Preface to the English Translation
of
"On Modelling Respiratory Arrhythmia of Heart rate"
Hans Strasburger

When, in the nineteen-seventies, I joined the psychophysiology research group, led by Rupert Hölzl and Roman Ferstl at the Munich Max-Planck Institute for Psychiatry, Rupert Hölzl had come across an exciting earlier cybernetic study of Martin Clynes (then at Rockland State University, NY), who had shown that respiratory arrhythmia of heart rate (RSA) was well described by a non-linear system sensitive to the direction of breathing (Clynes, 1960, 1962, 1969). The interesting property of Clynes' model was that – unlike many other non-linear biological systems – it could not be approximated by a linear system, even at small amplitudes. Yet by taking the direction of breathing into account, i.e. by introducing a simple non-linearity, a system composed of two linear systems (one for inhalation and the other for exhalation) worked perfectly. This held the promise to uncover the reason for many contradictory results on RSA, e.g. whether breathing-in or breathing-out would accelerate or slow-down heart rate. Contradictory results were also obtained for the orienting response (OR) of heart-rate, a major topic in psychophysiology at the time, which might also have stemmed from the RSA, acting as a confounding variable. Similar puzzling results on the RSA and OR still seem to exist today. Clynes also showed a similar, direction-sensitive behaviour for another physiological system, control of the pupil of the human eye (Clynes, 1962). To describe such systems, Clynes coined the terms *unidirectional rate sensitivity,* and later *rein control* (Clynes, 1969), where – unlike in a linear system – an effect in a subsystem can only be exerted in a single direction, similar to pulling the reins in horse riding.

Shortly before I joined, the psychophysiology research group had acquired a state-of-the-art analogue computer, made by Electronic Associates Inc. (EAI), and, together with a PDP-8 running FORTRAN and assembler – an excellent digital laboratory computer system for real-time applications – and also extensive psychophysiological hardware, the lab was well-equipped for real-time physiological simulations. I was hired to implement, verify, and extend Clynes' RSA work, and work towards applications in, e.g., behaviour therapy. Indeed, by 1979 we had a running and verified RSA-simulation in real time, with individualised system parameters for a number of subjects, documented in my unpublished thesis.

Clynes' (1960) paper was seminal for unraveling the workings of respiratory arrhythmia of heart rate, with reference to it even today (Wang & Zhu, 2025). More than thirty studies have since explored its dependence on important factors, including respiration rate, tidal volume, vagal tone, lung volume, breathing patterns, subject age, and interindividual differences (see Grossman & Taylor, 2007, for a review). An application as a measure of vagal tone which we envisaged, important in assessing relaxation from stress, has indeed come true (e.g. Goldberger, Challapalli, Tung, Parker, & Kadish, 2001).

Research on RSA has thus indeed advanced enormously. However, what we considered Clynes' ground breaking new achievement – showing the non-linear, unidirectional character of RSA and other biological systems – appears to have rarely been explored further. Hirsch & Bishop (1981), e.g., who cite Clynes (1960), show Bode diagrams of RSA vs frequency, which presupposes linearity. Saul et al. (1991), who also cite Clynes (1960) and even have *transfer functions* in their paper's title, use that term in a colloquial manner (1991, p. 1231) to mean the amplitude and phase response, ignoring that converting these to a transfer function requires linearity of the underlying system. Indeed, the main message of Clynes (1960) is that this is *not* the case.

One exception to the above is the work of F. Foerster in Freiburg (1978, 1984). As a mathematician, he published (in German) a unidirectional-rate-sensitive third-order digital filter along the model of Clynes, with transfer functions derived from step responses, *separately for inhalation and exhalation* (Foerster, 1978). He later implemented the model in a collection of programs for biosignal analysis for further use (Foerster, 1984).

Notes on the translation. After all this time, the topic of respiratory arrhythmia has lost none of its topicality. Clynes' (1960) paper remains seminal and is widely cited. At the same time, however, its main message – the RSA's removable non-linearity – has been, except for Foerster (1978, 1984), fully neglected in the literature I have reviewed. I therefore decided to transfer my type-set thesis to machine readable form and make it available online (Strasburger, 1979). In the corresponding English translation here, the figures are mostly left unchanged to preserve the character of the time, and are only occasionally annotated in English for readability. Equations were converted to current layout for legibility, however. Footnotes are from the original, except for a few (set in a different font) that refer to the translation.

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