173–90, 177. In contrast, Michael Hagner has shown that Purkinje's experimental investigations of vertigo were to reconcile the categorical distinction between the brain and the mind, thus challenging the dualistic positions of both Kant and the late eighteenth-century *Erfahrungsseelenkunde* or empirical psychology of Marcus Herz and Karl Philipp Moritz (see Hagner, 'Psychophysiologie und Sinneserfahrung', op. cit. (2), Section II, especially 256–7).

13 On this transformation see S. Moravia, 'From *homme machine* to *homme sensible*: Changing eighteenth-century models of man's image', *Journal of the History of Ideas* (1978), **39**, 45–60.

14 The roots of the notion of energy reach back to the works of Aristotle, which Müller knew well. See R. G. Mazzolini, 'Müller und Aristoteles', in *Johannes Müller und die Philosophie* (ed. M. Hagner and B. Wahrig-Schmidt), Berlin, 1992, 11–27.

these notions to explain the function of vision. Like the organism in its entirety, the sense of vision was in a continuous state of activity, every stimulus acting on it in such a way that when it was agitated it responded in its specific mode, thereby producing the sensation of light. This idea is encapsulated in Müller's famous doctrine of the specific energies of the senses.[15]

How can one investigate the process of vision? Müller claimed that to understand the 'life' of the sense of vision, experimenters had to monitor and record closely their own sensations. In particular, the causal relations between the stimuli and the organic responses had to be examined in self-experiments. Purkinje stated this methodological requirement at the very beginning of his treatise. He stressed that to investigate the process of vision, 'strict sensual abstraction, experiment on one's own organism', as well as the 'specific orientation of attention',[16] was required. In the concrete experiments, the sensory physiologists inflicted on their eyes diverse stimuli, ranging from pressure, chemicals and electrical impulses to the consumption of alcohol and vivid imagination. They recorded in detail what they experienced.

Because these experiments were targeted at the observer's sensations, this enterprise has often been portrayed as 'subjective' sensory physiology. Some of Purkinje and Müller's writings seem to support this view. For example, both Purkinje and Müller demanded that prior to the investigation the experimenter abstain from distinguishing between veridical sense impressions and illusions or pathological states. Purkinje claimed that 'from the point of view of pure research, there are no pathological states, as for the botanists there are no weeds, and for the chemists there is no rubbish'. In other words, every sensation had to be taken as evidence for the function of the organ of vision.[17] The entirety of the visual appearances (*Gesichtserscheinungen*) had to be treated as visual truths (*Gesichtswahrheiten*), and this ensemble of subjective appearances formed the empirical basis of the physiological theory of vision.[18]

Yet it is misleading to portray Purkinje and Müller's studies as 'subjective' sensory physiology. The sensations of the experiencing subject were only methodical vantage points for self-experiments. The investigations ultimately aimed at the relation between sensations and their objective causes. Purkinje explicitly noted that only in ordinary life might we be content to know that from time to time we experience subjective phenomena. But it was the task of the scientists 'to reveal their objective ground'.[19] Like Purkinje, Müller explicitly emphasized that his ultimate aim was an 'elucidation and solution of the problems of *objective* visual appearances'.[20] The whole point of Müller's

15 The doctrine states that each of the senses possesses energy specific to it. The specificity of the sense energy explains that a manipulation of the sense of hearing, for example, always produces the sensation of a sound, never the sensation of light. See W. Riese and C. E. Arrington, 'The history of Johannes Müller's doctrine of the specific energies in the senses: original and later versions', *Bulletin of the History of Medicine* (1963), **39**, 179–83.

16 Purkinje, *Beobachtungen*, 1823, op. cit. (5), 8.

17 Purkinje, *Beobachtungen*, 1823, op. cit. (5), 5.

18 It was in fact Purkinje's work, which Müller cited as a reference for his own methodical beginning with visual truths (Müller, *Zur vergleichenden Physiologie*, op. cit. (6), 46).

19 Purkinje, *Beobachtungen*, 1823, op. cit. (5), 4.

20 Müller, *Zur vergleichenden Physiologie*, op. cit. (6), p. vi, emphasis added.

experimentation on his own eyes was to provide a classification of his visual sensations with regard to the agents that produced them. The experiments were to link introspectively experienced sensations with the conditions that brought them about. Müller's experiments established that sensations could be produced on three different grounds: external grounds such as light rays and mechanical and chemical influences, internal organic grounds such as breathing, and internal mental stimuli such as the activity of the imagination.[21] Like Purkinje, Müller took the sensations as the methodical starting point of this investigation, but his aim was to explore the relation between the experiencing subject and the experienced object.

Purkinje's work on *mouches volantes* makes perfectly clear that sensory physiology aimed at uncovering objective grounds for subjective phenomena. *Mouches volantes* – dark spots and lines that sometimes appear before the eyes of observers – are a prime example of 'mere appearances'. They began their existence as accidental, pathological phenomena. Various men of science and medicine, among them Galen, the Oxford natural philosopher Thomas Willis and the mathematician Philippe de la Hire,[22] described 'fly-like' phenomena in or in front of their eyes and they all treated these phenomena as signs of disease. In the early nineteenth century spots and lines became objects of closer scrutiny. But they still made their appearance in articles and books concerned with diseases of the eye. The physician J. Ware, for example, published a paper in the *Medico-Chirurgical Transactions* which presented the results of his examinations of 'Muscae volitantes of nervous persons'.[23] As the title of the paper suggests, for Ware these phenomena were an outcome of unusual nervous agitation. He supported his view with three cases of patients who suffered from this 'imperfection' of vision, which Ware characterized as 'dark coloured moats [*sic*] before the eyes', which 'assume various shapes and figures, appear at different distances, and move in different directions, but have no tangible existence in the places where they are seen'.[24] In all three cases, Ware's patients had gone through distressing events and suffered from nervous disorders that Ware held responsible for these motes. To restore the healthy condition of his patients, and to make the motes disappear, he recommended camphor treatments and similar relaxing remedies, by which treatment, as the article reports, the condition of each of the 'nervous persons' had considerably improved. This shows that Ware conceived of the motes as symptoms of abnormal bodily conditions, which would vanish if these conditions were put back in order.

Purkinje approached these phenomena from an entirely new perspective. Following his methodological principles, he did not treat them as pathological states but as 'visual truths', whose 'objective grounds' had to be established. To do so, Purkinje surveyed the various forms and movements of the *mouches volantes* – as he called them – as well

21 Müller's book on 'fantastic visual appearances' shows how the imagination could also produce sensations (Müller, *Ueber die phantastischen Gesichtserscheinungen*, op. cit. (6)), but these appearances could be understood as 'fantastic' only in contrast to other sensations that were brought about by external stimuli of various kinds.

22 For the history of *mouches volantes* see H. Plange, 'Muscae volitantes – Von frühen Beobachtungen zu Purkinjes Erklärung', *Gesnerus* (1990), **47**, 31–43.

23 J. Ware, 'Muscae volitantes of nervous persons', *Medico-Chirurgical Transactions* (1814), **5**, 255–77.

24 Ware, op. cit. (23), 255.

as the circumstances under which they appear. The relevant chapter of his book describes the bodily conditions that are likely to bring them about: intense movements, as lifting 'something heavy with one's head bent' or 'vigorous leaps'[25] followed by a 'fixed stare' on a bright surface. As a consequence of such activity, one would then experience fly-like objects, moving black spots and lines in one's visual field. Because the spots and lines could be seen only with open eyes and only in external light, and because they had shadows, Purkinje inferred that they must be bodies. Their form and the fact that they appeared more frequently when the observer in question was excited or agitated indicated that they were caused by blood globules, as excitement was generally accompanied by higher activity of these globules.[26] In this way, the chapter establishes a causal relation between certain 'subjective' visual phenomena and 'objective' material causes. Although the appearances of fly-like phenomena are 'subjective' in the sense that they are located in the individual's organ of vision, they are no mere appearances (*Schein*), nor are they impossible to analyse. Purkinje's experiment-based argument shows that although these fly-like objects are visible only to the experiencing subject, the phenomenon can be objectified and explained as effects of material objects, which in this case happened to be located in the organic body of the experimenter. Purkinje's experiments did not aim at regulating abnormal bodily conditions, as Ware's treatments did. Rather, the observations of and experiments with one's own visual sense aimed at clarifying the nature of a regular relation between subjective – or, better, subject-sided – sensations and their objective grounds. Even though the methods and means of the sensory physiologists' self-experiments were quite similar to the experiments that Ritter had conducted, they were based on different assumptions. Ritter had proceeded on the metaphysical assumption that the self and nature, self-knowledge and knowledge of nature, each implied the other. Purkinje, as well as Müller, aimed to establish the very nature of the subject–object relation with experimental means.[27]

One might in hindsight observe that in Purkinje's and Müller's experiments, the boundary region between the mind and the physical world was black-boxed rather than illuminated. The self-experiments cut across this boundary region merely by associating

25 Purkinje, *Beobachtungen*, 1823, op. cit. (5), 129.

26 Purkinje, *Beobachtungen*, 1823, op. cit. (5) 130–1.

27 According to Crary, the relocation of vision in the so-called 'physiological thickness' of the body encountered in Purkinje's and Müller's work had grave and far-reaching epistemological consequences. It 'presents the outlines of a visual modernity in which the "referential illusion" is unsparingly laid bare. The very absence of referentiality is the ground on which new instrumental techniques will construct for an observer a new "real" world. It is a question, in the early 1830s, of a perceiver whose very empirical nature renders identities unstable and mobile, and for whom sensations are interchangeable. In effect, vision is redefined as a capacity for being affected by sensations that have no necessary link to a referent, thus imperiling any coherent system of meaning' (Crary op. cit. (3), 91). Crary suggests that early nineteenth-century vision research created an 'autonomous observer' who moved in a world of experiences that was severed from the external world. My interpretation of Purkinje's and Müller's works points to a different conclusion. The referential link between sensations and external objects was not severed, and no autonomous observer emerged. Rather, the experiments showed how exactly sensations and perceptions were linked to the external world. The sense organ's activity might affect and occasionally impede veridical perception but it was assumed that the eye's impact on perception could be determined in self-experiments.

physical, material agents acting on the nervous substance with the sensations of light that are produced. The sensations had a peculiar double nature as changes in the energetic state of the nervous substance and as visual impressions of light. Nevertheless, one must take seriously the pronouncements with which Purkinje and Müller asserted their investigative aims, in particular Müller's description of his research as an investigation of the 'mediation of subject and object through the sense of vision'. This was the title of Chapter 2 of his book.[28] As Purkinje put it, the experiments on the sense of vision were to show it 'both in the life of its own *and* in its peculiar reaction *against the external world*'.[29]

Edinburgh: enlightened optics

While Purkinje and Müller explored the nature of visual truths, David Brewster, the Scottish 'martyr of science',[30] sought to establish truths of another kind. Brewster's investigations emerged from a quite different context, that of optics. In the eighteenth century and the early nineteenth, optics was a multifarious enterprise, as writings on the subject impressively demonstrate. The treatises specifically devoted to optics, as well as the relevant parts on optics of natural philosophy textbooks, comprised chapters on vision, the anatomy of the eye, light and optical instruments.[31] Brewster was a typical representative of the field. His research covered all of these topics. Less typical, however, was his professional occupation. For most of his career Brewster had to support himself, his research and his family by various literary endeavours. The editor of and contributor to scientific journals and encyclopedias, he made just about enough money to allow himself some time for scientific pursuits. Most of Brewster's work concerned light, especially polarized light, but he also studied instruments with the aim of making them ever more perfect. He designed improved telescopes and achromatic eyepieces, devised novel micrometers, explored the fibres used in micrometers and invented, among other things, the kaleidoscope.[32]

Optical illusions were one focal point of Brewster's studies on vision. In 1826 he published his paper 'On the optical illusion of the conversion of cameos into intaglios, and of intaglios into cameos' in the *Edinburgh Journal of Science*.[33] This conversion

28 Müller, *Zur vergleichenden Physiologie*, op. cit. (6), 39, see also footnote 66.

29 Purkinje, *Beobachtungen*, 1823, op. cit. (5), 7, emphasis added. About fifteen years later Purkinje spoke (op. cit. (11), 48) of a 'boundary region between the external world and the inner intellectual'.

30 This is the title of a collected volume on diverse aspects of Brewster's life and career: A. Morrison-Low and J. R. Christie (eds.), '*Martyr of Science*'*: Sir David Brewster 1781–1868*, Edinburgh, 1984.

31 G. N. Cantor, 'The historiography of "georgian" optics', *History of Science* (1978), **16**, 1–21, Section iii; see also *idem*, *Optics After Newton: Theories of Light in Britain and Ireland 1704–1840*, Manchester, 1983, 19–21. It was only in the nineteenth century that vision studies (physiological optics) and the study of light (physical optics) became separated. Historians who have reconstructed these developments from the perspective of the discipline of physiological optics have therefore described the decade before 1840 as a 'pre-paradigmatic' period; see Turner op. cit. (2), 11.

32 Morison-Low, op. cit. (1).

33 D. Brewster, 'On the optical illusion of the conversion of cameos into intaglios, and of intaglios into cameos, with an account of other analogous phenomena' (1826), in *Brewster and Wheatstone on Vision* (ed. N. Wade), London and New York, 1983, 56–65.

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illusion was one of the best-known deceptive phenomena in the history of microscopy. The eminent Robert Hooke had drawn attention to it. The phenomenon was also recorded in the minutes of a meeting of the Royal Society when a new compound microscope was presented, and in the mid-eighteenth century the German Philip Friedrich Gmelin described it in greater detail.[34] In the 1780s the American David Rittenhouse undertook further examinations of this illusion and related it to the inversion of the shadow by the eyepiece.[35]

Brewster referred to these earlier investigations to introduce his own analysis of the nature of optical illusions. But a closer examination of his research shows that this analysis was in fact part and parcel of his attempt to promote a particular concept of perception.[36] For Brewster, viewing an object meant inferring its shape and properties on the basis of previous knowledge about light and shadow and a judgement about the circumstances of the actual perceptual situation. This conception of vision is in tune with judgemental theories of perception common in eighteenth-century vision studies. In the eighteenth century it was widely assumed that sense perception involved a cognitive act, a mental operation.[37] Since the days of Kepler and Descartes, vision had been described as a two-step process including physical and mental elements. In this account the eye is likened to an optical apparatus and the retina likened to a kind of projection screen. The act of vision begins with a physical process. Light rays pass through the transparent media of the eyeball and terminate at the retina where they create impressions. The visual act is completed by a cognitive act which synthesizes the visual impressions on the retina to form a perception. The accounts of vision that were offered in eighteenth-century optics thus comprised mechanistic models of the optical apparatus of the eye, geometric models of the passage of light rays, and theories of the cognitive acts involved in vision. Two competing theories existed to explain this second step, the cognitive act, one of them judgemental, the other associational.[38] According to the judgemental explanation, the synthesis of the visual impressions is a judgement. In contrast, the associational explanation describes the synthesis as a pre-judgemental act of association.

34 T. Birch, *History of the Royal Society*, London, 1967 (1744), 348–9; P. F. Gmelin, 'Epistola de Radice Ipecacuanhae Observationes Quasdam Medico-Physicas, & de Fallaci Visione per Microscopia Composita Notata Nonnulla Continens', *Philosophical Transactions of the Royal Society of London* (1744–5), **43**, 382–91.

35 B. Hindle and H. M. Hindle, 'David Rittenhouse and the illusion of reversible relief', *Isis* (1959), **50**, 135–40.

36 See especially his critical response to the anatomist and physiologist Charles Bell about the role of the eyeball's muscular activity in vision. Bell had published his discoveries concerning the muscles of the eyeball in 1823 (C. Bell, 'On the motions of the eye, in illustration of the muscles and of the orbit', *Philosophical Transactions of the Royal Society of London* (1823), **113**, 166–86). Brewster's refutation followed two years later (D. Brewster, 'Observations on the vision of impressions on the retina, in reference to certain supposed discoveries respecting vision announced by Mr. Charles Bell' (1825), in *Brewster and Wheatstone on Vision* (ed. N. Wade), London and New York, 1983, 49–56). Brewster utilized the last paragraph of this paper to air his views about the power of mental activity in perception (55–6).

37 See John Yolton's survey of accounts of sense perception in the seventeenth and eighteenth centuries: J. Yolton, *Perceptual Acquaintance from Descartes to Reid*, Minneapolis, 1984.

38 Hatfield, op. cit. (2), 39.

Brewster clearly advocated the former, judgemental, conception of perception. The case of the conversion illusion provided supporting evidence for such a conception. The article describes several experiments with engravings on a seal. These experiments show that the illusion occurs with inverting eyepieces of compound microscopes and telescopes. Brewster argued that the conversion illusion resulted from an erroneous judgement based on the observer's mistaken notion of certain peculiar circumstances under which the observation was made, in particular, of the direction of the illumination. He explained that the conversion illusion was 'the result of an operation of our own minds, whereby we *judge* of the forms of bodies by the knowledge we have acquired of light and shadow'.[39]

This was in fact not just an explanation of the conversion illusion but a general point about the nature of vision. Brewster's experiments demonstrated that the element of mental activity was a general feature of sense perception and he showed how precarious was the act of perception because of this element of mental activity. Brewster supported his more general point with additional experiments on varying arrangements that contained additional objects and light sources. He reported that similar illusions presented themselves when he viewed with a telescope the growing cornfield on Sir Walter Scott's estate at Abbotsford. The field was divided into furrows. At sunset certain furrows appeared elevated.[40] Even more disconcerting was Brewster's final observation. If the eye is directed to an intaglio mould in such a way that the surrounding objects are not viewed, 'we may coax ourselves into the belief that the intaglio is actually a bas-relief'. In other words, the illusion could be produced 'by a continued effort of the mind to deceive itself'.[41]

The demonstration of the 'power of fancy' and its dangers is the principle aim of Brewster's article. He framed his study of the conversion illusion with a general warning addressed to those who adopted a 'presumptuous confidence' in their own judgements. The study of optical illusions was to show the extent to which judgement could be deluded. Brewster's investigations were particularly effective for this purpose because the illusions appeared even in those experiments that were undertaken with the very intention to find the truth: 'how much more liable must they [the senses of sight and touch] be to error, where their passions, their prejudices, or their feelings, concur in promoting the delusion, or even in any remote degree prepare the mind for its reception'.[42] This passage shows that the study of the conversion illusion was in fact a study of the range of circumstances and influences that could diverge the judgement, namely unusual material circumstances as well as peculiar mental states.

It is helpful that Brewster also reported experiments with *mouches volantes*, because the comparison between Purkinje's and Brewster's investigations of these phenomena is highly instructive. The comparison shows how much the conceptual framework of eighteenth-century optics shaped Brewster's experiments on vision and the ways in

39 Brewster, op. cit. (33), 60, emphasis added. Notably, Brewster maintained that the greater our knowledge is about the distribution of light and shadow, the more susceptible are we to the deception.

40 Brewster, op. cit. (33), 63–4.

41 Brewster, op. cit. (33), 65.

42 Brewster, op. cit. (33), 56, 57.

which visual phenomena were explained. As we have seen, Purkinje drew on new developments in medical theory. His self-experiments sought to establish the 'objective grounds' of subject-sided sensations, conceived of as changes of the level of organic activity. The ways in which Brewster investigated and explained the *mouches volantes* were very different not only from the physicians' attempts at restoring healthy bodily conditions, but also from Purkinje's concerns with excitations of the nerves and the increased activity of the blood globules. Brewster employed optical instruments, the laws of optics and the judgemental theory of perception to model and explain the nature and mechanism of *mouches volantes*.

In the late 1830s Brewster encountered the problem of *mouches volantes* in his own eye and took the opportunity to study it more closely. The investigations resulted in a paper presented to the Royal Society of Edinburgh. According to Brewster none of the available explanations of *mouches volantes* had 'even the slightest pretension to accuracy',[43] neither with regard to the shape of these phenomena nor with respect to their nature. Brewster also stressed that *mouches volantes* were neither signs of disease nor indicators of its approach. He obtained the descriptions and illustrations presented in the paper by fixing his attention on one *mouche* in his own eye and by submitting this phenomenon to various experiments in the manner of those that he had carried out to study the relief illusion. Brewster described how the phenomenon appeared under different circumstances and illuminations. A lens or microscopic doublet of very short focus served Brewster as an experimental means to create a specific perceptual environment. To be sure, Purkinje had also suggested that gazing through a small hole or a lens directly in front of the eye was an effective means for the study of the globules and fibres in front of the eye.[44] For Brewster, however, the microscopic doublet not only provided the means to make *mouches volantes* appear but also the material model for the entire organ of vision. In some of his experiments he modelled the eye's function after the microscope. To demonstrate the mechanism through which the phenomena of *mouches volantes* were produced, Brewster sought to imitate them by crushing a crystalline lens in distilled water and observing a drop of it 'with a fine microscope a little out of focus, or with an ill-adjusted illuminating apparatus'.[45] This experimental arrangement would 'display the very same phenomena as the analogous bodies within the eyeball'.[46] Brewster regarded this as evidence for the fact that *mouches volantes* were produced by organic matter and divergent light rays. To determine the size of the *mouches volantes* and their distance from the retina, Brewster again employed the laws

43 D. Brewster, 'On the optical phenomena, nature, and locality of Muscae Volitantes; with observations on the structure of the vitreous humour, and on the vision of objects placed within the eye' (1844), in *Brewster and Wheatstone on Vision* (ed. N. Wade), London and New York, 1983, 279–87, 279.

44 Purkinje, *Beobachtungen*, 1823, op. cit. (5), 121. It is likely that Brewster was acquainted with Purkinje's work. Although the 1844 article does not cite Purkinje's writings, Brewster most probably knew Wheatstone's English rendering of Purkinje's *Contributions to and Experiments on a Physiology of the Senses* in the *Journal of the Royal Institution* of 1830 (C. Wheatstone, 'Contributions to the physiology of vision – No. I' (1830), in *Brewster and Wheatstone on Vision* (ed. N. Wade), London and New York, 1983, 248–62).

45 Brewster, op. cit. (43), 283.

46 Brewster, op. cit. (43), 283.

and methods of optics, calculating the distance of the double image that he obtained by using two different beams of light.

In the conclusion of his article Brewster took the opportunity again to stress the utilitarian and liberating character of science, which could help supply human wants and alleviate sufferings. In the case of the *mouches volantes*, a 'recondite' property of divergent light helped demonstrate that they were completely harmless. As in the case of the conversion illusion, Brewster justified his research by pointing out that science had the power of delivering us from ignorance. The optical explanation of *mouches volantes* could demonstrate that neither were these phenomena caused by disease nor were they indicators of it. Brewster stressed that it was not the least important function of science that 'she enables us, either in our own case, or in that of others, to dispel those anxieties and fears which are the necessary offspring of ignorance and error'.[47]

This is the general message that Brewster conveyed to his readers in many of his works. It is most explicitly expressed in his *Letters on Natural Magic*. Written to Sir Walter Scott and made accessible in book form to the general public, the letters deal with the very issue of elucidating the nature of optical illusions. They examine the 'principal phenomena of nature, and the leading combinations of art, which bear the impress of a supernatural character'.[48] The purpose of these letters was to reveal the mechanisms behind these deluding phenomena and thus to show that there was nothing supernatural at work. Illusions were in fact produced by artificial arrangements with mechanical contrivances through which unusual perceptual situations were created.

For Brewster, revealing the mechanisms of these arrangements was a task with moral and socio-political implications, as it helped liberate the human mind from intellectual slavery. In this regard, Brewster proved to be a true representative of the Scottish Enlightenment. Scottish scholars understood learning as a contribution to the improvement and liberation of man in the broadest sense – intellectually, morally and socially.[49] In this spirit, Brewster noted that the rulers of the past – 'even the Catholic sanctuary'[50] – had exploited the mechanisms of optical illusion to suppress and torment their people. Brewster even provided evidence from ancient texts, according to which 'a concave mirror was the principal instrument by which the heathen gods were made to appear in the ancient temples'.[51] The powerful machinery of science was then set to work, for an oppressive regime would lose its destructive power once the working of the machinery was fully understood. Optics, in particular the study of optical illusion, played a special role in this context. As Martin Kemp has aptly put it, Brewster understood optics as a tool to help present man 'with the freedom to see God's creation truly and to practise devotion unfettered by superstition'.[52] From this perspective even Brewster's seemingly frivolous invention of the kaleidoscope appears in a new light.[53] It

47 Brewster, op. cit. (43), 287.

48 D. Brewster, *Letters on Natural Magic*, London, 1832, 6.

49 N. Phillipson, 'Sir David Brewster: some concluding remarks', in Morrison-Low and Christie, op. cit. (30), 79–81.

50 Brewster, op. cit. (48), 57.

51 Brewster, op. cit. (48), 66.

52 Kemp, op. cit. (1), 206.

53 Kemp, op. cit. (1), 209.

was not just an optical toy but, along with the microscope and other optical devices, also served as a tool for the study of the perceptual link between man and God's creation and as a vehicle to make this relation transparent. It was in the hope of promoting the liberation and religious elevation of the individual that Brewster presented his work on visual phenomena, optical illusions and optical toys. As the closing line of the article on entoptical phenomena demonstrates, such statements about the liberating force of science were not confined to Brewster's writings for a popular audience.

Brewster's work on the visual organ was firmly rooted in Enlightenment conceptions and visions.[54] The judgemental theory of vision together with a mechanistic conception of the eye provided the conceptual framework that allowed for an enlightened observer. Benighted observers would be deceived either if they lacked the optical knowledge that was required to interpret sense impressions correctly or if their passions and prejudices impaired their judgements. The enlightened observer possessed sufficient knowledge about these mechanisms and about the specific circumstances of the particular perceptual situation. Optical deceptions and all kinds of natural magic could then be circumvented or at least identified as such. The conceptual tools and practices of optics made both vision and optical instruments transparent and thus enabled the observer 'to see God's creation truly'.

London: peculiar optical deceptions

Almost throughout his scientific career Brewster had to earn his and his family's keep on the fringes of Edinburgh University. His unflagging resistance to the wave theory of light would soon isolate him from the community of optics.[55] He was in many ways remote from the English capital. Yet his approach to the phenomenon of optical illusion

54 For a similar project of Enlightenment optics see J. A. Paris's three volumes on *Philosophy in Sport Made Science in Earnest; Being an Attempt to illustrate the First Principles of Natural Philosophy by the Aid of Popular Toys and Sports*, written for adolescents. The book relates the story of a certain Tom Seymour, a boy who spends his school vacations with his family and learns from his father the scientific principles behind his various leisurely occupations. The third volume of the book ends with a narration of the festivities at the end of his vacations. The highlight of the party is the performance of a conjuror who entertains the audience with all sorts of optical illusions, as, for example, 'phantasmagoria' exhibiting 'a variety of ghastly objects, which alternately receding from, and approaching the audience, called forth shrieks of terror and amazement'. As one of the 'most appalling of these figures' appeared the 'headless horseman of Sleepy Hollow' (J. A. Paris, *Philosophy in Sport Made Science in Earnest; Being an Attempt to illustrate the First Principles of Natural Philosophy by the Aid of Popular Toys and Sports*, 3 vols., London, 1827, iii, 77–80). Although the book does not in fact provide explanations for these scary events – the boy, 'quite impatient' to know them, is promised further instructions during Christmas vacations – it is stressed that all these apparitions could be explained by scientific principles.

55 Brewster's early research on light culminated in the article 'Light' for the *Edinburgh Encyclopaedia* in 1822. In this article Brewster advocated a projectile theory of light that he compared favourably to the competing wave theory. Only a few years after the publication of the article the wave theory of light became prominent; see J. Z. Buchwald, *The Rise of the Wave Theory of Light: Optical Theory and Experiment in the Early Nineteenth Century*, Chicago, 1989; Cantor, *Optics After Newton*, op. cit. (31). Brewster, who did acknowledge the success of the wave theory, continued to claim that its explanatory power was limited, as it could not deal with such phenomena as selective absorption and refractive dispersion. See G. N. Cantor, 'Brewster on the nature of light', in Morrison-Low and Christie, op. cit. (30), 67–76, 72.

and other delusive phenomena was rather typical of the way in which the process of seeing was examined and explained in early nineteenth-century Britain.

In mid-1820s London vision and deception had also become matters of interest. At the Royal Institution Michael Faraday described and analysed several 'peculiar optical deceptions'.[56] His publication of 1830 begins by drawing attention to 'peculiar' kinds of deception that occur in everyday contexts, such as the cogs and spokes of the moving wheels of mills and carriages. When in motion these cogs and spokes appeared to behave in strange ways. They seemed to be bent or stationary. Faraday not only described such appearances as he encountered them in various everyday contexts but also contrived arrangements with cardboard wheels, pins and different light sources to study their nature and mechanism. Like Brewster, he conducted series of experiments on such arrangements, altering the circumstances of the perceptual situation, such as the position of the wheels, their speed and their direction of spin, as well as colour and illumination.[57] As with the mill and carriage wheels, he found that when set in motion the wheels of his contraptions produced the appearance of stationary cogs, curved arcs and the like.

What was 'peculiar' about these phenomena? It might at first seem peculiar that Faraday was at all concerned with such investigations. Around 1830 he was mainly interested in the relations between electricity and magnetism. He conducted research on the nature of light, but only later in his career.[58] His early researches in the field of optics were confined to experiments with the quality of optical glass.[59] But a glance at Faraday's immediate social context suggests that his interest in perception was very likely inspired and stimulated by the works of his colleagues and friends. At least two, Peter Mark Roget and Charles Wheatstone, were deeply engaged in research on sense perception. Roget was the secretary of the Royal Society from 1827 to 1848. In this function he was also Faraday's addressee in matters relating to optical glass. Among other things, he was the inventor of a calculating machine, and the author of the celebrated *Thesaurus*, of an 1834 treatise on animal and vegetable physiology and, more importantly for the present context, of an article on the 'wheel illusion' published in 1825. This article describes the peculiar appearance of the spokes of moving wheels. Gazing through the slits of venetian blinds at carriages passing by, Roget noted that the spokes of their wheels appeared curved. Puzzled by this observation, he then studied the

56 M. Faraday, 'On a peculiar class of optical deceptions', in *idem*, *Experimental Researches in Chemistry and Physics*, Brussels, 1969, 291–311.

57 On Faraday's 'perceptual rehearsal' of the optical deception see M. F. Ippolito and R. D. Tweney, 'The inception of insight', in *The Nature of Insight* (ed. J. E. Davidson and R. J. Sternberg), Cambridge, MA, 1995, 435–9.

58 F. A. J. L. James, '"The optical mode of investigation": light and matter in Faraday's natural philosophy', in *Faraday Rediscovered: Essays on the Life and Work of Michael Faraday, 1791–1867* (ed. D. Gooding and F. A. J. L. James), New York, 1985, 137–61.

59 These investigations, which occupied Faraday for several years, were made on request of the Joint Commission of the Board of Longitude and the Royal Society and were intended to improve the quality of British glass-making. The improvement of optical glass was thought to be necessary because the British hegemony in the production of optical instruments had become increasingly threatened by the Bavarian optical industry (see M. W. Jackson, *Spectrum of Belief: Joseph von Fraunhofer and the Craft of Precision Optics*, Cambridge, MA, 2000, 136–41).

phenomenon under different circumstances, changing the illumination, the velocity of the moving wheel and the order and size of the slits. To explain the peculiar appearance of the curved spokes, Roget parallelled the phenomenon to the visual illusion that can be produced if a bright object is wheeled around in a circle: such an object seems to draw a line of light.[60] The curved spokes and the traces of light as well as numerous analogous phenomena could be explained as an effect of the retina's power of retaining visual impressions for a certain time.

Faraday linked his work explicitly to this paper. Roget also noted that he and Faraday were in communication about Roget's work in the 1820s.[61] It was in the 1820s, too, that Faraday befriended Charles Wheatstone. Intrigued by Wheatstone's work on acoustics and musical instruments, Faraday communicated some of Wheatstone's results to the audience of the Royal Society Friday Evening Lectures.[62] In the context of his work on acoustics, Wheatstone also dealt with questions concerning visual perception. His 1827 paper on the kaleidophone, a 'philosophical toy' designed by Wheatstone, described 'several interesting and amusing acoustical and optical phenomena'.[63] The kaleidophone consisted of thin steel rods mounted vertically on a base and surmounted with reflecting glass beads. If the rods were set in motion through vibrations, the observer could see peculiar curvilinear, epicycloidal forms, which were produced by the movements of the beads. Like Roget, Wheatstone pointed out that these phenomena were due to the retina's power of retaining visual impressions. In a footnote Wheatstone explicitly linked his investigations to optical research that had been carried out in the mid-eighteenth century. He referred to experiments by the Chevalier d'Arcy of 1765, which had determined the exact duration in the same place of the visible images.[64]

Once again, what is 'peculiar' about the optical deception that Faraday presented? Faraday notably described the optical deceptions not merely as 'peculiar' and 'very curious'[65] but also as 'striking',[66] 'extraordinary'[67] and 'very beautiful'.[68] Like Wheatstone, he stressed that they promised 'amusement'[69] and could be observed with the 'utmost facility'.[70] For example, a very striking deception could be obtained if a single cogwheel were revolved in front of a looking glass in such a way that the

60 P. M. Roget, 'Explanation of an optical deception in the appearance of the spokes of a wheel seen through vertical apertures', *Philosophical Transactions of the Royal Society of London* (1825), **115**, 131–40, 135.

61 P. M. Roget, *Animal and Vegetable Physiology Considered with Reference to Natural Theology. Bridgewater Treatise V*, London, 1834, 524, footnote.

62 L. P. Williams, *Michael Faraday: A Biography*, London, 1965, 17.

63 C. Wheatstone, 'Description of the kaleidophone, or phonic kaleidoscope; a new philosophical toy, for the illustration of several interesting and amusing acoustical and optical phenomena' (1827), in *Brewster and Wheatstone on Vision* (ed. N. Wade), London, 1983, 205–12.

64 Wheatstone, op. cit. (63), 211.

65 Faraday, op. cit. (56), 310.

66 Faraday, op. cit. (56), 295, 303.

67 Faraday, op. cit. (56), 295.

68 Faraday, op. cit. (56), 303, 311.

69 Faraday, op. cit. (56), 309.

70 Faraday, op. cit. (56), 291.

experimenter might see the glass through the cogs. Then the image in the glass would appear perfectly still, whereas under direct vision the cogs could not be distinguished from each other. Roget would later also allude to the 'amusing' nature of such phenomena. He related in his *Physiology* that he had constructed an optical toy on the same principle as Faraday's cogwheel, a phenakistiscope. But 'in consequence of occupations and cares of a more serious kind'[71] he had not published an account of this machine, probably much to his chagrin, because by 1834 the Belgian equivalent, devised by Plateau not long after Roget's experiments, had already become a great success.

Such phenomena were peculiar, very striking and amazing, but certainly not anomalous for Faraday. He was by no means at a loss about how to interpret them or unable to offer an explanation for the optical deceptions. He not only repeatedly remarked that the observations and the apparatus that were required were 'very simple' and that the effects could be obtained 'with great simplicity',[72] but also emphasized that they could be explained through the retina's power of retaining visual impressions for a certain period of time. Due to this power, recurring visual impressions were connected in perception and appeared as one continued impression. Thus a superposition of phenomena could occur, since

> during such impressions, the eye, although to the mind occupied by an object, is still open, for a large proportion of time, to receive impressions from other sources; for the original object looked at is not in the way to act as a screen, and shut out all else from sight; the result is, that two or more objects may seem to exist before the eye at once, being visually superposed.[73]

The cause of the effects Faraday observed was 'sufficiently obvious' – it was a familiar power of the sense organs. 'The eye has the power, *as is well known*, of retaining visual impressions for a sensible period of time; and in this way, recurring actions, made sufficiently near to each other, are perceptibly connected, and made to appear as a continued impression.'[74]

Faraday's paper also draws connections to other 'effects of this kind *which are well known*', effects which occurred with optical toys such as the kaleidoscope and the thaumatrope and the 'schoolboy experiment of seeing both sides of a whirling halfpenny at the same moment'.[75] What did Faraday mean when he described these phenomena as 'well known'? Faraday himself never explicitly developed a theory of vision. Most likely, he simply referred to the work of his colleagues Wheatstone and Roget on persistence of visual impressions, which built on similar researches of the later eighteenth century.[76] In any case, it is obvious that Faraday himself did not regard the

71 Roget, op. cit. (61), 524, footnote.

72 Faraday, op. cit. (56), 293, 303.

73 Faraday, op. cit. (56), 296–7.

74 Faraday, op. cit. (56), 296; emphasis added.

75 Faraday, op. cit. (56), 296, 297; emphasis added.

76 Chevalier d'Arcy's experiments are mentioned above. Closer to home, Robert Waring Darwin and Erasmus Darwin published on ocular spectra in the *Philosophical Transactions* of 1786 (R. W. and E. Darwin, 'New experiments on the ocular spectra of light and colours', *Philosophical Transactions of the Royal Society of London* (1786), **76**, 313–48). The Darwins accounted for a number of remarkable visual phenomena related to the persistence of vision.

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'peculiar' wheel illusions as anomalies or surprising violations of expectations. They were curious, striking and amazing, but not puzzling. In particular, they did not transgress the boundaries of eighteenth-century optics. Apparatus such as Faraday's cardboard contraptions changed the material conditions of seeing and the circumstances of observation to reproduce the deceptions in question and to understand the mechanisms behind them. The deceptions produced by Faraday's optical devices demonstrated once more the general dependence of visual perception on the circumstances in which the act of perception took place. Complex experimental settings directed attention to the external conditions of perception, light and the unusual arrangements and movements of perceptual objects.

Brewster explicitly tied his investigations of optical illusions to the Enlightenment visions of liberating the mind from intellectual slavery through the power of mental education. Faraday's interest in mental education was no less explicit. In later years he published a methodological paper entitled 'Observations on mental education'. It is the text of a lecture whose principal aim was the avoidance of error through the education of the mind. If Faraday had attached any fundamental epistemological or methodological importance to the deceptive powers of the eye, he surely would have discussed it in this paper. But there are no references to 'peculiar' or otherwise remarkable optical deceptions in this essay. Faraday did acknowledge that one could be mistaken in perception, but he held that this was due to erroneous judgements made about the impressions presented by the sense organs. 'Our sense perceptions are wonderful', Faraday declared, but 'the mind has to be instructed with regard to the senses and their intimations through every step of life'.[77] Faraday suggested that deceptions occurred to the 'uninstructed', to those who wrongly believed their senses. Perceptual error 'ought to be considered, rather, as an *error of the judgment* than of the sense, for the latter has performed its duty; the indication is always correct, and in harmony with the great truth of nature. Where, then, is the mistake? – almost entirely with our judgment'.[78] The mind constructed perceptions through inferences from sense impressions and in this could err. What might go wrong in perception was the judgement by which the circumstances relevant to our perceptual situation were assessed. The experiments established the characteristics of those perceptual situations in which deceptions appeared in order to help observers make correct judgements about their perceptual environments. Light sources and modes of illumination, as well as optical devices like Faraday's little machines with moving cardboard wheels, served as the crucial variables in such perceptual environments.

In summary, it might be said that Brewster and Faraday were concerned with metaphysical questions respecting vision. They explored the possibility of acquiring knowledge of nature in visual perception. This was the broader context and the driving force for their research into optical deceptions. Both Brewster's and Faraday's researches show that the introduction of experimental devices and arrangements of novel kinds did not immediately and per se yield a new image of the observer.

77 M. Faraday, 'Observations on mental education', in *idem*, *Experimental Researches in Chemistry and Physics*, Brussels, 1969, 463–91, 466. The text was originally published in 1855.

78 Faraday, op. cit. (77), 468; emphasis in original.

Experiments with self-made optical toys served to illustrate and reinforce well-established theories of vision and the nature and role of the enlightened observer that were described by these theories.

How distant the British work was from the German approach to vision becomes strikingly apparent in Wheatstone's short introduction to the translation of Purkinje's experiments on sensory functions which he published in the *Journal of the Royal Institution* in 1830. The text is not a complete translation but an abridged rendering of Purkinje's early contributions to the physiology of the senses. Remarkably, Wheatstone omitted most of the introductory paragraphs in which Purkinje had outlined his goal to study the sense of vision in its own life and in its peculiar reaction against the external world. He rather presented Purkinje's investigations as part of the ongoing study of vision, which 'has a peculiar claim on the attention of philosophers, as presenting some of those links which *connect physical with mental phenomena*'.[79] Wheatstone called this project 'physiology', but as the quote shows, his was a physiology rooted in eighteenth-century optics. This was a physiology still in the spirit of Kepler and Descartes, based on the dualism of mind and (physical) body, not a physiology concerned with an organic body as an extended region mediating between the mind and the external world.

London: worlds apart

Does this mean that the British did not take part in the 'embodiment' of vision in the form encountered in the German lands? To answer this question, it is instructive to take a closer look at the work of Faraday's colleague Peter Mark Roget. While Roget's article on the wheel illusion fits squarely with Faraday's research and indeed motivated it, Roget approached the problem of optical deception from a significantly different angle in his physiological treatise *Animal and Vegetable Physiology*. Roget also acknowledged the complex heterogeneous nature of perception and stressed that the enquiry into 'the origin, the formation, and the laws of our perception' required 'the combined efforts of the physiologist and the metaphysician'.[80] Roget's conception of sensory physiology, however, was quite different from Wheatstone's. In his *Animal and Vegetable Physiology*, Roget divided perception between three aspects: bodily processes brought about by external agents, sensations or mental affections brought about by bodily activity, and perceptions derived from sensations by intellectual processes. As in almost all works on vision from the period, the structure of the eye is still presented in optical terms. The section on the 'physiology of perfect vision' in the *Physiology* begins with a description of the conditions of perfect vision. Regarded as an optical apparatus, the eye has several deficiencies such as the aberration of sphericity, the aberration of the parallax and chromatic aberration. Roget stressed, for instance, that this latter deficiency 'necessarily impairs the distinctness of all the images produced by refraction'. This 'defect' is 'incident to the power of a simple lens' and hence also to the eye.[81]

79 Wheatstone, op. cit. (44), 248–9, emphasis added.
80 Roget, op. cit. (61), 509, 510.
81 Roget, op. cit. (61), 474.

But Roget also pointed out that the eye was more than an optical device for conveying nature's properties to the mind. It was an organ of vision whose activity conditioned and indeed potentially impeded the perception of the external world. Roget's text draws particular attention to the fact that sensations could not be 'depended upon as being always exactly correspondent with the qualities of the external agent which excites them'.[82] In Roget's account of perception, the observer becomes a dual entity, a mind furnished with active, spontaneously acting sense organs.

Roget's threefold theory of perception provides the basis for the taxonomy of perceptual illusions. One particular class of illusions is linked to each of the three aspects. The first class contains those illusions produced by unusual circumstances of observations, such as echoes and ventriloquism, which might mislead the judgement. The conversion illusion and similar deceptions belong to this class. The third class consists of illusions produced solely by erroneous reasoning processes. But, most remarkably, Roget delineated a class of illusions that were produced by 'internal' causes, in particular 'the peculiar condition of the nervous surface receiving the impressions'.[83] Roget ventured the opinion that these illusions were 'occasioned by spontaneous affections of the retina itself, which are conveyed to the sensorium'.[84] These spontaneous affections were due to organic nervous actions.

Roget's enquiries into the laws of sensation and perception indicated not only that the healthy eye was structurally imperfect, but also that its performance did not always yield veridical perceptions of the external world. Roget's conception of vision as a threefold physical, bodily and mental process seems very closely to approach the German accounts. Should it then be concluded that Roget's work exemplifies the embodiment of vision on the British side of the Channel? To an extent this conclusion is correct. But one should not overlook the still significant differences between Roget's physiology and the physiological experiments in the German lands, which reflect the different argumentative contexts in which these researches took place. Roget was a staunch advocate of natural theology, and his *Animal and Vegetable Physiology* was in fact published as the fifth volume of the *Bridgewater Treatises: On the Power, Wisdom, and Goodness of God, as Manifested in the Creation*. The *Treatises* were meant to reconcile science and religion by showing how any branch of science could serve the purposes of natural theology.[85] This purpose also informed Roget's account of sensation and perception. His reference to the 'power and wisdom' of the Creator in the *Physiology* is not pious lip-service for a broader audience. The authors of the *Bridgewater Treatises* were a carefully chosen group, hand-picked for their beliefs.[86]

82 Roget, op. cit. (61), 515–16.

83 Roget, op. cit. (61), 533.

84 Roget, op. cit. (61), 525.

85 Their authors were clergymen, physicians and eminent men of science such as Charles Bell (on the *Hand, Its Mechanism and Vital Endowments, as Evincing Design*, London, 1833) and William Whewell (on *Astronomy and General Physics, Considered with Reference to Natural Theology*, London 1833). See Jon Topham, 'Science and popular education in the 1830s: the role of the *Bridgewater Treatises*', *BJHS* (1992), 25, 397–430.

86 For details of how the authors of the Bridgewater Treatises were chosen, see William Brock, 'The selection of the authors of the Bridgewater Treatises', *Notes and Records of the Royal Society of London*

In his *Physiology*, Roget advanced the belief that on 'none of the works of the Creator, which we are permitted to behold, have the characters of intention been more deeply and legibly engraved than in the organ of vision'.[87] Like others before him, most notably William Paley, Roget presented the eye as an ocular machine, a camera obscura, 'an infinitely more perfect instrument than the latter can ever be rendered by the utmost efforts of human art'.[88] It was precisely the perfection of the ocular machine that testified to the great power and wisdom of the Creator.

The detailed accounts of the processes of sensation and perception in *Animal and Vegetable Physiology* intended to offer an illustration of the higher meaning of these processes. It is initially astonishing to find that according to Roget the performance of the organ of vision is riddled with various deficiencies. Deficiencies like spherical and chromatic aberrations are fundamentally different from those other deficiencies of the eyeball that cause near- and farsightedness. The latter problems are due to an individual divergence from the healthy state of the eye, but the former are built-in deficiencies that belie the notion of the 'perfect ocular machine' that had been so central to natural theology. Roget's *Animal and Vegetable Physiology* demonstrates, however, that these features could well be combined with the metaphysical principles of natural theology. The argument from design as it is presented in this book builds on a notion of functional adjustment rather than on a concept of the perfection of a mechanical device in terms of its mechanical properties, delicate mechanism and fine detail.[89] The eye's defects could be remedied 'almost perfectly', so that they eye, 'though not an absolutely achromatic instrument, as was asserted by Euler, is yet sufficiently so for all the ordinary practical purposes of life'.[90] Drawing on the notion of functional adjustment, Roget could concede that there were situations and contexts for which the eye was not perfectly suited, while suggesting that our senses 'have been studiously adjusted, not only to the properties and the constitution of the material world, but also to the respective wants and necessities of each species, in the situations and circumstances where it has been placed by the gracious and beneficent Author of its being'.[91]

Roget certainly did stress the 'discordance' between perceptions and external agents, which he traced to the 'peculiar' conditions and 'imperfections' of the sense organ. But the agenda behind his work was very similar to his contemporaries' epistemological goals. In the Gulstonian Lectures which Roget read to the Royal College of Physicians in 1832 he explicitly stated that an 'intimate acquaintance' with the laws of sensation and perception was 'necessary for the discovery of the most effectual methods of acquiring knowledge, and of discriminating truth from

(1966), **21**, 162–79; and more generally Jon Topham, 'Beyond the common context: the production and reading of the *Bridgewater Treatises*', *Isis* (1998), **89**, 233–62.

87 Roget, op. cit. (61), 445–6.

88 Roget, op. cit. (61), 459.

89 This is also true of William Paley's *Natural Theology*. On Paley's functional interpretation of organic mechanisms see N. C. Gillespie, 'Divine design and the industrial revolution: William Paley's abortive reform of natural theology', *Isis* (1990), **81**, 214–29.

90 Roget, op. cit. (61), 474–5. A footnote to this sentence refers to Thomas Young, who had rectified Euler's error.

91 Roget, op. cit. (61), 534.

error'.[92] His sensory physiological writings helped Roget acquaint his readers with those laws. One should not underestimate the epistemological resources Roget had at his disposal to compensate for the imperfection of the eye and the activity of the sense of vision. 'Spontaneous' actions of the retina, internal 'disorders' and 'disordered conditions' could bring about deceptions but the illusions caused by internal agents were constrained by the very physical laws that governed ordinary perception, only acting under 'unusual or irregular combinations of circumstances'.[93] While Brewster sought to elucidate the relationship between humanity and God's creation with the means of physical optics, Roget sought illumination in the physiology of vision. However, both projects were epistemologically optimistic in the sense that optics and physiology were expected to make possible 'the discovery of the most effectual methods of acquiring knowledge, and of discriminating truth from error'. In the investigations and experiments on peculiar optical deceptions – including the classical conversion illusion – the possibility of acquiring visual knowledge as such was never at stake.

The common agenda: epistemological optimism

Previous sections of this paper showed that the experimental practice and the conceptual tools with which the problem of vision was approached east and west of the North Sea differed considerably. The British scholars devised experimental set-ups that directed attention both to the external conditions of perception and to the judgemental powers of the observer. Light sources and modes of illumination, as well as optical contrivances such as mirrors, lenses, telescopes and microscopes, were the crucial variables in these perceptual environments. Apparatus like Faraday's cardboard devices aimed to uncover the mechanisms by which perceptual deceptions were produced. In contrast, the physiologists in the German lands designed their experiments in such a way that the experimenter's sense organs were directly manipulated. Eighteenth-century optics and natural theology produced a very different conceptual framework from medical theories of sensibility and the reflexive philosophy of subject–object. The former relied on regulations for the observer and a body of knowledge, namely optics, that could 'help man see God's creation truly'. The latter acknowledged and reckoned with the irreducible activity of the knower's body in experience. We have seen that even Roget's physiology is worlds apart from the German physiologists' concerns with the organic body and its activity. The contexts, practices and conceptual frameworks for early nineteenth-century vision studies were fundamentally different in Britain and in the German lands.

Nevertheless, similar epistemological consequences were drawn from these studies. If Purkinje's and Müller's agendas are compared with the agenda behind the investigations of their contemporaries in Britain, one can highlight significant parallels. None of these investigators drew radically sceptical epistemological consequences. Purkinje

92 P. M. Roget, 'Abstract of the Gulstonian Lectures, read to the Royal College of Physicians on the 2nd, 4th, and 9th of May, 1832', *London Medical Gazette* (1832), **10**, 273–82, 273.

93 Roget, op. cit. (61), 532.

and Müller revealed the mediation of subject and object through the sense of vision. Brewster and Faraday uncovered the mechanisms of optical illusions. Although Roget acknowledged that the 'spontaneous' activity of the retina could impede the act of perception, he based his epistemological assessment of the relation between the perceiver and the external world on the fact that an analysis of this relation in terms of physical laws was possible. In this respect, Roget's results were epistemologically encouraging. Although the sense organ's activity was understood as affecting and occasionally impeding veridical perception, it was assumed that the eye's impact on the outcome of acts of perception could be determined and truth and error in perception could be teased apart. Taken together, the implications of the studies of perception and its failures did not have any disastrous epistemological consequences. In fact, the experiments suggested that deceptions could be avoided – or at least uncovered – through correct interpretations of the perceptual situation in question. The possibility of acquiring empirical knowledge was not threatened. On the contrary, it appeared secured.