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Magnetic flimmers: 'light in the electromagnetic darkness'

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Transcranial magnetic stimulation has become an important field for both research in neuroscience and for therapy since Barker in 1985 showed that it was possible to stimulate the human motor cortex with an electromagnet. Today for instance, transcranial magnetic stimulation can be used to measure nerve conduction velocities and to create virtual lesions in the brain. The latter option creates the possibility to inactivate parts of the brain temporarily without permanent damage. In 2008, the American Food and Drugs Administration approved repetitive transcranial magnetic stimulation as a therapy for major depression under strict conditions. Repetitive transcranial magnetic stimulation has not yet been cleared for treatment of other diseases, including schizophrenia, anxiety disorders, obesity and Parkinson's disease, but results seem promising. Transcranial magnetic stimulation, however, was not invented at the end of the 20th century. The discovery of electromagnetism, the enthusiasm for electricity and electrotherapy, and the interest in Beard's concept of neurasthenia already resulted in the first electromagnetic treatments in the late 19th and early 20th century. In this article, we provide a history of electromagnetic stimulation circa 1900. From the data, we conclude that Mesmer's late 18th century ideas of 'animal magnetism' and the 19th century absence of physiological proof had a negative influence on the acceptance of this therapy during the first decades of the 20th century. Electromagnetism disappeared from neurological textbooks in the early 20th century to recur at the end of that century.

Keywords: history of medicine; history of electromagnetic stimulation; phosphene; d'Arsonval; transcranial magnetic stimulation

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Introduction

> 'Right hemisphere [electromagnetic] stimulation decreases lying, left hemisphere stimulation increases lying. Spontaneous choice to lie more or less can be influenced by brain stimulation'. (Karton and Bachmann, 2011)

Transcranial magnetic stimulation has been a hot topic since the 1980s both with respect to research (e.g. the pathophysiology of migraine; Mulleners *et al*., 2001) as well as treatment, for depression among others (Barker *et al*., 1985; Lisanby *et al*., 2002; Walsh and Pascual-Leone, 2003; Bolotova *et al*., 2006; Wu *et al*., 2008). Magnetic stimulation, however, is not a new phenomenon. At the end of the 19th century and at the beginning of the 20th century, French as well as German scientists and physicians exposed their patients to the influence of electromagnets. This type of research was part of a physical approach to nature and to therapeutic possibilities based on August Comte's

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(1798–1857) positivistic philosophy, applied to medicine by Claude Bernard (1813–78), Emil Du Bois-Reymond (1818–96), Hermann von Helmholtz (1821–94) and Rudolf Virchow (1821–1902) (Paul, 1985; LeGouis, 1997) among others. At the time, patients had the choice to visit several institutes to be treated with light therapy, hydrotherapy, massage, gymnastics and electrotherapy. Physicians working at such institutes had knowledge of general medical as well as neurological diseases. The discovery of electromagnetism, enthusiasm for electricity and electrotherapy (Killen, 2006) and the interest in Germany in Beard's concept of neurasthenia would lead to the first electromagnetic therapies at the end of the 19th and the beginning of the 20th century (Sicherman, 1977; Berrios and Porter, 1995). In this article, we review the evolution of (electro)magnetic stimulation and try to answer the question why interest in this therapy waned after the first decade of the 20th century.

Electrical stimulation: pre-19th century

To get a grasp of the evolution of magnetic stimulation, it is important to understand its relation with electricity and electrical stimulation. During the 16th and 17th century, these phenomena were interesting study topics. William Gilbert (1544–1603), the English physician at the court of Queen Elizabeth I, Niccolò Cabeo (1586–1650) and Robert Boyle (1627–91) investigated the phenomenon of electricity. In 1743, professor of philosophy and medicine Johann Gottlobb Krüger (1715–59) was one of the first to suggest that electrification could influence deeper structures within the human body, which could heal and sustain health. The discovery of the Leyden jar (1745) became an enormous stimulant for medical application of static electricity. The Swiss professor of experimental philosophy and mathematics Jean Jallabert (1712–68) was the first to cure a paralytic patient with static electricity. In the second half of the 18th century, the idea took hold that there was a relationship between electricity and the nervous system. The discovery of the nature of the effect of electric fish played a role with this respect (Koehler *et al*., 2009). This and several other events at the end of the 18th century resulted in medical electricity becoming more or less accepted as official medical treatment.

Beyond static electricity at the end of the 18th century, Luigi Galvani (1737–98) proposed the existence of what he thought of as autonomous 'animal electricity'. In 1781, he observed muscle contractions when an assistant touched the femoral nerve of a dead frog with a scalpel. In 1786, he again saw muscle contractions when he connected a frog on a brass hook with an iron fence. Alessandro Volta (1745–1826) was not convinced that intrinsic animal electricity existed; all of Galvani's results could be explained by bimetallic electricity. A fierce international debate about the origin of animal electricity ensued. The discussion ended when in 1797 Alexander von Humboldt (1769–1859), after extensive research, proved that both animal and bimetallic electricity existed. Du Bois-Reymond came up with conclusive evidence some 50 years later. Galvanism—as the newly discovered bimetallic electricity was called—gave an extra boost to the therapeutic use of electricity. Although criticism was voiced (Finger, 2006*b*), these treatments were largely considered successful and at the end of the 18th century, medical electricity was more or less accepted as official medical conduct (Rowbottom and Susskind, 1984, pp. 7–54; Vijselaar, 1999, pp. 51–5; Finger, 2004, pp. 101–17; McComas, 2011, pp. 21–40).

Magnetic stimulation: pre-19th century

Medical practitioners exposed their patients to mineral magnetism since ancient Greek medicine. They used mineral magnets with a weak magnetic field. Around 1600, Gilbert was the first person to extensively describe magnetic phenomena (Gilbert, 1600). John Michell (1724–93) took an important technological step around 1750, when he was able to create more powerful magnets artificially (Michell, 1750).

At the time, naturalists assumed electricity and magnetism were related. Electricity as well as mineral magnets could attract and repel other objects. At the same time, the idea took hold that electricity and nerve function were related (Aepinus, 1759), although the relationship between magnets and the nervous system was not obvious (Piccolino, 1998; Finger, 2006*a*; Koehler *et al*., 2009). Electrical stimulation was painful, it caused tingling and made muscles contract, whereas magnets did not. As electrical stimulation became very popular, it was a small step for therapists to treat patients with (artificial) mineral magnets.

Mineral magnetism and mineral magnetic treatment were taken seriously. In 1774, the Bavarian Scientific Academy held a contest about the possible electric and magnetic effects on the nervous system. In France, physicians Charles-Louis-François Andry (1741–1829) and Michel-Augustin Thouret (1748–1810), associated with the Paris Société Royale de Médicine, concluded that mineral magnets indeed influenced the human nerve system. They were able to increase fever, migraine and itching.

In the USA, Elisha Perkins (1741–99) treated patients with two artificial mineral magnets, so called 'tractors'. During one of the sessions, he observed a muscle contraction, which convinced Perkins of the efficacy of his mineral magnets. This treatment, applied to treat headaches, rheumatic symptoms, paralysis and other symptoms, became popular in the USA and England (Perkins, 1798; Rowbottom and Susskind, 1984, pp. 55–70; Vijselaar, 1999, p. 64).

During the last quarter of the 18th century, physician Franz Anton Mesmer's (1734–1815) ideas played a paradoxical role in propagating medical magnetism. He stimulated the use of mineral magnets initially, but subsequently developed a new theory, notably 'animal magnetism'. A therapist, according to Mesmer, should be able to magnetize a patient without tools, thus also without a mineral magnet. According to Mesmer's ideas, a healthy person contained a balanced quantity of magnetic fluid. A diseased person was supposed to have a lack of this magnetic fluid, whereas a therapist had it in excess. By 'magnetizing' his

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patient, the therapist was supposed to be able to transfer some of his excess magnetic fluid to the patient (Vijselaar, 1999, p. 60–70).

At first, Mesmer's 'animal magnetism' and Perkin's tractors were received with enthusiasm in Germany, France and England. However, eventually the scientific community would consider medical magnetism as quackery. In 1784, a French Royal Commission, set up by Louis XVI and including Antoine Lavoisier (1743–94), Joseph-Ignace Guillotin (1738–1814) and Benjamin Franklin (1706–90), examined Mesmer's claims. Although patients were sometimes cured by 'animal magnetism', the commission found no evidence for the existence of Mesmer's magnetic fluid. The therapeutic effect was based on suggestion and fraud. In 1799, physician John Haygarth (1740–1828) and surgeon Richard Smith showed that Perkins' therapeutic effect was based on suggestion and fraud (Vijselaar, 1999, p. 236). The ideas of quackery, suggestion and fraud would continue to haunt both animal and mineral magnetic stimulation for at least a century.

Discovery of electromagnetism

An important step in determining the relation between the human body and magnetism was the discovery of electromagnetism and the electromagnet. In 1820, the Danish scientist Hans Christian Ørsted (1777–1851) uncovered the relationship between electricity and magnetism. During one of his lectures, he observed movements in a magnetic needle in the vicinity of an electric current. Based on this observation, Ørsted concluded that electricity evoked magnetic effects.

Using Ørsted's result, the French professor of mathematics André-Marie Ampère (1775–1836) built a complex electromagnetic apparatus. Among others, he constructed a big 'solenoid' (derived from the Greek words 'solen' meaning 'pipe' and 'eidos' meaning 'shape') (Harper, 2011). This solenoid consisted of a spiral-shaped electrical wire. He concluded that this solenoid worked as a magnet if an electrical current flowed through the wire.

The most important contribution came from Michael Faraday (1791–1867), who published the principle of reciprocity. A magnet could induce electricity in an electrical wire and vice versa, an electrical wire could move a magnet. The principle became the basis for electromotors and electromagnets. Faraday demonstrated these results in 1831 and published them in 1832 (Faraday, 1832).

In 1854, Faraday concluded that electromagnets influenced not only metal conductors but also moist conductors. This increased the possible span of influence of electromagnets to the human body (Faraday, 1854). In 1861, James Clerk Maxwell (1831–79) published his fundamental equations by which he mathematically proved mutual induction. From the equations it became clear that mutual induction is driven by the change of the magnetic field in time and not by the strength of the magnetic field (Maxwell, 1890).

Physiological research

Ørsted's and Faraday's discoveries stimulated new interest in electrotherapy and it became a discipline on its own. With the discovery of the electromagnet, which produced stronger magnetic forces and time-varying fields, researchers hoped to strip (electro)magnetic stimulation from its Mesmeric stigma. First, electromagnets could produce stronger magnetic fields than mineral magnets. Second, researchers could use time-varying magnetic fields for stimulation. The easiest way to generate such a magnetic field is to interrupt and start the current at certain time intervals.

Because electricity and magnetism were related and because moist conductors were influenced by electromagnets, researchers in magnetic stimulation began looking for the (possibility of) magnetic induction of muscle contractions and other physiological proof. Therefore, they exposed dead and living tissue to different magnetic fields. The results varied significantly. Some researchers such as Heidenreich (*nk*) in Germany (Hermann, 1888) and M'Kendrick (*nk*) in England (M'Kendrick, 1879) found evidence that (electro)magnetic fields caused muscle contractions in dead tissue. Others [Du Bois-Reymond, Brunner (*nk*)] questioned these results (Hermann, 1888). Also, agreement on the influence on living tissue was not reached. Professor Keil (of Jena) exposed Faraday to a strong magnetic field but Faraday did not notice anything. Keil's observations did not agree with observations documented by the Roman physician Carlo Maggiorani (1800–85) who described the occurrence of dizziness in subjects after exposure to a mineral magnet. These symptoms matched the symptoms of persons with lesions in the cerebellum (Magini and Maggiorani, 1886). Around 1880, a physician from Dublin reported that human subjects experienced headaches, disturbance of consciousness and dizziness after being exposed to strong electromagnetic fields. But at the end of the century, Lord Lindsay, later Earl of Crawford (1847–1913) and C. F. Warley (*nk*) reported that their subjects did not experience any symptoms at all in an electromagnet with a time-varying magnetic field. Nevertheless, Lord Kelvin (1824–1907) was convinced that magnetic fields [in the future] would have a noticeable effect on human beings (Colombo, 1906). As a result of the complexity and because of lack of added value, therapists almost only used mineral magnets for magnetic therapy during the second half of the 19th century.

Mineral magnetic therapy

Despite lack of proof and Mesmer's shadow, therapists continued to use mineral magnet therapy. They applied the mineral magnet therapy in three forms. First, a magnet could be used as an inductor for hypnoses. The Scottish surgeon James Braid (1795–1860) asked his patients to fixate on a mineral magnet. As a result, he believed, the nervous system became exhausted and the patient became hypnotized. Vienna's famous electrotherapist and neurologist Moritz Benedikt (1835–1920) also used a mineral magnet as an inductor for hypnosis. However, induction of hypnosis was not limited to a magnet. Other objects such as a candle also induced hypnosis. Second, in hysterics, a mineral magnet could be used to transfer symptoms from one part of the body to another [Marie-Ernest Gellé (1834–1923), Alfred Binet (1857–1911), Charles Féré (1852–1907)]. In 1886, the French physician Joseph Babinski (1857–1932) was able to transfer hemianaesthic symptoms from one hysterical patient to another (Babinski, 1886). Joseph Bernard Luys (1828–97) continued this work after Babinski recalled his results. Third, therapists, for instance Benedikt, used a

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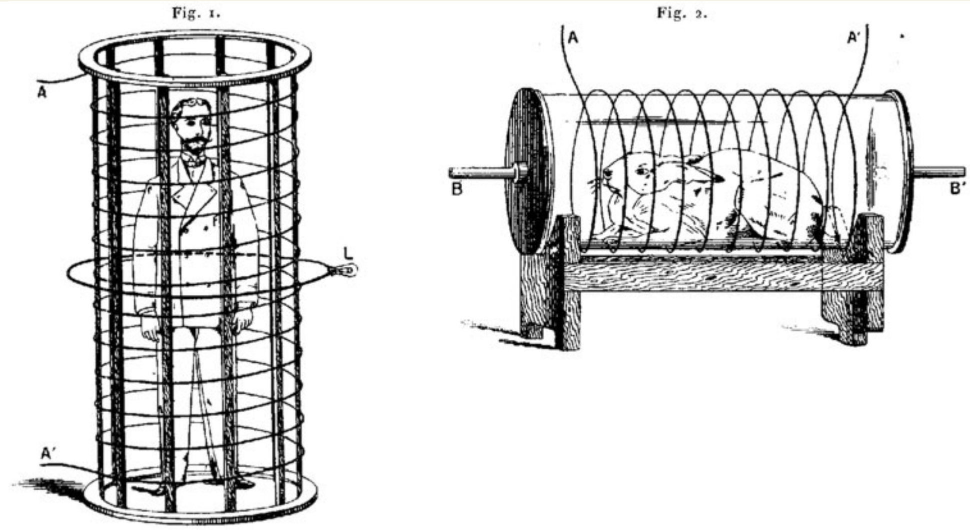

Figure 1 Illustration of d'Arsonval's solénoïdes (d'Arsonval, 1893*b*), with thanks to the Biodiversity Heritage Library, and Harvard University, MCZ, Ernst Mayer Library.

magnet as direct therapy (without hypnosis) for gastralgia (pain in the stomach), rachialgia (pain in the back) and hysterical pains (Benedikt, 1892, 1894).

Magnetic stimulation: late 19th century and early 20th century

Phosphenes: French light in the electromagnetic darkness

As mentioned earlier, no exclusive proof existed that (electro)magnetic fields produced a physiological effect. Jacques-Arsène d'Arsonval (1851–1940), professor of physiology at the prestigious Paris Collège de France, successor to Charles-Edouard Brown-Séquard (1817–94), and today mainly known for his work in diathermy, continued scientific research and took the first steps to prove a real effect. He investigated the consequences of tissue exposure to time-varying electric and (electro)magnetic fields. Between 1881 and 1892, he discovered that low frequency (electro)magnetic fields increased tissue oxygen absorption and carbon dioxide excretion due to increased metabolism and that high-frequency electric currents were able to anaesthetize the skin and lower blood pressure as a result of vascular dilatation. In 1893, he exposed animals and humans to high-frequency magnetic fields of at least 10 000 Hz. For this purpose, he constructed small and large solenoids in which a subject could stand upright. Around the cage the electrical wire ran in a spiral form (Fig. 1). To prove the presence of the (electro)magnetic field, d'Arsonval first placed a mercury thermometer and an animal in a small solenoid. Within seconds, the thermometer rose to 150°. Next, d'Arsonval placed bulbs, without any connection to an external energy source in a large solenoid. They burned when the time-varying (electro)magnetic field was turned on. Nevertheless, subjects did not experience any direct physiological effects, but according to d'Arsonval, this (electro)magnetic field had a positive effect on metabolism as did the time-varying electric field. The excreted carbon dioxide increased from 17 to 37 l/h, blood pressure decreased and temperature increased. d'Arsonval also exposed yeast and bacteria to the time-varying (electro)magnetic fields. Long exposure caused the death of yeast and bacteria, whereas moderate exposure decreased the toxicity. Owing to these results, patients with supposed metabolic disorders, such as diabetes, rheumatoid arthritis (considered as such at the time) and obesity would benefit from 'd'Arsonvalization'. But the symptoms of skin diseases were also believed to improve. Remarkably, d'Arsonval never used the word 'magnetic field' or 'magnets' in his articles, but always referred to high-frequency currents (d'Arsonval, 1893*a*, *b*; Rowbottom and Susskind, 1984, pp. 120–40).

Although still no direct physiological effect was observed after exposure to time-varying electromagnetic fields, physicians Georg Apostoli (1847–1900) and Augustin Joseph Anthelme Berlioz (1853–1922) used d'Arsonval's solenoid to treat 75 patients with various disorders. To avoid Mesmer's stigma, they set up their experiment to prevent the interference of 'suggestion'. The question of suggestion being the main effect of electrotherapy was a hot topic at the time, defended by Paul Möbius (1853–1907) and for which a special debate was held, known as the 'Frankfurt Council' (Koehler and Boes, 2010; Steinberg, 2011). In total, Apostoli and Berlioz treated their 75 patients 2446 times. Patients with rheumatoid arthritis and gout benefited most, whereas patients with certain forms of hysteria and neuralgia did not show any improvement. Overall, they concluded that d'Arsonvalization could best be applied to patients with metabolic disorders (Apostoli and Berlioz, 1895).

A breakthrough came in 1896, when d'Arsonval, during a lecture at the *Societé de Biologie* in Paris, announced that subjects observed phosphenes, and some almost fainted, while being exposed to a time-varying magnetic field. Phosphenes had been

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observed for many years (Purkyne, 1823; Marg, 1991; Wade, 2005). A phosphene is defined as awareness of light due to excitation of the retina not caused by light. A phosphene caused by electricity is called an electrophosphene and that by magnetism is called a magnetophosphene. Because d'Arsonval had no apparatus to objectify the phosphene, he had to rely on his subject's feedback. Nevertheless, he was convinced that this phenomenon was caused by a physiological effect, especially when combined with other effects of time-varying magnetic fields, such as muscle contractions. The physiological relation between phosphenes and time-varying magnetic fields, however, would not be elucidated until 1947 (d'Arsonval, 1896; Barlow *et al*., 1947).

d'Arsonval's results were not received with enormous enthusiasm. Several physicians investigated d'Arsonval's claims. The French physicians François Moutier (1881–1961), Challamel (*nk*) and Gidon (*nk*) confirmed the decrease in blood pressure. Roman physician Gay (*nk*) concluded that d'Arsonvalization not only decreased blood pressure (Fig. 2), but also decreased subjective suffering. Owing to this combination, d'Arsonvalization was preferred above other therapies for neurasthenic patients, a popular concept at the time, with high blood pressure (Gay, 1904). Unlike the previously mentioned physicians, Boedeker, Delherm and Laquirrière noted an increase in blood pressure. The German electrotherapist Albert Eulenburg (1840–1917) also confirmed an increase in blood pressure instead of a decrease. But Jean Alban Bergonié (1857–1925), André Broca (1857–1925) and G. Ferrié (*nk*) did not note any effect at all (Zimmer and Turchini, 1910). Not everyone was convinced, including the German physician Toby Cohn (1866–1929), who concluded that the effects were the result of suggestion and imagination, as only 22 of 76 patients benefitted subjectively from the treatment without improvement of an objective (physiological) parameter (Cohn, 1900; Loewy and Cohn, 1900; Gay, 1904). Although physicians and physiologists did not agree on the results of d'Arsonvalization, the treatment was described in various handbooks in particular in the German-speaking countries, which suggests that it was applied in daily practice (Cohn, 1910, 1912; Guilleminot, 1922; Mann, 1937).

d'Arsonval had already distanced himself from the discussion about the therapeutic consequences of his treatment. He focused on the physiological phenomena (Eulenburg, 1900).

A clash between manufacturers

Although the French discussion focused on therapeutic consequences, the discussion in Germany focused on the physiological effects and the theoretical explanation. Three possible theories were usually cited: (i) magnets cause a psychological effect without the occurrence of an objective physiological phenomenon; (ii) magnets cause an electrical effect, due to mutual induction, as described by Faraday; and (iii) magnets attract or repel magnetic particles. These particles were supposed to move because of magnetic forces and fields. If these forces changed their direction periodically, the particles also changed direction periodically. This was supposed to cause a vibration that, in turn, heated the tissue due to friction. For the last two explanations to be true, exposure to a time-varying magnetic field would be necessary (Hermann, 1888; Beer, 1902).

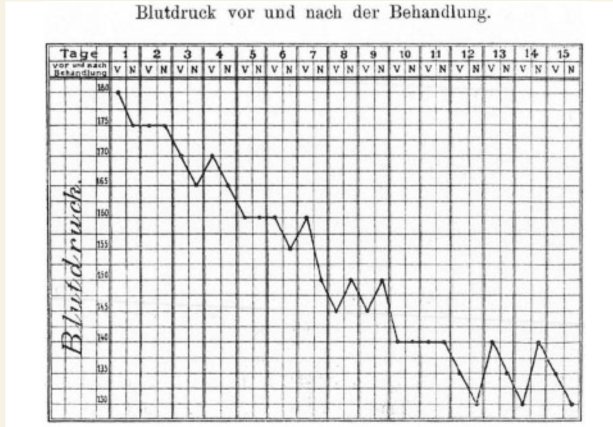

Figure 2 Decrease in blood pressure after treatment with d'Arsonval's autoconduction (Gay, 1904).

Much electromagnetic research was done in Germany, in particular, Berlin. Ludimar Hermann (1838–1914), a pupil of Emil Du Bois-Reymond, was a physiologist working at the Prussian Physiological Institute in Berlin. Early in his career, he investigated the influence of mineral magnets on tissues. One of the reasons to repeat his research was the rise of a new method in medical treatment—a mineral magnet-induced hypnosis. According to Hermann, who had also been critical about cerebral localization based on (pathological) anatomy until it was proven physiologically (by Fritsch and Hitzig in 1870; see Hagner, 2012), such treatments should not be used until it was proven that magnets, both mineral and electromagnets, had a physiological effect. Otherwise, its effect was nothing but suggestion. After extensive research, Hermann concluded in 1888, that mineral and electromagnets did not cause any physiological effect in a living body.

> 'Selbst unter den günstigsten Umständen ist mit den uns zu Gebote stehenden Mitteln nicht die geringste physiologische Wirkung der Magneten auf thierische (und anscheinend auch pflanzische) Gebilde und Organismen nachweisbar'. [trans; Martens: Even under the most favourable circumstances, with the current means, not the slightest physiological effect of magnets on animal (and probably also on plant) objects and organisms is demonstrable.] (Hermann, 1888)

Hermann's conclusions would greatly influence electromagnetic research because over and over again researchers had to refute the findings of this important physiologist (Hermann, 1888).

Not only scientists and physicians were interested in electromagnets and (electro)magnetic stimulation. In 1883, the Swiss electrical engineer Eugen Konrad Müller (1853–1948) noticed a kind of flicker in his eyes during repairs of an apparatus with a time-varying electromagnetic field. The flicker disappeared if he distanced himself from the machine or if he changed the machine to a non-time-varying magnetic field. Between 1883 and 1887, Müller started research on (electro)magnetic stimulation. He was able to reproduce his earlier findings. Later on he would state that the phenomenon was most clear in a bright-lit room and did not

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appear in a darkened room. The flicker also disappeared if he closed his eyes.

For his research (1887–96) he designed a new apparatus called the 'radiator'. He believed exposure to this 'radiator' increased his mental capacity. He also concluded that his apparatus had other effects: it had a soporific effect; it had a positive effect on coughing; and it influenced the nerve system (taste, hearing, speech and seeing). This convinced Müller that his 'radiator' had a physiological effect and might have a medical application. It was not until 1897 that he installed his device in the *Krankenanstalt* in Aarau, Switzerland. The results were promising, but not published until 1901, when he sent applications for patents to the Swiss, Danish and English patent offices. According to Müller, his 'radiator' differed substantially from d'Arsonval's solenoid (Fig. 3). Although d'Arsonval's solenoid operated with low currents and high frequencies (>10 000 Hz), Müller's radiator functioned with high currents and low frequencies (~60 Hz). The effect of the solenoid was based on mutual induction, whereas the radiator had a pure magnetic effect according to Müller. As a result, the physiological effects also differed. d'Arsonval's solenoid had a stimulant effect, whereas Müller's radiator had a depressive effect on the nervous system. Therefore, he believed that diseases with an abnormally irritable nervous system could be indications for treatment (Müller, 1901, 1902*a*, *b*).

In 1898 or 1899, Müller started his own institute 'Salus' in Zürich and Palmyro Rodari (1873–1912) was one of the physicians to work for Müller, publishing the first results in 1901 (Figs 4 and 5). In 70% of patients with anomalies of the sensory nervous system, such as neuralgia, migraine, sciatica and irritative forms of neurasthenia with sleeplessness, symptoms improved (Rodari, 1901*a*, *b*, 1902). Nevertheless, neurologist Berchtholdt Beer (*nk*) had reservations with respect to the results as Ludimar Hermann had shown that (electro)magnets had no physiological effects. However, he gave up his reservations after seeing phosphenes while exposing himself to Müller's radiator. The phenomenon was convincing although he could not explain its occurrence. The treatment of patients by Beer was also successful, as 90% of 43 patients benefitted. He even patented a therapeutic device based on (electro)magnetic fields (Beer, 1902; Beer and Pollacsek, 1903, 1904). Other physicians including Fritz Frankenhäuser (1868–*nk*) at the medical Universitätspoliklinik in Berlin, Carl Lilienfeld (*nk*) in Berlin, Károly Schaffer (1864–1939) and Arthur von Sarbo (1867–1943) at the electromagnetic institute in Budapest also treated patients with Müller's radiator. They obtained more or less similar results (65–90% improvement) as Rodari and Beer, but they were unable to present a clear physiological explanation (Frankenhäuser, 1902; Lilienfeld, 1902, 1904; Von Sarbó, 1903). Despite all the positive therapeutic results, Müller's 'radiator' was never incorporated into regular medicine as an article by Rodari (1903) indicated. He summarized the results up to 1903 and hoped that it would lessen the sceptical approach (Rodari, 1903).

Müller's radiator was not the only therapeutic magnetic apparatus. On 12 March 1902, the German patent office received a request for a patent from Trüb and Co., which was awarded on 30 June 1903. The apparatus consisted of a mineral magnet or an electromagnet placed on a rotating axis (Fig. 6; Trüb, 1903*a*, *b*). Usually, Trüb's apparatus was equipped with a mineral magnet.

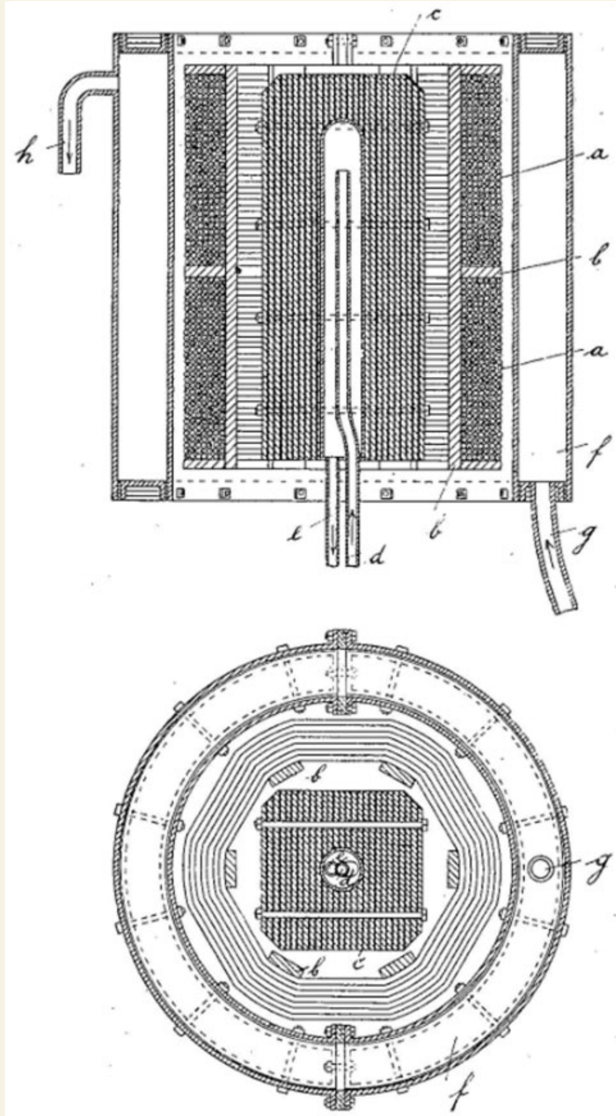

Figure 3 Schematic drawing of Müller's radiator (Müller, 1902*b*).

Müller, who probably wanted to protect his own patents, started a written discussion with physicist professor Salomon Kalischer (1845–1924), who translated Faraday's *Experimental researches in electricity* into German. The discussion focused on the difference between a rotating time-varying mineral magnetic field and a time-varying electromagnetic field, which resulted in the following three arguments posed by Müller. First, during exposure to a rotating mineral magnetic field a subject was always exposed to the north and south pole of the mineral magnet. Second, a subject in a time-varying electromagnetic field was intermittently exposed to the north and south pole. Third, the electromagnetic field strength intermitted as opposed to the static field strength of Trüb's apparatus. Owing to these differences, the physiological effects of both apparatus differed. The discussion ended without a winner because Müller did not react to Kalischer's request *einen der Würde der Wissenschaft*

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Tabelle 1.

	Heilungen	Besserungen	Ungeheilt	Bessg. nur während der Appl.	Bemerkungen
Peripherenneurosen:					
1. Neuralgien: des N. Trigeminus	1		1		
des N. occipitalis	2	4	2	1	
habit. Kopfschmerz.	2		2		
des pl. brachial....	8	3	2		
der Rückennerven		7	2		
Coccygodynie	1				
Ischias	8	1	6		
Lumbago		2	2		
2. Krampfzustände:					
Schreibkr., Nähkr.	1		4		
3. Traumat. Paresen		2			
4. Neuropath. Hautödeme............	1	3	1		
Centrale Neurosen:					
Epilepsie (3 Jackson'sche Formen)		3	9		Bei den Jackson'schen Formen anscheinend Abn. der Intens. und Häufigkeit d. Anfälle.
Neurasthenie	1	4	5		
Traumat. Neurosen (mit Schwindelanfällen)	1	1			
Rückenmarkskrankheiten (Friedreich'sche Ataxie, Tabes, Sklerose, Spast. Spin. Paralyse, Spina bifida. Poliomyel. ant.) ...		4	10		3 spin. Kinderlähm. in circa je 40 Sitzungen bed. gebessert. Ein Fall von Tabes dors. mit fragl. Erfolg.
Neurosen innerer Organe:					
Stenocardie		2			
Hyperaesth. des Magens		5	4		
„ des Darmes	1	1			
Habit. Obstipat. (Enterospasmus) abwechselnd mit Diarrhoe		1		1	
Habit. Obstip. bei Gravidität			1		
Incont. urinae und Enuresis noct.		1	3	6	
Diabetes			1		
Paresen nach Apoplexien			3		
	27	44	58	8	
	20%	31%	43%	6%	

Total: 137 Fälle.

Figure 4 Patients treated by Rodari in Aarau (Rodari, 1901*b*). The columns with the results mention 'cured', 'improved', 'not cured' and 'improvement only' during the application.

Tabelle 2.

	Geheilt	Gebessert	Ungeheilt
I. Periphere Nervenleiden (Neurosen).			
Neuralgien:			
N. trigeminus	6	7	5
N. occipital.	2	3	2
N. temporalis		1	
Diffuse Kopfschmerzen	5	4	4
Migräne	4	7	5
Pl. cervico brachial.		3	3
Nn. intercostales	2		3
Rückennerven	2	3	1
Ischias	12	20	10
Lumbago	2	6	3
Muskelrheumatismen	7	6	9
Krampfzustände (neuralg. Natur):			
Caput. obstip. rheum.	2	3	
Schreibkrampf	2	1	1
Wadenkrampf	1	1	
Incontinentia urinae und Enuresis noct. (Blasenhyperaesthesie)	1	2	2
II. Centrale Neurosen.			
Irritative Formen erworbener Neurasthenie mit Schlaflosigkeit	6	30	22
III. Sensible Erkrankungen innerer Organe.			
Angina pectoris	1	2	1
Hyperaesthesien des Magens und Darmes	1	3	3
IV. Locale acute Gicht	2	2	
Tabes dorsalis (Ataxie und rheumatoide Schmerzen) ...		4	2
	58	108	76

Total 242 Fälle.
Hiervon geheilt 58, gebessert 108, ungeheilt 76.
„ „ 24 pCt., „ 47 pCt., „ ca. 30 pCt.
Günstige Resultate also in ca. 70 pCt. der Fälle.

Figure 5 Patients treated by Rodari in Zürich (Rodari, 1901*b*). The columns with the results mention 'cured', 'improved' and 'not cured'.

geziemenden sachlichen Ton einzuhalten [translation: Martens: considering a professional tone appropriate to the dignity of science] (Kalischer, 1903*a*, *b*; Müller, 1903).

Several physicians treated their patients with Trüb's rotating mineral magnet. According to the Stuttgart physician Eduard Gottschalk, (electro)magnetic therapy in general was a welcome addition to the therapeutic arsenal for patients with rheumatic diseases and neurasthenia. Gottschalk (1903) preferred Trüb's rotating mineral magnet to Müller's radiator, as the first was easier to operate. According to physicians Adolf Loewy (1862–1937) and Neumann, Müller's and Trüb's devices produced the same electromagnetic fields and were therefore therapeutically interchangeable. They reported observing phosphenes after exposure to Trüb's mineral magnet and experienced that 75% of their patients improved after treatment (Loewy, 1903). A critical note came from Toby Cohn, who had also criticized d'Arsonval's solenoid. Although he and his colleagues reported seeing phosphenes, he opined that both mineral magnetic and (electro)magnetic therapy was nothing but *Suggestiontherapie* (Cohn, 1904).

Overall, the medical profession did not enthusiastically welcome Müller's radiator or Trüb's mineral magnet. At the 79th Naturforscher und Ärztekongress in Dresden (1907), K. Martin (*nk*), chief physician of the Lorettoberg sanatorium (Freiburg i.B.), opined that only a few physicians were still interested in therapeutic electromagnetism (Martin, 1909). In his 1912 guide *Elektrodiagnostik und Elektrotherapie*, Cohn reported that (electro)magnetic therapy was hardly applied anymore. He used the argument that had been heard previously, notably that many physicians did not treat their patients with (electro)magnetic therapy because it was not clear how (electro)magnetic therapy worked, not accepting suggestion as a proper treatment (Cohn, 1912). Remarkably, at the time, references to (electro)magnetic therapy are lacking in many of the English and American handbooks. In the well-known *Handbuch der Neurologie* of the 1930s, the author summarizes [in a subchapter entitled 'Die elektromagnetische Behandlung (auch Permea-Elektrotherapie genannt)'] that the method was popular in the first decade of the 20th century, when it was advised as a sedative treatment not only in all kind of painful conditions, including neuralgias, lancinating pain in tabes dorsalis, joint and muscle rheumatism, but also for sleeplessness, vasomotor disturbances, angina pectoris, and so forth. He continued to mention that the method had not found general application, but in a few special institutes, particularly in Switzerland, which may be understood from Müller's influence. The author referred to K. E. Müller, Kalischer, Eulenburg, Lilienfeld and T. Cohn, concluding the chapter by mentioning that the medical literature of the past 20 years (1917–37) had not shown scientific publications or clinical reports worth mentioning (Mann, 1937).

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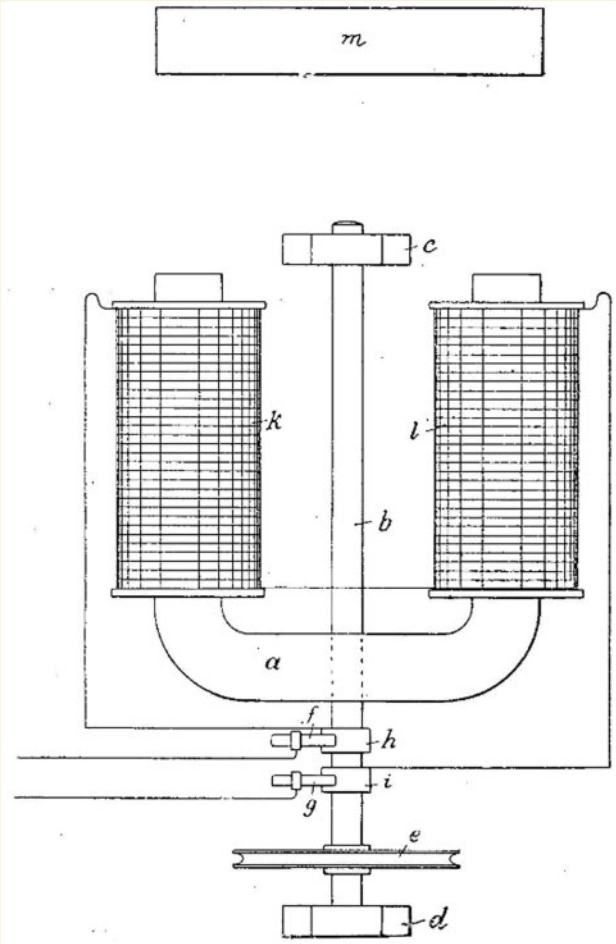

Figure 6 Schematic drawing of Trüb's apparatus (Trüb, 1903*b*).

Conclusion

In the 18th century, the Bavarian Scientific Academy concluded that mineral magnets influenced the nervous system, but soon after, animal magnetism as proposed by Mesmer was condemned as quackery by the French commission. With the discovery of electromagnets in the 19th century and the popularity of electrotherapy, the interest in (electro)magnetism increased again, but needed to dissociate from the Mesmeric stigma. Mineral magnets were used again around the middle of the century in particular for hypnosis, transfer of hysterical symptoms and pain. In the meantime, convincing evidence of physiological effects from electromagnets was lacking until d'Arsonval, during the last decade of the 19th century, demonstrated direct (phosphenes) as well as indirect (metabolic) effects.

Research in and application of (electro)magnetic stimulation has a long history, but peaked in the first decade of the 20th century. According to various handbooks, the method seems to have been used for several painful conditions, in particular in German-speaking countries, but subsequently only on a small scale in Switzerland. Enthusiasm waned in the second decade because of the lack of clear proof and because, similar to electrotherapy, the effects were considered to be based on suggestion. In the margins of medicine, a minority of physicians continued applying electromagnetic therapy, but electromagnetic physiological research continued (Geddes, 1991). In 1947, Barlow came up with the physiological explanation of magnetophoshenes (Barlow *et al*., 1947). In 1965, Bickford and Fremming used a pulsed magnetic field instead of sinusoidal alternating currents and observed muscle twitching in frogs, rabbits and humans (Bickford and Fremming, 1965). Also, in 1985, Anthony Barker successfully stimulated the human cortex with an electromagnet, resulting in an enormous increase of interest in transcranial magnetic stimulation at the end of the 20th century and into the 21st century (Barker *et al*., 1985).

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