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Mini Review

Researches on Physiological Biophysics of Human Semicircular Canals Forty Years Later

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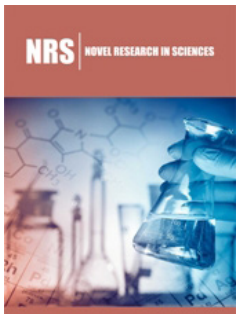
Abstract

The author began to deal with the biophysics of semicircular canals, with initial reference to problems of space medicine, in the early 1970s as a student of the degree course in physics (at that time, four years after high school) and as an experimental thesis. The results were approved by the Council of Europe's competent committee, and the thesis was also approved with distinction. The research was rapidly and encouragingly developed both as a mathematical and physical modelling and as a study of situations of vestibological interest, but they had to be abandoned for reasons not intrinsic to the project and despite the results already achieved. Some forty years later, the discourse is resumed, in continuity and for coherent lines, in particular on the evolution of the physical-mathematical models to be used, with regard to concerning the anisotropy of perceptual space, about the possible new ways of experimenting on young volunteers and their innovative equipment, and about the enormous expansion and considerable differentiation of application domains

Keywords: Semicircular canals; Human vestibular apparatus; Biophysics; Classical physics; Physiology; Sense organs.



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Premise

Talking about scientific research dating back decades on issues and in venues that should all be up to date might seem out of place. However, the history of science is full of episodes of minimal importance, such as the present one, or of enormous importance, in which discoveries, theories, laws and hypotheses set aside in a certain period have been rediscovered and valued for their propulsive thrust and for their cognitive and also for their application value only in following periods. Latine loqui: si parva licet componere magnis citing Vergilium. How to speak English: Virgil citing, admitting that it's permissible to compare small things with the great ones, an example of fundamental importance for the science of the nineteenth-twentieth century and present will be enough. The three laws of genetics that we still call by the surname of Abbot Mendel (Gregor Johann Mendel, 1822–1884) were presented to the scientific community in 1865 and remained shelved; then the monk- turned-abbot would devote himself to a different commitment. It was not until the beginning of the 20th century that this fundamental theory was revived. The discourse is more valid for research processes than for the laws and theories that serve as a paradigm for a new period of "normal science" in Kuhn's sense.

Research on Semicircular Canals' Biophysics in the 1970's

Originally, there was a research project by the Council of Europe (Committee on Science and Technology -Working Party on Aerospace Physiology and Medicine) in the early 1970s, relating to the planned putting of permanent space stations into the Earth orbit. In those years, the term "space medicine" was in use. There were reasons to suspect the problematic character in many respects of the permanence of the human body in a state of imponderability for prolonged periods. It was then proposed to build space stations in the toric form to rotate slowly around its axis, thus replacing the centrifugal reaction to the force of gravity. The solution was not as simple as it could appear to those who did not know the mechanics, since the centrifugal reaction follows principles other than the force of gravity, but above all, a rotary drag motion exposes the motions related to the appearance of an additional type of forces, namely the forces called "Coriolis" , which can produce effects that a doctor could classify as pathological. The Coriolis' forces, and the resulting accelerations, are also called "compound

centrifugal" or "complementary": such alternating designations present obvious explanatory motivations.

It is elementary to calculate that the centrifugal reaction, and the resulting acceleration, would be equal to g, i.e. 9.8 m/s^2, in a toric station with a major radius of only 4 meters would have been enough a rotation of π/2 s-1 (90°/s), and this angular speed decreases with the increase in the size of the station. As part of a collaboration between the E.N.T. Clinic of the University of Padua (dir. Michele Arslan), and the National Legnaro Laboratories of the National Institute of Nuclear Physics (dir. Renato A. Ricci), was assigned to us as a thesis the study of the phenomenon with physical and mathematical models and with experiments that reproduced or simulated the situation. Starting from a head orthogonal position at the axis of rotation, young volunteers carried out three round-trip sessions of the head along the three axes on special rotating seats, in a silent environment and were blindfolded. The aim was to study the effects of this force, with detection of the two-dimensional nystagmus, neurovegetative effects by a doctor and with the description of subjective sensations. The angular drag speed ranged from π/10 s-1 to π/2 s-1 (from 18°/s to 90°/s). We also experienced higher drag speeds, but they were clearly useless for the original application purpose. The speech would have been different for subsequent reflections that were not foreseeable at the time, and which would have covered fields other than space medicine.

Generally speaking, the results were clearly negative as to the sustainability of Coriolis' forces in general, even for very low drag speeds. The European project had been initiated during the Apollo program, whose main purpose was to bring man to the moon, The goal had been achieved for the first time on 21 July 1969, as part of a series of 11 missions of various types with three astronauts between 11 October 1968 and 7 December 1972, bringing to the moon a total of five pairs of astronauts. Our research was then launched later. The Skylab platform was launched on 14 May 1973 and after the turnover of three crews for 28, 59 and 84 days, from 8 February 1974, it underwent a series of technical experiments until the relapse on 11 July 1979. It was derived from the third stage of Saturn's missile, essentially a cylinder, which excluded the centrifugal hypothesis. Other platforms followed, but there was no re-enacting of the artificial field.

As is immediately understood by knowing the rudiments of the theory of relative motions, such a substitution would have been affected by all the consequences of the onset of Coriolis' force every time the head was moved. This force is zero when the two vectors are parallel, or one of the two is null: that is, there is no drag rotation, or there is no relative motion. Symptoms similar to those of pathological arousal by Coriolis' force can be presented in the medical field: but, in this case, it is more precisely referred to as the "Coriolis effect".

It will be worth remembering that the physical and physiological study of the vestibular apparatus dates back to the XIX century like other similar studies of human physiology, that in the case of sense organs were ascribed to psychology just founded as science. In these physiological studies have distinguished medical physics scholars such as H.L.M. von Helmholtz (1821-1894) and J.L.M. Poiseuille (1799-1869). The pioneer of vestibological physiology was the great physicist and epistemologist Ernst Mach (1838-1916), along with Joseph Breuer (1842-1925), the same doctor who interacted so successfully with Freud, and the chemist Alexander Crum Brown (1838-1922). In the 1900s, research had a great development that intensified recently, and these historical foundations were also discussed, going back to the Renaissance. Biophysics, that is the study of biological phenomena with conceptual tools of physics, in turn goes back at least to those nineteenth-century studies of physiology, in particular of the sense organs. However, some authors date back to Luigi Galvani (1737-1798) and animal electricity studies (Blezza 1983), and even to Leonardo da Vinci (1452-1519) and his studies on bird flight (Vecli. page 16.1).

That Research of Vestibological Biophysics and its Closure

Using a rigid-body model, the core of mathematical processing was a complex of calculations that was somewhat long but free of difficulties, also because there were several possibilities of simplistic approximations. This exposes physicists' criticism of being a "classic" process, that is, non-quantum and non-relativistic one; moreover, the application of classical mechanics to human physiology had such development mentioned. The result of the convergence of the two studies was the expected and most obvious one: the movement of the head was possible, but only around an axis parallel to the axis of the drag rotation, the effect of which is null; in every other hypothesis there were considerable effects from Coriolis forces, disorientation, dizziness, nystagmus, neurovegetative effects, appreciable even quantitatively. The thesis was dissertated (and approved with distinction) on 24/3/75, experimental research was discontinued a few months later due to the unavailability of the machinery, and those modelistic ones were continued until 1981 by the writer on his own, that is, until it was materially possible in times when there were neither PCs nor the today internet nor other equally necessary resources.

Some twenty scientific papers were expressed, between 1976 and 1985, three of them in English, and there were some participations in conferences of both doctors and physicists. Those results were widely cited in the most authoritative academic circles and treatises, which can still be found online today. Then the research project was progressively abandoned for non-intrinsic reasons. The author of those writings and the paper present is known as a pedagogist: the last biophysics publications came out with the header of the Institute of Pedagogy of the University of Trieste where he began his new academic career, with the advantage of a firm experimental scientific training. In short, those searches stopped for reasons not dependent on the will of the researcher. But Unended [is the] quest (Popper 1976), and the research, always hypothetical and always fallible, has no deadline or prescription. Moreover, the

physiological biophysics of the vestibular apparatus is still a field of research whose prospects still open up endless horizons.

Not in the Space, but...

Many interpretations that were then given to the research results tended to refer the movements of the head to the body, and not to the axis of the drag rotation: "fold the head to the left or to the right" became a kind of warning, instead it should have been formulated alternately as a rotation of the head on the same plane (or around the same axis) of the drag rotation. That idea of surrogate gravity with the centrifugal reaction was senseless in its simplism, and it would have had no follow-up. Space stations would have had a future of great interest, even then, especially as an application research, but no one would have proposed more than toric forms, rotation and surrogate of absent gravity. In the next space station called Spacelab, active on European initiative between '83 and '98 hosting 22 missions, a rotating chair was also mounted; the proposal for experiments that we advanced was not followed up. Research on the head motions in a rotational field with perpendicular axis had, in short, no follow-up to the astronautics and space medicine. However, this was a dynamic situation of obvious application interest in other application fields, where there was also terrestrial gravity as in the experiments that had been conducted in the E.N.T. Clinic. This was already clear to us at the time, at least concerning some critical situations of the Air Force. There are maneuvers in which the aircraft is rotated right around a perpendicular axis, or almost, to that of the pilot's head, and with angular speeds far greater than conceivable in the fallen space medicine project.

It is, first of all, the "tonneau" in which the aircraft revolves around its axis and linear route, the "barrel" tonneau in which the aircraft is revolutionized around the longitudinal axis describing a helical trajectory on an ideal cylindrical surface, or if you prefer to flow along with the threading of a huge screw. Then there is the "Looping" or "death lap", the cabrata of the aircraft until it completes an entire loop-shaped turn. A perfect looping should draw a circular trajectory that closes exactly in the same situation in which it began. The narrower turns, the Schneider, should also be mentioned, with approximation. And, of course, the fall into lives. It may not be frequent for the pilot to anticipate a tonneau by swinging its head around the drag axis, that is, tilting it from right to left shoulder and vice versa; but it is certainly of great use in looping the flexing the head backwards as it is a matter of anticipating the vision of the next positions until the resumption of the linear and horizontal route. They are harmful because they generate Coriolis forces the rotator movements of the head around the other two orthogonal axes, that is, back and forth in the tonneau, left and right in looping, and rotating the head around its axis, in both.

Any reference to the possible motions of the head to the body would be misleading. Instead, the possible influence of relative movements of the head as Coriolis forces depends on the orientation of the axis of those movements relative to the drag rotation axis, which is not said to be parallel to the axis of the human body. This can be understood, for example, by the car driver, in his movement generally on two dimensions, and that when turning orders the car to make a drag rotation, more or less narrow and more or less fast, around an axis that is parallel to the axis of its head: to rotate the head around that same axis, better if with the head tilted forward by 30 degrees, it is perfectly a harmless maneuver as it is completely free from accelerations of Coriolis, as the experience of any motorist can corroborate, which indeed must be accomplished to see the turning places first.

The (well-known) Anisotropy of the Perceptual Space of the Semicircular Canals

From the perspective of physiological biophysics, the discourse was more complex than the models that considered the three semicircular canals as if they were whole toruses, while it is well known that they are not independent, all flow into the utricle, and the two vertical canals have a common duct, latine loqui "crus commune". A result obtained in those researches requires attention and suggests further research, always in the combination of physical and mathematical models and experiments on volunteers. It is the anisotropy of perceptual space, at least as far as this part of the vestibular apparatus is concerned, which requires a more general study and theory: the same angular force is perceived more intense with the head ahead by 30 degrees, that is, with the excitement only of the lateral canals, compared to other positions. As much as everyone knows that the canals are not semi-toric, the simplistic diction "semicircular canals" has prevailed. Modelling also has a long way to go to correct the obvious error of approaching the canals as independent of each other. We showed physically that the consideration of crus commune could help to explain this anisotropy; a biophysical consideration of canals in their geometric reality and in particular in their non-independence can open up boundless horizons of study and application.

We all know that semicircular canals are activated to reveal only angular forces, which can be physiological, and Coriolis forces that can be pathological even in very limited doses. Angular forces can be well reproduced, the problem is how to orient them with respect to the canals, that is, with respect to the head. If the problem shifts from the position of the head with respect to the body to the position of the head in the space compared to any vector drag speeds, a review of the models of this part of the vestibular apparatus is required. First of all, it was necessary to study more rigorously the geometry and therefore the mechanical characteristics of these three canals with all their mutual dependencies, and also the not insignificant differences in size. This would have involved anatomical research, which is not the expertise of either a physicist or a biophysicist, and experiments on volunteers with specific assessments of the excitability of each pair of contralateral semicircular canals, starting with angular forces and then continuing possibly with Coriolis forces designed to prioritize the excitement of a pair of canals over the other two.

The problem arises as to whether this anisotropy stems from the fact that the canals are not independent of each other, as applies to the crus commune in relation to the two vertical canals, i.e. the superior and posterior ones. In fact, for the same conditions, the mere fact that the two vertical canals have a common duct explains the lower sensitivity of these compared to the lateral canals. But it is one of the many partial answers we have for such questions. But above all, the canals are not "semi"circular, we did an estimate of 2/3 for the two verticals, and do not depend only by the common duct, as all three canals flow into the utricle and communicate with other components of the vestibular apparatus. Modelling needs more anatomical adherence, which could mean a considerable complication. Hence, the need for experiments on human volunteers with absolutely special equipment precisely for the knowledge of this anisotropic perceptual space, that is, the different sensitivity of the canals. This is a condition for a significant evolution of physical and mathematical models, condition of the evolution of knowledge, and condition of more effective application.

Here is another difficulty. because excitement is always about pairs of canals; and moreover, the posterior canal of one side is on a plane roughly parallel to that of the superior counterlateral canal, and vice versa. However, this means that we can experience anisotropy, but for plans and not for canals. We cannot compare the sensitivity between the superiors and the posteriors canals, but between a superior and the posterior counterlateral canal with that of the other pair of vertical canals at the two sides, and each pair with the pair of lateral canals.

A simple rotating chair can be used, in the most favorable hypotheses, for rough experimentation on the pair of lateral canals, not forgetting the dependencies mentioned above and the not negligible dynamics resulting in the endolymph. Each can imagine the acrobatics to be performed by sitting and fastening to the chair to make horizontal the two planes of the two pairs of vertical canals control laterals and (roughly) on the same plane. You might even succeed, but how to get the fixity of the head? Do not forget that even very small movements would give rise to forces of Coriolis, which are also proportional to the angular speed of drag, which would soon become high with the administration of constant angular accelerations above the threshold for a not short time and increasing steps. It was hypothesized at the time, but those researches had to be abandoned.

Much more complex equipment would be needed, allowing the two planes of the vertical canals to be excited separately one at a time, as well as the plane of the two lateral canals, with the possibility of comparison. It takes, for example, a platform to ensure the head and the whole body reliably, and for the head, the best system remains the dental one; and can be oriented in such a way as to make each of the three pairs of planes horizontally, and then apply a series of steps of increasing angular forces, around a vertical axis that is perpendicular to that plane, within the subjective tolerability. The subjective comparison data is not simple and can be altered by many disturbance factors, so some training on suitable subjects and a repetition of the tests with different sequences will be required. These data, together with the detection of the nystagmus at least two-dimensional, and with the medical evaluation of the various neurovegetative effects also considered in their relative intensity, should then be compared with the accurate geometric and weight studies that give us rigorous evaluations of the system. The models resulting from this evolution will allow a better application to situations of unusual arousal of the apparatus, and a more precise knowledge.

Can we do it with Coriolis' Forces?

In theory, one might think of the similar cycle of experimentation with semicircular canals arousal on the three planes with Coriolis forces rather than with angular forces. There is no reason to assume that the anisotropy being researched has some difference in the perception of one force or the other. The same observations apply to the difficulty of orienting the head and holding it still in a rotating chair equipment, and about the need for a device that is considerably more complex in its mechanics. In addition, there is the difficulty because the head should be not fixed but moving in a constant direction. In principle, it is not impossible to obtain a Coriolis force in a constant direction and therefore with respect to which to orient once each of the three planes: the direction is perpendicular to the axis of drag rotation and to the relative speed of the head on this non-inertial system. However, the motions of the head can only to a small extent considered linear and for such to be reproduced, among other things with many approximations: usually the relative motions of the head are rotational motions, therefore with non-constant vector speed. Also, moving the head would be problematic to maintain a constant orientation of the other factor, that is, precisely the angular drag velocity. In short, it is possible, but in a rough way and with a supplement of difficulty. The difficulties are considerable for an experimental investigation only with angular forces.

Not Theory or Practice, but Application and Professional Mediation

Here one could fall back into the theory-practice dualism, more or less consciously. It is a mistake that is not infrequent among my colleagues pedagogist, despite the teachings of Dewey (1916), Pragmatism and Epistemology of the last century and a half, including the Empiricism of the aforementioned Ernst Mach. Those who have a very specific profession in front of them, such as medical surgeons and how pedagogists should be, or those who are well aware of the asymmetrical relationship between theory and the empirical part such as physicists, biophysicists or chemists, whose science is constitutively experimental and has professional consequences, knows that the discourse must be given on the mediation level between theory and praxis, which benefits both and makes them mutually communicating and aimed at man. From the comparison between the possible modelling predictions, however, based on more realistic geometric and mass considerations than those available today, and the effects on the organisms of volunteers with the machinery of the type of what has been hypothesized, it can achieved not only a

considerable advance in knowledge on this small but important human sensory apparatus but also a whole range of indications about the operation in situations of abnormal and pathological excitation.

These situations are increasingly occurring in a world like our continuous non-physiological movement and induced by the most varied machinery, even without mechanical propulsion. We had to deal with space flight, with air flight, with the car; we could talk alternately, for example, about children's (and not only) recreations based on abnormal excitement also of the vestibular apparatus, and there are many; we could continue with helicopters, with mobility on the water and under the water, with air mobility also on passive instruments (delta plans, paragliders), or with exercises such as bungee jumping, and so on. But these are just examples. Think of skiing, not just the acrobatic (hot dog), in the slalom, the angular accelerations and round-speed drags are, at times, very high. Think of the dancers or gymnasts who make pirouettes and know that in that drag the motion of the head around its axis can be accomplished with due caution, while it is much more difficult to tilt the head.

Even more pronounced is the phenomenon of dancing on roller skates, and the speed of drag rotation is even greater for ice skaters when they make accelerated pirouettes by bringing their arms closer to the body. It will not be a negligible fact to keep the head fixed by the ice skaters of speed, save a barely anticipate the curves with a rotation of the head, once again, on an axis parallel to the drag rotation. The world record for 1000 meters of ice speed (Shani Davis) is 1m 6s 42/100 i.e. at a speed of 15,058m/s, while the world record of the 100 meters flat, all in straight, is 9s 58/100 (Usain Bolt) i.e. at a speed of 10.438m/s. Vestibular problems are today's problems that tend to become more relevant in a readable future perspective. Biophysical studies can offer an important help.

References

1. Michele Arslan: *Otorinolaringoiatria*. Cedam, Padova 1945 n. e. 1970
2. Franco Blezza *Studio sperimentale sulle proprietà fisiche del sistema dei canali semicircolari umani (Ricerche, aerospaziali)* Tesi di Laurea in Fisica, Relatori Renatp A. Ricci e Michele Arslan, , a.a. 1973/74
3. Franco Blezza *Galvani e Volta – La polemica sull'elettricità*. La Scuola, Brescia 1983
4. Joseph Breuer und Sigmund Freud *Studien über Hysterie*. Franz Deuticke, Leipzig und Wien 1895
5. Philip G Cox and Nathan Jeffery *Semicircular canals and agility: the influence of size and shape measures*. J Anat., 216(1), pag. 37–47, Jan 2010.
6. John Dewey *Democracy and education: an introduction to the philosophy of education*, The Macmillan Company, New York 1916.
7. Laura Gastaldi, Stefano Pastorelli e Massimo Sarli *Vestibular apparatus: Dynamic model of the semicircular canals*, Conference Paper, may 2009. In the Web
8. Thomas S. Kuhn *The Structure of Scientific Revolution,* University of Chicago Press, Chicago 1962, 1970 with the *Postscript 1969*.
9. Marta M. Iversen and Richard D. Rabbitt *Wave Mechanics of the Vestibular Semicircular Canals* Biophysical Journal, 113, 5, 1133-1149, September 2017
10. Hans H. Kornhuber *Handbook of sensory physiology* 2 voll. Springer-Verlag, Berlin-Heidelberg-New York 1974.
11. Ernst Mach *Grundlinien der Lehre von den Bewegungsempfindungen*. W. Engelmann in Leipzig. 1875
12. Charles M. Oman, Edward N. Marcus and Ian S. Curthoys *The Influence of Semicircular Canal Morphology on Endolymph Flow Dynamics: An Anatomically Descriptive Mathematical Model*. Acta Oto-Laryngologica, volume 103, Issue 1-2, pages 1-13. 1987.
13. Karl R. Popper *Unended Quest - Intellectual Autobiography*. Collins, London 1976.
14. Mauro Pozzi *Motion Cueing per simulatori dinamici di veicolo: algoritmi MPC basati su modelli percettivi*, Tesi di Laurea Magistrale in Ingegneria dell'Automazione, rel. Alessandro Beghi, corr. Mattia Bruschetta e Fabio Maran, Univ. Di Padova, a.a. 2010/11.
15. Gustav Schubert *Die physiologische auswirkung der Corioliskràfte bei trudelbewegung des flug-zeuge*. Pfiiger's Arch., 233, 537, 1934.
16. Bernd Sokolowski (ed.) *Auditory and Vestibular Research - Methods and Protocols*. Springer, New York 2016.
17. Wilhelm Steinhausen *Über die beobachtungen der cupula in den bognegängsampullen des labyrinthes des libenden hecths*. Pflügers Arch. Ges. Physiol. 232, 500–512, 1933.
18. Martina Vallicelli *Un modello matematico del sistema vestibolare* Tesi di Laurea in Analisi Matematica, Relatore Giovanna Citti, a.a. 2017/18
19. Arnaldo Vecli *Biofisica*. In Roberto Fieschi (ed.) *Enciclopedia della fisica*, vol. 2 cap. 16, ISEDI, Milano 1976.
20. Rosario Vega, Vladimir V. Alexandrov, Tamara B. Alexandrova and Enrique Soto *Mathematical Model of the Cupula-Endolymph System with Morphological Parameters for the Axolotl (Ambystoma tigrinum) Semicircular Canals*. The Open Medicei Informatics Journal, 2,138-148, 2008