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Pursuing paradoxes posed by the waterfall illusion

Robert Addams (1789-1875) described the waterfall illusion following observation of the Falls of Foyers (figure 1) in 1834. It is a special case of the motion aftereffect (MAE). Addams's brief article introduced paradoxes about processes, history and interpretations of motion aftereffects, some of which remain with us.

Figure 1. The lower Falls of Foyers (artist T. Allom, hand-coloured engraving by E. Radclyffe and published by George Virtue, London, 1836). A monochrome version of this engraving was printed in Beattie (1838). Addams would have observed the waterfall from the platform shown.

The waterfall illusion and MAEs generally stimulated a torrent of research since the 19th century. Addams (1834) wrote:

> Having steadfastly looked for a few seconds at a particular part of the cascade, admiring the confluence and decussation of the currents forming the liquid drapery of waters, and then suddenly directed my eyes to the left, to observe the vertical face of the sombre age-worn rocks immediately contiguous to the water-fall, I saw the rocky face as if in motion upwards, and with an apparent velocity equal to that of the descending water, which the moment before had prepared my eyes to behold this singular deception. (p. 373)

The observation was considered to be of sufficient significance for a translated summary to be published in Poggendorff's prestigious *Annalen* (Addams, 1835). Despite its appearance in German several subsequent descriptions of the phenomenon by German scientists failed to cite Addams. The phenomenon was given the name of the 'waterfall illusion' by Thompson (1880) and it raised a number of paradoxes, some of which remain unresolved. The first is: why is it called the waterfall illusion when the apparent motion is seen in the adjacent rocks? It displays confusion between the adaptation and test phases of MAEs. Clearly, the water could not be stopped in the case of a waterfall and so some stationary stimulus was required to test it. Subsequent descriptions of the MAE were based on stimuli, like rotating spirals (Plateau, 1849) or sectored discs (Wundt, 1874; Aitken, 1878, Thompson, 1880) that could be stopped after motion so that the same pattern was used for adaptation and test. An assumption has been that the two phases involve the same neural processes to express MAEs. However, different rules apply to adaptation and test, with the former being based on local and the latter on global processes (Wade, Spillmann & Swanston, 1996).

Waterfalls must have been observed throughout human history. This leads to a second paradox: why was it so late in descriptions of visual phenomena that attention was directed to the aftereffect evident following viewing waterfalls? Two thousand years ago MAEs were reported by Aristotle and Lucretius in flowing river waters (see Wade & Verstraten, 1998). The critical distinction between their observations and Addams's is that fixation aids were available in the former. Aristotle was able to fixate on stones beneath the water and Lucretius could look at the leg of his horse partially submerged in the fast flowing river. The natural response when viewing descending water is for the eyes to follow the descent and return – optokinetic nystagmus. There needs to be a reason to look steadfastly "for a few seconds at a particular part of the cascade". This reason could have been the emerging appreciation that the methods of physics could be applied to perception. Only one year earlier instruments for inducing apparent motion had been described by Plateau (1833) and Stampfer (1833) and these involved maintaining a steady eye position. Moreover, these instruments had been stimulated by observations reported by Faraday (1831) who was a scientific acquaintance of Addams. The shift of visual observations from the natural environment into the laboratory was made explicitly by Addams who suggested that the phenomenon "is also producible by mechanical means, such as by a rapid unrolling of pieces of calico having some pattern or markings on them" (p. 374). Downward moving horizontal gratings were the stimuli later used by Bowditch and Hall (1881) and Wohlgemuth (1911) in their investigations of MAEs.

The third paradox concerns the eye movement interpretation of the phenomenon adopted by Addams: apparent motion of the rocks was considered to be a consequence of unconscious pursuit eye movements when viewing descending water. Eye movements are almost always initially invoked for interpreting novel visual motion phenomena (Wade, 2017). The paradox is that an aftereffect of eye movements cannot be restricted to an isolated part of the visual scene, as was pointed out by Mach (1875) and Thompson (1880). In his interpretation Addams provided one of the earliest estimates of the time course of optokinetic nystagmus.

> I conceive the effect to be owing to an involuntary and *unconscious* muscular movement of the eyeball, and thus occasioning a displacement of the images on the retina. Supposing the eyes to be intently gazing at any point in a transverse plane passing through a vertically moving body, they will naturally and even irresistibly tend to follow the motion of that body; nor can the muscular apparatus of the eye maintain a stable equilibrium when the sight is fatigued and bewildered with a rapid change of moving forms before the eye. Now in the case of the descending water, the eyes, being directed to a particular part in a horizontal section of it, cannot be prevented moving downwards through a small space: every new form in the moving scene invites the eyes to observe, and for that reason to follow it; but the voluntary powers are engaged to raise the axes of the eyes again to the section. This depression of the axes below the *intentional point of sight* seems to be repeated three or four times per second, whilst looking at the water-fall. Then, when the eyes are suddenly turned upon the rock, the muscles, having been brought into a kind of periodic contraction, will perform at least one of these movements after the exciting cause ceases to act; and thus the axes of the eyes, by moving downwards, will occasion a motion of the image of the rock over the retina in a direction from above downwards, and consequently the object giving that image will *appear* to move the contrary way, that is, upwards, agreeably to observation. (Addams, 1834, p. 374)

Perhaps the final enigma is: who was Robert Addams? Very little is known about him. He was born in 1789, died in 1875 and he appears to have been a peripatetic lecturer on scientific topics. He described himself as a lecturer on chemistry and natural philosophy. Records exist of payment for courses of lectures given on hydrostatics, hydraulics, pneumatics, galvanism, magnetism, electricity, electro-magnetism, acoustics, music and optics to philosophical societies and mechanical institutes from Bath to Newcastle-upon-Tyne (Bishop, 1961; Cooper and Hall, 1982; Neve, 1984; Steer, 1962). His most constant contacts were with the London Institution, the Royal Institution and the United Service Museum. He resided at various addresses in London including Jermyn Street, St James's (in the 1820s) and Pembroke Square, Kensington (in the 1840s). He subscribed to the annual lectures at the Royal Institution in 1824, and he applied unsuccessfully to said institution for the vacant Professorship of Natural Philosophy in 1837. In 1843 Wheatstone provided an electromagnetic chronoscope for Addams, who used it in lectures at the United Service Museum and elsewhere (Wheatstone 1845). In 1844 he supplied Michael Faraday both with liquid and with solid carbonic acid of high quality, some of which was used in lectures at the Royal Institution; Faraday also went to Addams's house to experiment with a pump of the latter's devising (Martin 1933). He corresponded with Talbot on instruments involved in photography (see Schaaf). Addams was an annual subscriber to the British Association for the Advancement of Science in 1837, and was elected a member in 1856. Thereafter, he appears to have drifted into obscurity since his address was no longer known to the

Association in 1865. He presented reports of experiments to the British Association in the 1830s and published papers on physics in the *Philosophical Magazine* and on acoustics at around the same time (Addams, 1836). In January 1833 he delivered a talk "On optical Illusions, accompanied with illustrative machinery" to the Bristol Philosophical and Literary Society of which he was an honorary member (Neve, 1984). Otherwise, there is little in this outline to suggest the contribution to visual science he made in 1834. Unlike almost all the other workers on the waterfall illusion, he was not a visual scientist, and the article in the *Philosophical Magazine* constituted his only foray into this domain.

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