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THE PHYSIOLOGY OF WEEPING

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WILLIAM MACKENZIE, to do honour to whose memory we are gathered together here to-day, wrote two books, one on the Physiology of Vision and the other on Diseases of the Eye, thereby showing that he recognized the necessity of a study of the former in dealing with the latter; or in other words that pathology is perverted physiology, and that correct pathology is the keystone to treatment.

I need, therefore, offer no apology in taking as the basis of this address, which you have so kindly invited me to give in his memory, a physiological phenomenon, and endeavouring to draw from its investigation some suggestions to guide us in our clinical work.

Meeting of Darwin, Bowman and Donders

In the autumn of 1869 Sir William Bowman took Professor Donders to visit Darwin in his country residence at Down. The agreeable impressions awakened by this memorable meeting of these three savants continued for long afterwards, and is referred to in the subsequent writings of each of them. They had many subjects of mutual interest, but that which was uppermost in Darwin's mind at the time of this meeting was the expression of the emotions, for his book on which he was then engaged in collecting evidence. The subject which he discussed with his two visitors was the physiology
of weeping. Why, he asked them, do infants when screaming keep their eyes firmly closed? That this is so he proved by having a series of instantaneous photographs taken of them when crying, which are reproduced in his book. Darwin\(^1\) pointed out that the observation of this phenomenon had previously attracted the attention of Sir Charles Bell,\(^2\) and he asked Bowman's and Donders' opinion of the following explanation which Sir Charles Bell gave of it.

**Sir Charles Bell's explanation of the firm closure of the eyelids during acts of violent expiration**

"During every violent act of expiration, whether hearty laughter, weeping, coughing or sneezing, the eyeball is firmly compressed by the fibres of the orbicularis; and this is a provision for supporting and defending the vascular system of the interior of the eye from a retrograde impulse communicated to the blood at that time. When we contract the chest and expel the air, there is a retardation of the blood in the veins of the neck and head; and in the more powerful acts of expulsion, the blood not only distends the vessels, but is even regurgitated into the minute branches. Were the eye not properly compressed at that time, and a resistance given to the shock, irreparable injury might be inflicted on the delicate textures of the interior of the eye." He further added, "If we separate the eyelids of a child to examine the eye while it cries and struggles with passion, by taking off the natural support to the vascular system of the eye, and means of guarding it against the rush of blood then occurring, the conjunctiva becomes suddenly filled with blood, and the eyelids everted."

Donders, at Darwin's request, agreed to investigate experimentally the influence of the action of the eyelids in connection with determination of blood to the eyes in expiratory efforts.

He published an account of these experiments in the "Nederland. Archiv vor Genees en Naturkunde" for 1870; a translation of the article into English by Dr. W. D. Moore appeared in Beale's "Archives of Medicine" in the same year. Both this article and Darwin's chapter on weeping in his book on "Expression of the Emotions" raise many points of ophthalmic interest deserving of further discussion.

**Darwin's explanation of the origin of weeping as an expression of the emotions**

Darwin sums up his views on weeping as follows:—

"Weeping is probably the result of some such chain of events as follows. Children, when wanting food or suffering in any way, cry out loudly like the young of most other animals, partly as a call to their parents for aid, and partly from any great exertion serving as
a relief. Prolonged screaming inevitably leads to the gorging of the blood-vessels of the eye; and this will have led, at first consciously and at last habitually, to the constriction of the muscles round the eyes in order to protect them. At the same time the spasmodic pressure on the surface of the eye, and the distension of the vessels within the eye, without necessarily entailing any conscious sensation, will have affected, through reflex action, the lacrimal glands. Finally, through the three principles of nerve-force readily passing along accustomed channels of association, which is so widely extended in its power, and of certain actions being more under the control of the will than others, it has come to pass that suffering readily causes the secretion of tears, without being necessarily accompanied by other action.”

As Darwin points out the primary function of the secretion of tears, so far as the eyes are concerned, is to lubricate their surface. Another equally important function is to wash away particles of foreign substance which may get into the eyes. This latter function is a reflex action, the afferent impulse being due to a stimulation of the nerve fibres at the surface of the cornea; a form of impulse which may be excited by firm pressure on the cornea by the margins of the lids as by the presence of a foreign body.

Entoptic evidence of the squeegee action of the lid margins in man

The squeegee action of the lid margins on the surface of the cornea in man is well demonstrated by a method of entoptic examination devised by the late Dr. George Bull. He allowed the light from a small candle flame five metres distant to be thrown in circles of diffusion upon the retina by a convex lens of about five centimetres focus held within two centimetres of the eye. The field seen by this method of examination is circular, more or less uniformly granular, and limited by a dark shadow of the iris. By the passage of the eyelids over the front of the eye two different sorts of bright bands bounded by darkened areas may be produced in the field, varying in appearance according to the amount of pressure exerted by the lid margins on the cornea. When the pressure is slight, as in winking, the bright bands are due to the curvature of the lubricating fluid which the eyelids push before them, they advance and recede with the movements of the eyelids, and a single sweep of the lids over the whole cornea, as in natural winking, instantly effaces them. When strong enduring pressure of the tarsal edge of the lid is made against the cornea, in what Bull speaks of as clignement (a French word for which he says there is no English equivalent), more persistent bright bands, which are not obliterated but made brighter by winking, are produced due to a depression formed in the surface epithelium.
Reflex lacrimal secretion precedes psychical weeping

As is well known infants do not weep or shed tears until they are several weeks old. Darwin found from observations which he made or had made for him, that the time at which free weeping commences is very variable; in one case when only 20 days old and in another not until the age of 104 days. He remarks:—"This circumstance is not exclusively due to the lacrimal glands being as yet incapable of secreting tears. I first noticed this fact from having accidentally brushed with the cuff of my coat the open eye of one of my infants, when 77 days old, causing the eye to water freely; and though the child screamed violently, the other eye remained dry, or was only slightly suffused with tears." The tears did not run over the eyelids and roll down the cheeks of this child until it was 139 days old.

This observation of Darwin's, that the reflex secretion of tears may be excited in infants before psychical weeping has developed is confirmed by Axenfeld’s\(^5\) histological examination of new-born infants' lacrimal glands. He found the secreting cells of such glands, their blood-vessels, and their nerves all well formed. At one time he thought the absence of adenoid interstitial tissue might account for the absence of secretion, but at a later date said this could not be the case, for this adenoid tissue steadily increases in old age, whilst the gland itself slowly atrophies. Besides many glands have none of this interstitial tissue, \textit{e.g.}, the liver.

A differentiation between the secretion of fluid by the lacrimal gland as a reflex act excited by irritation of the surface of the eye, from that produced by a psychical stimulus as in weeping, is not only of physiological interest but also of clinical importance.

Lysozyme in the lacrimal secretion and its protective influence

The observations of Alexander Fleming\(^6\) in 1922, and of Frederick Ridley\(^7\) in 1928, have shown that the lacrimal secretion contains an enzyme, termed lysozyme, which is able to destroy not only the non-pathogenic bacteria, but also most of the organisms pathogenic to man and animals.

In his "Arris and Gale Lecture" Fleming said: "The great concentration of lysozyme in the tears is very striking . . . . it is clear that some cells in the lacrimal gland are capable of elaborating lysozyme very rapidly in high concentration, or of effecting an enormous concentration of the lysozyme which they might obtain from the blood fluids."

It has been suggested that as new born infants do not weep, therefore their conjunctiva is at that time unprotected by this antibacterial lysozyme. As, however, the lacrimal glands are well
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developed and capable of secreting in response to irritation at birth, such reasoning must be fallacious. On the other hand I would suggest that the immunity of infants from ophthalmia neonatorum in whom Crede's treatment, or one of its substitutes has been employed at birth, is more likely due to the antibacterial lysozyme in the lacrimal secretion, an outpouring of which the chemical irritant excites, than to any germicidal property in the collyrium employed, which must quickly lose its potency by dilution.

It is also possible that the remedial effects of chemical irritants in other conjunctival affections may, likewise, be due to the lysozyme content in the outpouring secretion which they excite.

Psychical weeping phylogenetically and ontogenetically late in development

Darwin goes on to say, "a habit like weeping must have been acquired since the period when man branched off from the common progenitor of the genus Homo and of the non-weeping anthropomorphous apes." In other words, weeping, which is a flow of tears from a psychical stimulus is both phylogenetically and ontogenetically late in development. It has arisen in human infants as a purposive action to attract attention with the object of eliciting aid and sympathy. As age advances, and an independence of sympathetic aid becomes established, so this means of eliciting it becomes controlled or inhibited, more especially in the male sex than in the female, which latter being physically the weaker has in the past felt less assured of its independence. Circumstances of emotional stress, however, from time to time arise, such as some overbearing calamity or sense of failure either to oneself or to some relative or friend, when this power of control or inhibition is over-mastered and the old method of eliciting sympathy of childhood again manifests itself. A sense of relief is obtained by ceasing to exert control, and allows unrestrained weeping to take place as an outlet for nervous energy, though utterly ineffectual in its primary intent.

Comparison of lacrimal and salivary secretion, both of which may be "conditioned reflexes"

A comparison may aptly be made between the mechanism for the secretion of the salivary glands and that for the lacrimal glands. Primarily the secretion of the salivary glands is excited by an afferent impulse set up from contact of food with the mucous membrane of the mouth, just as the lacrimal secretion is primarily set up by an afferent impulse from contact of a foreign substance with the conjunctiva. Secondarily salivary secretion has come to be excited by a psychic influence, such as the thought of food, which
makes the mouth water. The lacrimal secretion has likewise come to be excited by a psychic influence such as sorrowful thoughts.

It has been shown by Pavlov that in dogs, if at the time food is presented to them, a bell is rung, and the experiment repeated a sufficient number of times, what he calls a "conditioned reflex" may be established so that on hearing the bell in the absence of food salivation is stimulated. Under certain conditions a similar "conditioned reflex" may arise in connection with the lacrimal secretion, weeping taking place apart from any cause for grief. Thus Darwin says that "Dr. J. Crichton Browne (now Sir James) informed him, that nothing is more characteristic of simple melancholia, even in the male sex, than a tendency to weep on the slightest occasions, or from no cause. They also weep disproportionately on the occurrence of any real cause of grief. The length of time during which some patients weep is astonishing, as well as the amount of tears which they shed. One melancholic girl wept for a whole day, and afterwards confessed to Dr. Browne that it was because she remembered that she had once shaved off her eyebrows to promote their growth. Many patients in the asylum sit for a long time rocking themselves backwards and forwards, and if spoken to, they stop their movements, purse up their eyes, depress the corners of the mouth, and burst out crying. In some of these cases, the being spoken to or kindly greeted appears to suggest some fanciful and sorrowful notion; but in other cases an effort of any kind excites weeping independently of any sorrowful idea."

Do animals weep?

To weep has aptly been defined as to express grief by shedding tears. If we accept this definition then the secretion of tears as a reflex act from stimulation of the surface of the eye or of the mucous membrane of the nose—or from any direct stimulus of the efferent nerves proceeding to the lacrimal glands—is not included under the term weeping, no matter the amount of the secretion, and I think it is very doubtful if any animal other than man really weeps. Many of the accounts which have been given of weeping in animals are either myths or travellers' tales which have not received adequate verification.

Amongst the myths we have the ancient one of the crocodile which was said to weep either to allure a man for the purpose of devouring him, or whilst devouring him. Lindsay Johnson says that he squeezed the juice of an onion mixed with common salt into the eyes of four species, but found that it had no effect on their moisture beyond the slight normal secretion. Tears shed hypocritically as a pretence of sorrow are still spoken of as "crocodile's tears."

Deer have also been credited with weeping when they shed their horns. Thus Shakespeare makes Hamlet exclaim, when the King
stops the play which was designed to expose his crime:—"Why, let
the stricken deer go weep." Another sixteenth century author,
Webster, writes:—"Here is a stag, my Lord, hath shed his horns,
and for the loss of them the poor beast weeps." The reason for
attributing sorrow to deer on the loss of their horns would appear
to have arisen from them drooping their heads after they have shed
the horns, more especially when passing under trees, being for the
time unmindful of their loss and the lack of necessity for so lowering
their heads.

Though Darwin devoted considerable attention to the expression
of the emotions in domestic animals such as dogs, cats and horses,
he makes no mention of ever having observed them weep as an
expression of grief. He does, however, refer to some hearsay
evidence as to elephants weeping. He quotes the following
description which Sir E. Tennent⁹ gives of captured elephants
which he saw bound in Ceylon—some "lay motionless on the
ground, with no other indication of suffering than the tears which
suffused their eyes and flowed incessantly." Speaking of another
elephant he says, "When overpowered and made fast, his grief was
most affecting; his violence sank to utter prostration, and he lay on
the ground, uttering choking cries, with tears trickling down his
cheeks." Darwin failed to obtain any confirmatory evidence as to
captured elephants weeping from those to whom he applied to make
special observations on the matter for him. The Rev. Mr. Glenie
wrote to him: "Captured elephants when irritated screamed
violently; but it is remarkable that they never when thus screaming
contracted the muscles around the eyes. Nor did they shed tears;
and the native hunters asserted that they had never observed
elephants weeping."

In a foot-note in the second edition of his book Darwin also
quotes Gordon Cumming's¹⁰ statement concerning a large bull
elephant which he lamed, without at first killing, by a shot in the
shoulder. Cumming then made some experiments to find a vulner-
able point, and fired several bullets at different parts of the animal's
enormous skull, "which did not affect him in the slightest." Finally
after having received a further nine shots behind the
shoulder, Cumming says: "large tears now trickled from his eyes,
which he slowly shut and opened; falling on his side he expired." In
this case I think the secretion of the lacrymal gland was more
likely to have been excited by some stimulus of one of the efferent
nerves from one of the numerous shots fired into its head than by
an emotion of grief.

Darwin also quotes the statement of the keeper of the Indian
elephants in the Zoological Gardens to the effect that he had
several times seen tears rolling down the face of the old female
when distressed by the removal of the young ones. He himself
says he watched Indian elephants when the keeper had made them trumpet loudly and then observed their orbicularis muscle, both upper and lower, to contract strongly, but makes no mention of his having seen any secretion of tears to have overflowed.

In the issue of the Illustrated London News\(^\text{12}\) for February 21, 1931, there were pictures and a description of the Australian Kola Bear, a marsupial animal that lives in trees, and for which Mr. Noel Burnett has recently acquired a forty acres of bush reserve in the West Pennant Hills near Sydney. In the description it was stated:—“That when molested or hurt it whimpers and cries piteously like a child; tears roll down its face, and it rubs its eyes with its forepaws.” On reading this I wrote to Mr. Noel Burnett on the matter and received a most interesting and courteous letter in reply. In it he said:—“The statement that bears cry piteously, and that tears roll from their eyes when molested or hurt is not altogether mine . . . occasionally a female may be teased by a male, or we may have to take a female against her will, or administer some veterinary attention in which case the bear will certainly cry, but it is only a cry of fear and not of pain, and I have noticed no tears.”

Robert M. Yerkes, the Professor of Psychobiology, in Yale University, who has published his extensive original and historical researches connected with anthropoid life, in his book entitled “The Great Apes,”\(^\text{12}\) writes:—“I have never seen anthropoids weep or laugh in quite the human sense of the term.” Speaking of chimpanzees he says:—“That depression, grief, and sorrow, are occasionally manifested by the chimpanzee is beyond dispute. Definitely established also is the fact that weeping in the human sense does not occur. The typical approach to it is whining, moaning, or crying in the manner of a person in distress. Tears we have never observed, and in this we are confirmed by statements of Garner, Rothmann and Teuber, and Köhler.”

In a letter he kindly wrote to me in response to some enquiries of mine on the matter, he says:—“I have often wondered why weeping with tears happens to be so peculiarly human. So far as I have observed or learned with assurance from reliable authorities, no other animal weeps.” “Young anthropoid apes,” he goes on to say, “frequently cry under certain circumstances which would induce like response in the human infant or child, but never in such instances even when the response is extreme have I seen tears.”

It is interesting here also to note that some human beings, with perfectly normal eyes, never develop the capacity of weeping, \textit{i.e.}, of shedding tears in response to an emotional stimulus. Only last month a lady of mature years came to me complaining that she had never been able to weep, and saying how much she envied other women who could find relief for their emotions in “a good cry.”
Protective mechanisms for the surface of the eyes in mammals

Neither the three distinguished savants at their meeting in 1869, nor Darwin in his subsequent writings on the "Expression of the Emotions," seem to have taken into account the important part played in the protection of the surface of the eye by the nictitating membrane in air-breathing vertebrates below primates.

In many of the amphibia and mammals a powerful retractor bulbi muscle by drawing back the eyeball in the orbit causes this nictitating membrane to move over the surface of the cornea, between it and the eyelids. The eyeball is restored to its former position partly by the recoil of the elastic membrane, the "cornet," which fills the gap in the outer bony wall of the orbit, and partly by the contraction of the muscle of Gegenbauer which lines it.

The margins of the upper and lower eyelids in such animals do not come into contact with the cornea on closure of the eyelids as they do in primates, in whom the nictitating membrane is only represented by the vestigial semilunar fold, and in whom the retractor bulbi and protrusio bulbi muscles are either absent or likewise vestigial. There is, therefore, an anatomical reason which renders it unlikely that any animals other than primates really weep.

Development of the facial muscles in mammals, correlated with suction and the separation of the thoracic and abdominal cavities by the diaphragm

In the cold-blooded vertebrates the bony mask of the face is covered merely by skin, which is tightly stretched over it. It is in the warm blooded mammals that the facial muscles first commence to grow in between the skin and the bone. The following description of their formation is given by Dr. William K. Gregory13 in his book entitled "Our Face from Fish to Man":—"Even in the most primitive of living mammals the hard bony mask of the face has already begun to sink beneath the surface, and a more or less pliable skin has been developed. But the most remarkable fact is that as the bony mask sank beneath the surface the "facial muscles," so characteristic of the mammals alone among vertebrates came into being. Where did they come from? In the reptiles the neck and throat are covered by a thin wide band of muscle called the primitive sphincter colli, which is activated by a branch of the seventh cranial nerve. In mammals this muscle, besides giving rise to the platysma muscle, has grown forward between the bony mask and the skin, along the sides and top of the face. As it grew forward over the cheek it sent out various subdivisions which either surrounded the eyes, or covered the forehead and cheeks, or surrounded the lips, or connected the lips with the cheeks, or were attached to the ears.
Whenever the muscle mass sent forth a new branch it also drew into this branch a twig from the main facial division of the seventh nerve. Thus what are called the mimetic or facial muscles of mammals arose by the forward migration and subdivision of a muscle formerly covering the neck. For this doctrine the anatomists Ruge and Huber have brought forward the most detailed and convincing evidence."

This exclusive characteristic of mammals, the development of the facial muscles, may be correlated with their two other exclusive characteristics, viz., the development of mammæ, which has given them their name; and the development of a diaphragm separating the thoracic and abdominal cavities, which converts the former into a species of bellows for the purposes of respiration.

The importance of the development of muscles around the mouth in mammals for purposes of suction is obvious. A like importance may, I suggest, be attached to the development of muscles around the eyes, for the protection of their blood vessels in connection with the contraction of the diaphragm, in violent expiratory efforts from the chest, in expulsatory efforts from the abdomen, and in certain other violent muscular exertions.

In speaking of the contraction of the muscles around the eyes, Darwin writes:—"It is not necessary, in order to lead to the contraction of these muscles, that air should actually be expelled from the chest; it suffices that the muscles of the chest and abdomen should contract with great force, whilst by closure of the glottis no air escapes. In violent vomiting or retching the diaphragm is made to descend by the chest being filled with air; it is then held in this position by the closure of the glottis, as well as by contraction of its own fibres. The abdominal muscles now contract strongly upon the stomach, its proper muscles likewise contracting, and the contents are thus ejected. During each effort of vomiting the head becomes greatly congested, so that the features are red and swollen, and the large veins of the face and temples visibly dilated. At the same time, as I know from observation, the muscles round the eyes are strongly contracted. This is likewise the case when the abdominal muscles act downwards with unusual force in expelling the contents of the intestinal canal."

That able anatomist and sculptor, Dr. Tait McKenzie, Professor of Physical Education at the University of Pennsylvania, who has not only made a study of the facial expression of violent effort, breathlessness and fatigue, but has also depicted it in masks modelled by himself, has shown that in violent muscular efforts of short duration, such as sprinting for a 100 yards race or for throwing heavy weights, in which the diaphragm is thrown into action with the chest distended and the glottis closed, the orbicularis muscles around the eyes are contracted as fully as possible. Thus he
Showing varying degrees of development of the subtarsalis muscle or ciliary muscle of Riolan.
writes:—"At the start of a hundred yard dash the runner catches his breath, and usually holds it during the entire race if closely pressed. During this time the body is under stress of the most violent action, the great muscle masses of the legs are in powerful alternate contraction and the torso is pulled and compressed by the vigorous action of the arms. The shutting of the glottis gives a more solid point d'appui for the muscles of the arms and shoulders, but it increases enormously the pressure on the heart and lungs. This increase in blood-pressure shows in the purple and swollen face and the red suffused eyes, in the lips retracted from the clenched teeth and the muscles of the neck fixed in contraction. This peculiar characteristic expression is also seen in jumpers, hurdlers, hammer-throwers, and football players. It indicates the acme of any violent effort . . . . Undoubtedly the runner would shut his eyes if he could, and the hammer-thrower occasionally does so at the moment of the greatest effort; but the runner must keep his course, and so the eye-openings are merely narrowed as much as possible."

For the protection of the surface of the eyes in man and primates the squeegee action of the tarsal margins of the upper and lower eyelids, and the secretions of the lacrimal glands and conjunctiva, have replaced the nictitating membrane, the retractor bulbi and protrusio bulbi muscles, and the secretion of the gland of Harder of other vertebrata.

The muscle of Riolan in man and other mammals

The close apposition of the lid margins to the cornea which may, as already mentioned, cause depressions in its surface epithelium, is brought about by the contraction of that portion of the orbicularis muscle situated within the line of the roots of the eyelashes and around the ducts of the Meibomian glands, the so-called subtarsalis muscle or ciliary muscle of Riolan.

Through the courtesy of Sir Peter Chalmers Mitchell and the pathologist, Col. A. E. Hamerton, of the Zoological Society, I have been able to have made and examine microscopical sections of the eyelids of a variety of different species of mammals; and have found in them very varying degrees in the development of the subtarsalis muscle of Riolan (vide Plate.) In none of them is it such a definitely separate and distinct group of fibres as in man. Its degree of development may be closely correlated with the presence or absence of an active nictitating membrane. In the only primate I have examined other than man, a brown Capuchin monkey (Cebus Fatuellas) it approached nearest to that in man. In a red frontal lemur (Lemur fulvus rufifrons) the orbicularis muscle extended to the border of the lid superficially, but only a few fibres were present on the tarsal surface of the ducts of the Meibomian
glands. The same applies to the reindeer (Rangifer Tarandus). In the sun bear (Ursus Malaganus) and the eland (Taurotragus Oryx), though the orbicularis muscle is well developed no subtarsalis muscle is present. This set of muscle fibres is also completely absent in the eyelids of rats and rabbits.

In association with this late phylogenetic evolution of the subtarsalis muscle of Riolan, it is interesting to note its late appearance in the human embryo. Miss Mann says:—"Riolan's muscle cannot be recognized as separate from the orbicularis muscle mass until 62 mm., by which time the lid margins are adherent and the rudiments of the cilia apparent."

**Donders' experiments on the effects of expiratory efforts on the extra-ocular, intra-ocular and retro-ocular blood vessels**

Donders' paper, written at Darwin's request, "On the action of the eyelids in determination of blood from expiratory efforts," is full of interesting observations and experiments. He first confirms Sir Charles Bell's observation as to the contraction of the orbicularis muscle during violent expiratory efforts, pointing out that at such times two factors tend to increase the blood pressure and distend the external, the intra-ocular, and the retro-ocular blood vessels; first the direct increase of pressure in the arteries, and secondly the delay in the return of the flow of blood through the veins. Fluctuations which show in a sphygmogram are spoken of as respiratory undulations.

Like Sir Charles Bell, Donders found that the dilatation of the external vessels on the surface of the eye, during violent respiratory efforts, can be readily observed by lifting the eyelid away from the globe at such times.

As to the influence of such efforts on the intra-ocular blood vessels Donders found evidence by observing the pulsations of the retinal veins on the optic disc. He says:—"In the place where these exhibit the systolic movements, in voluntary expiratory effort after tolerably deep inspiration, they become greatly distended, and remain distended, so long as expiratory pressure lasts, on the subsequent inspiration they suddenly collapse, and at first in a still constricted condition, rapidly again exhibit the phenomenon of the pulsus venosus."

This observation is confirmed by Duke-Elder who writes:—"Whenever the outflow from the veins is sufficiently obstructed the venous pulse will not occur, no matter what the pressure relations are. This is seen experimentally in the abolition of a pulse in any condition of venous engorgement as by prolonged expiration (Trigt, 1853: Donders, 1855), on raising the arms above the head (Manz, 1874; Laquer, 1877), on compressing the jugulars or the thorax (Helfriech, 1882), or on kinking the vein by rotating the eyes to the side (Graves)."
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As regards the influence produced on the intra-ocular circulation by strong contraction of the orbicularis muscle, Donders quoted the effects seen ophthalmoscopically and entoptically on the retinal circulation by pressure on the eyeball. He said how he had observed ophthalmoscopically that the moment pressure kept up for some time on the globe was relaxed all the vessels of the retina (and at the same time the vessels of the choroid) became suddenly distended. The same sudden distension he said could be seen entoptically in connection with the shadows of the retinal vessels in Purkinje’s experiment.

Donders describes his method of investigating the effects of respiratory movements, more especially powerful expiratory efforts, on the retro-bulbar venous system in the following manner:—

"The head was fixed and the eye directed to a point so that the axis of the cornea made a right angle with the axis of a Helmholtz ophthalmometer which was employed in the investigation. Care was thus taken that the cornea was seen exactly in profile. Two short black hairs were now, in a vertical direction and parallel to one another, stuck on a level with the cornea against the lateral wall of the root of the nose, so that they were seen together with the boundary of the cornea, and the distance from the latter to these hairs could be accurately measured by doubling the ophthalmometer images. Movements of 0.02 mm. should in this manner be certainly recognizable;” yet he did not succeed in ordinary respiration in demonstrating any movement.

"It was otherwise, he says, when the respiration was increased or laboured, and especially when a powerful expiratory effort was maintained for some time. In the first case, at least some expiratory movement of the eyeball is in most men perceptible, and in the second we see, while the face becomes red and swollen, the eyeball distinctly advances. In young men, this movement appeared to be less than at a somewhat advanced time of life. As the maximum I found in a man aged 42 years, 1.45 mm., in five cases, on an average, 1.1 mm. It is developed very gradually in eight or ten seconds to its maximum, and it requires from three to four seconds to disappear again entirely. This can be attributed to nothing else than dilatation of the veins of the orbit. There is, I think, no doubt that pressure of the eyelids is capable of preventing this dilatation.”

Advance of the eyeball on voluntary widening of the palpebral aperture and its recession on nictitation

In connection with his observations with the ophthalmometer as to the position of the eyeball in the orbit another noteworthy phenomenon attracted Donders’ attention. He found that on voluntary widening the palpebral aperture by raising the upper
eyelid the eyeball advanced, and that at each nictitation the eyeball receded in the orbit. He gives a table showing the mean of many measurements in millimetres of the recession of the globe on constriction of the palpebral aperture, and of its advance on the dilatation of the aperture. The total displacement varied from 0.78 to 1.46 mm.

He found that passive raising of the eyelid, as by a spatula, had no influence on the position of the eye, concluding, therefore, that its advance was the result of muscular contraction. He assumed that of the levator palpebrarum, apparently not taking into consideration the possible influence of the contraction of Müller's unstriated muscle fibres in the eyelids, and of similar fibres, also named after Müller, connected with the orbital periosteum in the inferior orbital fissure, both of which sets of fibres receive their nerve supply from the cervical sympathetic. The unstriated muscle fibres which form part of the orbital aponeurosis are the vestigial remains of Gegenbauer's orbital muscle or the protrusio bulbi muscle of the lower mammals. Their presence in man was demonstrated by Müller in 1858, by Sir William Turner in 1862, and again by Sappey in 1868. It is known that paralysis of the cervical sympathetic nerve gives rise not only to slight drooping of the upper eyelid, and narrowing of the palpebral fissure, but also to some recession of the eyeball in the orbit. Macallum and Cornell found that when a dog's head is removed from the body, and the blood allowed to drain away, stimulation of the cervical sympathetic results in an exophthalmos as pronounced as any produced in the living dog, thus demonstrating that it was brought about not by vascular distension, but by contraction of the musculus orbitalis of Müller. Jonnesco by employing strong stimulation of the sympathetic in man reports that he produced definite protrusion of the eyeball. It would, therefore, seem most probable that the phenomenon observed by Donders in normal conditions, of widening of the palpebral aperture being accompanied by slight proptosis, is due to the contraction of the unstriated muscle fibres of Müller in the eyelid and in the orbit, both of which are supplied by the cervical sympathetic nerve.

The proptosis and retraction of the upper eyelid with widening of the palpebral fissure which are so marked in Graves's disease are also, I suggest, due to over stimulation of these same sets of unstriated muscle fibres which may under such conditions become hypertrophied.

In summing up the results of his experiments and observations Donders says:—"We have satisfied ourselves that the external vessels of the eye, as well as the intra-ocular and retro-ocular, are dilated by increased expiratory pressure. We have seen that the eyelids in closing limit or entirely remove this dilatation, partly
by pressure, partly perhaps by a certain associated action. We have remarked, that on each increase of expiratory pressure the eyelids are closed, or are at least inclined to close. The conclusion is therefore evident, that by closing of the eyelids the injurious effect of an overflow of blood is warded off.

Besides the support which the ocular blood vessels receive from closure of the eyelids, the intra-ocular vessels are protected from over distension by the tense condition of the eyeball and the elasticity of its membranes. The retro-ocular vessels in the orbit have also the additional protection of their free anastomoses with the facial veins, the absence of valves in them allowing such anastomoses to be readily opened up in the event of any delayed flow of blood in the normal direction into the cavernous sinus.

So effectual are these protections under ordinary conditions, reinforced as we have seen they are at times by pressure on the eyeball from firm closure of the eyelids, that Donders was obliged to admit that he had found but little evidence of essential injury to the eyes occurring from want of support in expiratory efforts. Under exceptional conditions haemorrhages from all three sets of such vessels have, however, been recorded. These exceptional conditions may be classed as follows:—

(a) Dyspnoea and asphyxia resulting from compression of the chest or neck from without.
(b) Violent expiratory efforts from contraction of the diaphragm, after a deep inspiration followed by closure of the glottis.
(c) Violent expulsive abdominal efforts from contraction of the diaphragm under similar conditions.
(d) Undue weakness of the walls of the ocular blood vessels in association with (b) and (c).
(e) Lowered intra-ocular pressure in association with (b) and (c).

Ocular haemorrhages following dyspnoea from compression of the chest or neck from without

Max Knies\textsuperscript{19} says:—"In acute suffocation the pupil is generally, though not always narrow, and haemorrhages, often only punctate occur into the conjunctiva and retina. The latter are often not seen until the autopsy. The haemorrhages also often occur beneath the integument of the lids and are found occasionally in all the vascular parts of the eye and its vicinity (Schlemm's canal, Petit's canal, etc.). In chronic suffocation, in which similar haemorrhages may finally be produced, the retinal vessels, particularly the veins, appear with the ophthalmoscope to be unusually dark, often almost black as the result of overloading the blood with carbonic acid."

Webster Fox\textsuperscript{20} writes:—"Haemorrhagic foci appear especially in the conjunctiva, in those killed by asphyxia, hanging and strangulation, their importance being recognised from the standpoint
of legal medicine. Circulatory disturbances also cause retinal haemorrhages, as in pulmonary emphysema, emboli of the pulmonary artery, and cyanosis consequent to respiratory troubles where there is simultaneous formation of haemorrhagic foci in the retina and in the conjunctiva. This is especially observed in cases where death has been preceded by symptoms of suffocation."

Arnold Knapp\textsuperscript{21} says:—"Conditions which produce venous stasis, even if sudden and of high degree, rarely produce retinal haemorrhages. After severe injuries to the body, in which the thorax or the abdomen are compressed, it is frequent to find the head, neck and chest and the visible mucous membranes dark blue and covered with small haemorrhages. In a few cases haemorrhages have also been observed in the retina. Roenne has observed haemorrhages occurring in seven out of 60 cases. This rarity is explained by the protection which the retinal vessels derive from the ocular pressure. As a rule the retinal haemorrhages in these cases cause no visual disturbance and are rapidly absorbed."

Berrisford,\textsuperscript{22} in 1921, wrote an article on the ocular symptoms in traumatic asphyxia or apnoea, in which he described the case of a man who was for eight minutes accidentally pinned under a two-ton tunnelling machine, and discussed those in other recorded cases of a similar class, in which the patients had been crushed in crowds. The eyes in Berrisford's case were proptosed, the ocular conjunctiva protruded through the palpebral fissure and had haemorrhages in it; where, however, the lids stood in contact with the eyeball the conjunctiva though congested was free from haemorrhages. The fundi showed dilatation and tortuosity of the retinal veins, and bluish-grey patches which were supposed to be due to oedematous swelling in the nerve fibre layer. They disappeared completely in eight weeks, and may, I suggest, quite likely have been similar in nature to patches of commotio retinae, and caused by subchoroidal haemorrhage.

**Ocular haemorrhages from violent expiratory or abdominal expulsive efforts**

In the violent expiratory or expulsive efforts occasioned by contraction of the diaphragm after a deep inspiration, as in coughing, sneezing, vomiting, straining at stool, and in the second stage of parturition, it is the external vessels of the eye which are most liable to rupture, giving rise to subconjunctival ecchymoses. Most writers of textbooks on eye diseases refer to such subconjunctival haemorrhages in connection with whooping cough.

Clement Lucas\textsuperscript{23} in an article on "Ocular Ecchymosis" writes:—"Another cause of subconjunctival ecchymosis is any sudden violent arrest of respiration and circulation; such as occurs in
whooping cough, in severe vomiting and such as results from crushing blows upon the abdomen and thorax.”

That an accessory cause to the occurrence of subconjunctival haemorrhages may be compression of the jugular veins in the neck by too tight a collar I know from personal experience. At one time I had a recurrence of such little haemorrhages in my own eyes which entirely ceased when I adopted the use of a collar of a larger size.

Rupture of the orbital vessels from such expiratory or expulsive efforts must be of exceedingly rare occurrence, some such cases have, however, been recorded. Max Knies refers to a case observed by Dépontot in which spontaneous luxation of the globe in front of the eyelids was observed as a result of sneezing, and says that he himself has observed it as the result of sneezing in Basedow’s disease.

In connection with whooping cough Max Knies says:—“Orbital haemorrhages, unless extensive, are usually not noticed for several days, when the extravasated blood appears beneath the conjunctiva, in the eyelids and adjacent parts. Small haemorrhages are harmless; large ones, which are rare, produce exophthalmos.” Mackenzie mentions having seen a girl of eight years of age with exophthalmos of the right eye, produced by “chin-cough.” The eye was movable, and vision good. Her brother had been in the same state, but in him the eye retreated under cold applications.

Donders mentions a case of exophthalmos recorded by Dr. Gunning which he regarded as due to rupture of vessels in consequence of whooping cough.

**Weakness of the vessel walls or lowered intra-ocular pressure as coincident changes**

In the less violent expiratory efforts haemorrhage from congestion of the ocular vessels is most likely to occur where the vessel walls are brittle or where their surrounding elastic support has been decreased. Thus Max Knies writes:—“Sneezing, blowing the nose and coughing may give rise to haemorrhage in all vascular parts of the eye and its vicinity, most frequently in the conjunctiva, eyelids and retina. In such cases there are often coincident changes in the vessels particularly atheroma, and these naturally constitute a predisposing factor.” In illustration of this I may here quote the following case which recently came under my own observation.

A medical man, aged 67 years, came to see me on March 25, 1929, stating that two months previously after sneezing violently whilst walking in the snow, he noticed a blood-coloured shadow in front of his left eye, which had since slowly become reduced in size. The vision in his R. eye was 6/6 partly and in his L. 6/18 two letters. His blood pressure he told me at the time his vision failed
was 195 to 200, but had since become reduced. I found on ophthalmoscopic examination, a large circular sub-hyaloid haemorrhage above the macula in his left eye, and two small haemorrhages in the retina below it. His retinal arteries were thickened and kinked the veins where they crossed them in the neighbourhood of the optic disc.

Most of us have probably had the painful experience of haemorrhage occurring in an eye which has had the elastic support to its vessels lowered by an operation for extraction of cataract or for the relief of glaucoma. Such painful incidents were far more frequent when those operations were performed under a general anaesthetic which was not uncommonly followed by retching or sickness. Indeed in those days a nurse used to be seated beside such patients as they recovered from the anaesthetic with instructions to place her hand over the operated eye, to give it additional support, should the patient retch or vomit.

The influence of violent expiratory efforts in glaucomatous eyes or in eyes predisposed to glaucoma

The contents of the eyeball may in some respects be compared to the contents of the cranial cavity. In infants in whom the fontanelles are still open, movements in the cranial contents, due to variations in blood pressure, are easily seen in connection with respiration, rising during expiration and falling during inspiration. Similarly it has been shown by several different experimenters, that when a manometer is connected with the fluids in the interior of the eye, movements will occur which not only synchronise with the pulse but also with respiration, and may be as distinct as the pulse and respiratory waves in an ordinary blood-pressure curve.

Under normal conditions, any rise in intra-ocular pressure which is occasioned by violent expiratory efforts will be readily compensated for by an increased escape of aqueous humour through the filtration channels at the angle of the anterior chamber. In conditions, however, where, as in advanced life, the walls of the blood-vessels have lost some of their former elasticity, and where the free passage of fluid through the normal safety valves is in any way impaired, the rise in intra-ocular pressure occasioned by prolonged expiratory efforts might aid in the further closure of the safety valves or the intensification of glaucomatous symptoms. That this is so seems to be borne out by clinical experience. It is generally recognized that conditions which disturb the circulation and tend to congest the venous system predispose to the production of glaucoma. Both Priestley Smith and Col. Elliot mention bronchitis and chronic constipation as common antecedents of glaucoma, and Fuchs speaks of its frequent occurrence in connection with influenza.
Firm closure of the eyelids under certain conditions as a preventive of ocular lesions

The investigation of a physiological phenomenon will often afford valuable suggestions as to the preventive treatment of pathological disturbances. So the investigation of the physiology of weeping, and why children when crying contract their orbicularis muscles, suggests measures which may be taken in the prevention of vascular disturbances occurring in connection with violent muscular exertions or expiratory efforts.

In cases of recurrent sub-conjunctival haemorrhage, advising patients to adopt the simple precaution of consciously firmly closing the eyelids when straining, coughing violently or sneezing, as an infant does unconsciously; and also seeing that their neckwear is not so tight as to press unduly on their jugular veins, will check such recurrences.

Similar advice to elderly patients who show signs of sclerosis of the retinal arteries and have increased blood pressure, will be likely to prevent intra-ocular haemorrhages fraught with more serious consequences.

When the natural surrounding elastic external support of the intra-ocular vessels is diminished, by the lowered tension of the eyeball following an operation of extraction of cataract or for the relief of glaucoma, the advisability of giving extra external support by means of a pad and bandage becomes obvious. Such a practice is, I believe, almost universal in this country; on the continent, however, I know there was one surgeon who considered it as unnecessary and undesirable, arguing that the tying of an eye up after such operations tends to promote the accumulation of micro-organisms and their proliferation in the conjunctival sacs.

Patients suffering from glaucoma or a tendency to it should be advised to try and avoid anything likely to lead to prolonged or frequent expiratory efforts, such as attacks of bronchitis, of influenza, vomiting or constipation; and should such efforts be unavoidably incurred to keep their eyes firmly closed whilst they last. They should further be instructed to discard any article of clothing liable to retard the return of blood from the head by compression of their jugular veins.

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THE CONVERGENCE OF HUMAN BINOCULAR VISION

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In my work "Indications for the Kinetic Treatment of the Eyes," I have called the central kinetic factor of human binocular vision "Involuntary Convergence." In available literature I find convergence mentioned only as a voluntary movement. But voluntary convergence is not the kinetic factor of binocular foveal-macular vision. Therefore, in order to make it clear that I dealt with the reflex motor-co-ordination and not with the other function—the willed movement—I called it Involuntary Convergence.

I trust that this long term will soon make place for convergence, pure and simple. "Voluntary convergence" is really a misconception of voluntary binocular adduction, a movement of considerable importance to make the two visual fields overlap, but it is not the convergence of bi-foveal vision.

It appears that some serious confusion exists in the terms and definitions of binocular ophthalmology. One of the causes of this condition is, I consider, the overlapping of ophthalmological science with mechanics or optics on the one side (on account of the ocular media) and with psychology on the other side (on account of the visual fields in the cortex cerebri). This confusion obscures the outlook on the physiology of binocular vision.

Gantonnet complains that binocular vision is neglected: "mais qui s'occupe de la vision binoculaire?"