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Phase Locking Values and Analytics for Finding Patterns from Rhythms of Hormones

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Abstract— The body's hormones have exact timing patterns that function as codes for regular physiology. Sleep, metabolism, temperament, immunity, and reproduction are all influenced in the way a hormone is produced, not just its quantity. The same hormone level can have quite different consequences when these time patterns are disturbed, which can result in issues like poor glucose control, infertility, or sleep disturbances. Internal conflict results from improper signal timing, whereas organs and cells function in unison when signals are timed correctly. Light, food, and activity are examples of external stimuli that significantly affect these patterns. Natural-timing-restoring clinical treatments often perform better than dose-only alternatives. Essentially, the timing of hormone action is just as important to health as their intensity. However, data on all these hormones are not available in a single place to support a broader study using analytical techniques to identify any overall relationship. This paper describes the different hormones from available resources/data, and uses them to generate synthetic data for 50 hormones with temporal characteristics to support analytics for a broader overview.

Keywords—Phase locking value; Physiology, Hormones; Patterns; Circadian Rhythms

1. Introduction

Hormonal rhythms are organized patterns of hormone release throughout time in the human body. These cycles regulate vital behavioral and physiological functions, including reproduction, stress response, sleep, and metabolism. Hormonal rhythms can be categorized into three general categories: timing, amplitude, and frequency.

In humans, the rhythm of hormone release is often as important as its level. Biological information that regulates metabolism, sleep, stress reactions, reproduction, immunity, and brain function is encoded by rhythms. This concise diagram illustrates the relationships and effects, categorized by rhythm type, along with key mechanisms and the consequences of improper timing.

The suprachiasmatic nucleus (SCN), the brain's master clock, synchronizes the clocks of the liver, pancreas, adrenal glands, and gonads. Thyroid tone, melatonin (which promotes sleep at night), cortisol (which alerts in the morning), GH surges during early sleep, and daily insulin sensitivity are all influenced by this timing. Systems "expect" nourishment and activities during the day and repair and sleep during the night when clocks are in sync [1-3].

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Many people release hormones in pulses instead of continuously. The amplitude and frequency of the pulse have physiologic significance. Through glucocorticoid receptors, ultradian glucocorticoid pulses trigger pulsatile gene transcription; natural pulses and flat infusions of the same total cortisol result in distinct gene responses. The phenotypes of mood, energy, and sleeplessness are associated with disturbed pulsatility [4], [5].
Immune function, brain connection, vascular tone, and thermoregulation are all altered by cyclic estradiol and progesterone; these alterations affect symptoms, responses to exercise, and the effects of medications [6], [7].

Therefore, varied patterns lead to varied outcomes, even when the average hormone level is the same. All hormones do not follow circadian rhythms. Hormones exhibit a range of temporal rhythms, including event-driven (such as stress, eating, and puberty), infradian (monthly/yearly), ultradian (minutes to hours), and circadian (daily). Melatonin regulates sleep timing and indirectly influences glucose metabolism at night, while the SCN establishes daily windows of insulin sensitivity, cortisol secretion, and sleep drive. Even when calories remain constant, late eating or poorly planned meals fall inside a low-tolerance window, which exacerbates glycemia [8]. For pulsatile systems, therapies that imitate physiologic pulses (e.g., GnRH pumps; research-grade cortisol pumps) perform better than constant supply under certain conditions [9]. Timed light, melatonin, meal timing, and sleep regularity can realign the circadian phase.
Categorically, if rhythm-wise split, the hormones broadly fall as: The main hormones' primary function, temporal pattern, and rhythm type are given as below:

- **Circadian**: Daily (24-hour) rhythms, e.g., cortisol, melatonin.
- **Ultradian**: Shorter cycles (e.g., insulin spikes post meals, growth hormone pulses).
- **Infradian**: Longer cycles (e.g., menstrual hormones like estrogen, progesterone).
- **Stable/Triggered**: Some hormones show relatively steady levels or respond to specific stimuli.
- Some hormones (e.g., GH, testosterone) exhibit both circadian and pulsatile traits.
- Immune-linked and stress hormones (e.g., ILs, CRH) show event-driven pulsatility.

Insulin (β-cell hormone): A peptide that promotes the uptake and storage of glucose, lowering blood glucose levels. Healthy persons typically have fasting plasma insulin levels between 2.5 and 13 μU/mL (15 and 79 pmol/L)[10]. Pulsatile and meal-driven secretion occurs when β-cells release insulin in rapid bursts (about 5–10 min) on top of slower (approximately 50–120 min) ultradian oscillations, with significant postprandial surges following meals. It is suppressed during fasting and has a diurnal rhythm, being somewhat higher during the day. Age, body mass (a greater baseline in obesity), and circadian factors (e.g., nocturnal low vs. daytime high) all affect insulin sensitivity and basal levels [12, 13].
The peptide hormone glucagon, also known as the α-cell hormone, increases blood glucose levels by stimulating hepatic gluconeogenesis and glycogenolysis. Although methods vary, the normal range for fasting glucagon is approximately 50–100 pg/mL[13] (picogrammes per millilitre). Insulin and glucagon secretion are reciprocal; eating suppresses glucagon, which is elevated during fasting or hypoglycemia. It increases in response to stress, exercise, or hypoglycemia (an insulin-regulatory condition). Blood glucose, amino acid levels, and catecholamines all have an impact on glucagon, which exhibits a minor diurnal fluctuation (being slightly higher at night) [13].
The growth hormone (GH) is secreted by the pituitary gland and affects growth and metabolism through IGF-1. In healthy individuals, random (unstimulated) growth hormone levels are very low, usually less than 5 ng/mL for men and less than 10 ng/mL for women [14]. Pattern of secretion: GH is released in pulses, particularly during deep (slow-wave) sleep, with the biggest pulse occurring soon after sleep onset and occurring around once every three to four hours [14]. Values are usually close to zero during the day. Glucose suppresses circulating growth hormone, which is substantially age-dependent (much greater in youth, lowers with age); fat blunts GH peaks. Random GH readings vary wildly and do not accurately reflect typical levels due to the dominance of pulses.
The liver is the primary site of insulin-like growth factor 1 (IGF-1) production in response to growth hormone. IGF-1 circulates bound, and its levels are strongly correlated with age and sex (higher throughout adolescence and puberty). Adult ranges are approximately 70–200 ng/mL; age-specific charts are frequently used to provide this information. IGF-1 decreases with ageing and gradually integrates GH (flat levels with slight diurnal variation).
The stress hormone cortisol (adrenal glucocorticoid) controls metabolism. There is a noticeable diurnal/circadian pattern in cortisol levels, which peak in the early morning and decline after midnight. Adult blood total cortisol levels typically range from 5 to 23 μg/dL (138

to 635 nmol/L) at 8 AM and 3 to 13 µg/dL (83 to 359 nmol/L) at 4 PM [8]. The "cortisol awakening response," or spike in cortisol, occurs after waking up and peaks approximately 30 to 40 minutes after waking up [11]. Levels reach their lowest point by dusk or night. At any time, acute physical or emotional stress or disease can cause a brief increase in cortisol [11]. Factors: Lack of sleep or working shifts can disrupt the rhythm; peak levels are slightly attenuated with age.

Adrenaline and noradrenaline are catecholamines secreted by the adrenal medulla at the time of stress and are also known as "fight-or-flight" hormones. Adrenaline varies from approximately 0 to 140 pg/mL and noradrenaline ranges from approximately 70 to 1700 pg/mL [15] (numbers vary greatly). Acute increases in secretion occur with physical stress, exercise, panic attacks, or hypoglycemia. There is no discernible daily pattern to basal levels, although they do have a little circadian influence (being slightly higher in the morning). Sex and age have little bearing, but posture is important (standing raises noradrenaline). pg/mL (or nmol/L) is the unit.

Thyroid Hormones (T4, T3, TSH): Thyroid-stimulating hormone (TSH) regulates the secretion of thyroxine (T4) and triiodothyronine (T3), which in turn influence metabolic rate. Ranges: TSH (adult): ~0.4–4.5 µIU/mL [16], Free T3 (adult): ~2.3–4.2 pg/mL, and Free T4: ~0.8–1.8 ng/dL[11]. Circadian: While T3/T4 show less diurnal variability, TSH shows a circadian peak (~2–4 AM) and a nadir in the late afternoon. Influences: Dopamine and corticosteroids lower TSH; it increases when you sleep. The menstrual cycle affects women's values, and illnesses like "euthyroid sick syndrome" might change them. Types of units include TSH (µIU/mL), T4 (ng/dL or pmol/L), and T3 (pg/mL or nmol/L).

Leptin (adiposity signal) is a fat-derived hormone that resembles cytokines and indicates fullness. The normal range for serum leptin is ~0.5–15.2 ng/mL for females and ~0.5–12.5 ng/mL for males [17]. Leptin rises with meals and exhibits a circadian pattern, rising at night. Influences: Body fat and leptin are correlated; obesity increases leptin levels. It decreases with calorie restriction, sleep deprivation, or fasting, which increases hunger. Even at the same BMI, women often have higher leptin levels than men.

The "hunger" hormone produced in the stomach, ghrelin, promotes the release of growth hormone and appetite. Ghrelin has a distinct circadian and meal-related rhythm, rising before meals (a hunger signal) and falling afterward, peaking at night or in the early morning. Humans emit ghrelin pulsatility on an ultradian cycle of around one to three hours. Influences: Body fat has an inverse relationship with levels (lower in obese people, higher in thin/anorexic people). Ghrelin is elevated by sleep loss; sex variations are minimal. (Assay-specific absolute ranges vary, although they are generally around 1000 pg/mL fasting) [12][17].

Insulin is enhanced by gut hormones called glucagon-like peptide-1 (GLP-1) and GIP (incretins), which are released after meals. GLP-1 is relatively low at basal and increases approximately 30 to 60 minutes after carbohydrate ingestion (postprandial). GIP increases with meals in the same way. Both have extremely brief half-lives (minutes) and are influenced by eating patterns throughout the day.

2.1. **Reproduction Hormones**

Pituitary gonadotropin regulates gametogenesis through the follicle-stimulating hormone (FSH). Ranges (IU/L): ~1–9 IU/L during follicular/luteal phases in premenopausal women, ~6–26 IU/L during ovulation [18], and ~26–135 IU/L following menopause [18]. ~1.5 to 12.4 IU/L in male adults [18]. Patterns: Women's FSH levels peak mid-cycle, causing ovulation, and then fall throughout the luteal phase. Pulsatile GnRH drives Pulsatile FSH; however, there is no chronic circadian fluctuation. Factors include body weight (greater adiposity slightly elevates FSH), stress/illness, and age (increases after menopause).

Pituitary gonadotropin is the luteinizing hormone (LH). In women, the ranges (IU/L) are around 1.4 to 9 IU/L in the early follicular phase, 6.2 to 17.2 IU/L immediately prior to ovulation, and 1.1 to 9.2 IU/L in the mid-luteal phase [19]. LH levels are high (≈19–100 IU/L) after menopause. ~1.4–15.4 IU/L in men [19]. Patterns: Approximately 34–44 hours before ovulation, LH experiences a significant mid-cycle surge. Other than that, levels vary slowly in women and are comparatively constant in men. Age (postmenopausal up), sex steroids (negative feedback), and the time of day have little bearing.

Oestrogens (Oestradiol, E2; Oestrone, E1): Oestradiol levels in premenopausal women vary according to the menstrual cycle, ranging from around 20 to 350 pg/mL during the follicular phase, from 150 to 750 pg/mL during the ovulatory peak, and from 30 to 450 pg/mL during the luteal phase [19]. E2 levels in men are low (~10–50 pg/mL) [19]. Patterns: Women's cycle-dependent, with a dramatic mid-cycle peak accompanied by an LH surge. Slight circadian rhythm (morning is higher). Factors include pregnancy (highest oestriol levels), body fat (aromatisation), and age (declines after menopause).

The placenta and corpus luteum (ovaries) produce progesterone.

Men and women in the follicular phase: <50 ng/dL (<0.5 ng/mL)[22]. About 300–2500 ng/dL (3–25 ng/mL) in women in the luteal phase [16] much higher throughout the first and second trimesters of pregnancy. Patterns include low during the follicular phase, mid-luteal peak, post-ovulation spike (LH surge), and a fall in the absence of pregnancy. Influences include the use of exogenous hormones and age (postmenopausal ~0–60 ng/dL).

Testosterone levels in adults are approximately 291–1100 ng/dL (10–38 nmol/L) in males and 18–54 ng/dL (0.6–1.9 nmol/L) in females [16]. Patterns: Women's levels fluctuate with their menstrual cycle (slight mid-cycle surge), whereas men's levels are steady (diurnal peak early morning). Influences include disease, age (decreases in the elderly), obesity (lower free T), and SHBG levels.

The pituitary hormone for lactation is called prolactin. Ranges: ~3–13 ng/mL for males and ~3–27 ng/mL for nonpregnant females [16]. Prolactin levels during pregnancy might range from 20 to 400 ng/mL. Patterns: Exhibits a circadian pattern, peaking when you sleep and falling during the day. Influences include sleep/stress, hypothyroidism, breastfeeding (spikes), and some medications.

During pregnancy, the placenta produces human chorionic gonadotropin, or hCG. <2 IU/L if not pregnant [20]. Pregnancy: detectable ~1-2 weeks after fertilisation; in the early stages of gestation, it doubles every 48-72 hours, peaks at ~100,000 IU/L about 10 weeks, and then plateaus.

The hypothalamus produces oxytocin, which is released by the posterior pituitary and controls milk ejection and labour. Oxytocin levels in baseline plasma are extremely low (<10 pg/mL); pulses happen during social bonding, breastfeeding, or birthing. Nursing or parturition causes a brief rise in levels; there is no discernible diurnal regularity.

The corpus luteum and placenta release relaxin during pregnancy to relax the pelvic ligaments. Minimal in non-pregnant women (<50 pg/mL); peaks in the first trimester of pregnancy at approximately 400 pg/mL.

2.2. **Adrenal hormones and stress**

Pituitary-driven cortisol secretion is mediated by adrenocorticotropic hormone (ACTH). ~7–69 pg/mL in men and 6–58 pg/mL in women are considered normal plasma ACTH levels [16]. Pattern: Complies with the circadian rhythm of cortisol, which peaks in the morning and is elevated due to stress pg/mL is the unit. The stress chemicals adrenaline and norepinephrine (see catecholamines above) have short half-lives and an abrupt release that peaks seconds after stress baseline values mentioned above [15]. The hypothalamus secretes dopamine, a neurotransmitter that primarily inhibits prolactin. Pulses are correlated with food consumption, and plasma dopamine levels are relatively low (<20 pg/mL).

2.3. **Pineal and Circadian Hormones**

The pineal gland secretes melatonin at night to control sleep-wake cycles. Concentration: around 0–20 pg/mL during the day and 40–200 pg/mL at night [21]. The pattern is strictly circadian: it is minimal during the day, peaks between two and four in the morning, and then declines. As one ages, levels decrease (older persons typically make up about half of young adults) [21]. Influences: Season and latitude have a slight impact; light exposure inhibits secretion.

2.4. **Hormones for Fluid/Electrolyte Balance**

Vasopressin, an antidiuretic hormone produced by the brain and pituitary, is a water-saving hormone. 0–5.9 pg/mL is normal [22]. Pattern: Suppressed by increased fluid intake; increases at night and with dehydration/osmolality. Increased nighttime secretion, or a minor circadian peak.

Aldosterone: An adrenal mineralocorticoid that encourages the retention of salt. Adults typically have morning upright serum levels between 3 and 16 ng/dL (0.08 and 0.44 nmol/L). Pattern: sensitivity to posture (higher standing), sodium intake (suppressed by high Na), diurnal (slightly greater in the morning), and ACTH (little effect).

Renin: (Kidney enzyme in RAAS): usually (plasma renin activity) ~0.7–3.3 ng/mL/hr. Increases with hypotension, low sodium, and sympathetic drive.

The heart secretes atrial natriuretic peptide (ANP) in response to atrial strain (volume overload). The normal plasma range of ANP is ~20–77 pg/mL.

2.5. **Bone and Calcium Hormones**

PTH, or parathyroid hormone, controls calcium levels. 15–65 pg/mL is normal [23]. Pulsatile pattern; lowest in the afternoon, highest at night or early in the morning. Rises when blood Ca^2+ is low and falls when blood Ca^2+ and vitamin D are high. Influences include renal

function, dietary Ca^2+, and age (elderly people have a small rise).
Thyroid C-cells produce calcitonin, which reduces Ca^2+. Normal is ≤5.0 pg/mL for women and ≤8.4 pg/mL for men [24]. pulsatile secretion that increases when calcium levels are high. very slight circadian rhythm.

2.6. **Metabolites of Vitamin D:**

The storage form of 25-hydroxyvitamin D (25(OH)D). Normal range: 75–150 nmol/L (~30–60 ng/mL) [16]. Seasonal variations (greater after summer sun).
Calcitriol, or 1,25-Dihydroxyvitamin D, is the active form. 15–60 pg/mL is normal [31]. PTH and FGF23 cause levels to peak in the late afternoon and drop in the morning. Units: 1,25(OH)_2D in pg/mL (pmol/L); 25(OH) D in ng/mL or nmol/L.

2.7. **Hormones for Haematopoiesis**

The kidney hormone erythropoietin (EPO) promotes the synthesis of red blood cells. Normal serum: ~2.6–18.5 mU/mL[25]. Pattern: Minor circadian effect (slightly higher at night); increases with hypoxia/anemia. Influences include kidney illness (↓), androgens, and altitude (↑).

2.8. **Overview of Gastrointestinal Hormones**

Numerous gut hormones control hunger and digestion. Typical actions (no one "normal level" is specified):
After a meal, stomach G-cells secrete gastrin, which increases pepsin and HCl. In reaction to lipids or proteins, the duodenum releases cholecystokinin (CCK), which promotes satiety and the gallbladder. Acidity in the duodenum causes secretin, which in turn causes pancreatic bicarbonate. During fasting, motilin is released from the small intestine and causes a migrating motor complex every 90 to 120 minutes.
After carbohydrates, the small intestine produces GLP-1/GIP (incretins), which intensify insulin. Additionally, GLP-1 decreases stomach emptying. The ultradian (meal-related) release patterns of these GI hormones peak after meals. They exhibit daily fluctuations linked to meal times and periods of fasting. They are not commonly measured in blood; instead, their serum ranges vary by assay and context (typically reported as "postprandial curves" in studies).

2. **Materials and Methods**

The reliability with which the phase difference between two brain signals remains constant over time (or across trials) is measured by the Phase Locking Value (PLV). It is the magnitude of the average of their vectors representing the unit-phase difference [26], [27].

$$PLV = \left|\frac{1}{N}\sum e^{i\Delta\phi(t)}\right| \quad (1)$$

Where, $\Delta\phi(t) = \phi_1(t) - \phi_2(t)$, N is the number of trials, $e^{i\Delta\phi(t)}$ is the phase difference mapped into the complex unit circle.
The degree to which the phase difference between two impulses is fixed is how PLV gauges neuronal synchronization. It is obtained by taking the magnitude of the unit-length phase-difference vectors and averaging them. Strong phase-locking, or consistent timing, is indicated by values close to 1, whereas no synchronization is shown by values close to 0. It is extensively employed to investigate inter-regional coordination in oscillatory brain data, such as EEG/MEG [27].
Findings show that the treated patients' theta oscillations at F3 exhibit phase-locking that is just as intense as that of the control group [28]. A method shows that α and β cells in islets are universally phase-locked under glucose stimulation by skillfully combining dynamical systems modeling (phase variables, coupling, winding numbers) with statistics (correlation coefficients, cycle features, scatter plots) [29]. Each subject's melatonin rising time (DLMO) and sleep gate onset were measured during the study in dim, evening lighting. Phase locking was statistically demonstrated by showing a strong correlation between melatonin onset and sleep gate across individuals, as well as low inter-subject variability in the period between the two. These results demonstrate strict circadian regulation and support the idea that the commencement of melatonin secretion is consistently phase-locked to the behavioral sleep period [30].
PLV is frequently employed, regardless of amplitude, to measure neuronal synchronization. It is calculated as the consistency of the time-averaged phase difference between two signals (e.g., brain networks or EEG channels) [31].
PLV between the stomach's gastric cycle and every resting-state fMRI network, identifying a strong stomach-brain connection [31], and PLV matrices over many bands of EEG channels that are fed into machine learning classifiers, coupled with spectral properties [32].
Therefore, a synthetic dataset was used to generate sample hormones based on the above, to facilitate analytics that extract meaningful information about their inherent patterns and rhythms using phase-locking values.
Using this information, the paper provides a synthetic data-based study of approximately 50 hormones,

examining their rhythms to gain insight. Using PLV-based data analytics for so many hormones with synthetic dataset generation is the novelty of the paper.

3. Results and Discussion

The synthetic dataset of one year duration on about 50 number of hormones based on the cycle of generation was analysed and the results is explained below:

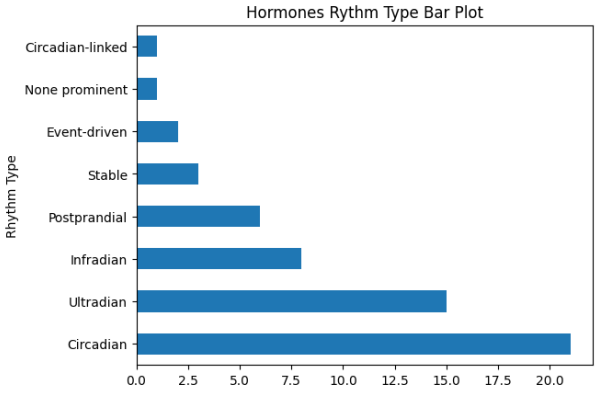

Fig. 1. Hormones Rhythm Bar chart

Fig. 1 illustrates the distribution of hormones across various rhythm types, which are associated with the temporal patterns of hormone release. The majority of hormones follow daily or sub-daily cycles due to the dominance of circadian and ultradian rhythms. Although they are uncommon, infradian rhythms are caused mainly by reproductive hormones. Event-driven and postprandial hormones regulate short-term reactions (feeding, stress, birthing). Certain hormones remain unchanged, ensuring essential processes like thyroid regulation.

Fig. 2. Hormones function word cloud

The word cloud in Fig. 2 is the "Hormone Functions Word Cloud." The magnitude of each word in a word cloud graphically depicts the frequency or significance of the text data. What the Word Cloud Means: The primary theme is the role of hormones in the human body. Biggest Words with the Most Vital Purpose: Regulation: Hormones are mostly responsible for controlling several functions, including blood sugar, metabolism, mood, and reproduction. Secretion: Glands release hormones into the bloodstream. Blood: A variety of hormones control blood pressure, calcium, and sugar levels. Other Important Words: Pressure refers to the regulation of blood pressure by hormones such as aldosterone and ADH. Appetite: Hunger and satiety are controlled by hormones such as insulin, ghrelin, and leptin. Balance ← Hormones maintain fluid and electrolyte balance. Stimulates/Inhibits: Hormones can either stimulate or inhibit physiological processes.

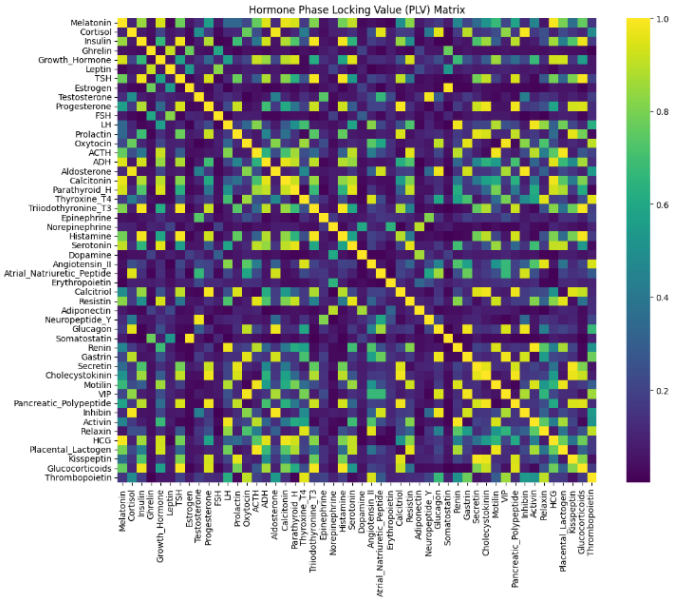

Fig. 3. Hormone plv matrix heatmap

Phase locking value, Fig.3 which ranges from 0 to 1, is a measurement of two signals' phase synchronization. A perfect phase lock occurs when two hormones oscillate in unison at a frequency of 1.0 (yellow). 0.0 (dark purple) => Total asynchronous with no phase relationship. High PLV suggests coupled circadian or ultradian rhythms (shared oscillatory patterns). For instance: Cortisol ↔ Melatonin: anti-phase circadian cycle (one peaks in the morning, one at night). Insulin ↔ Ghrelin ↔ Leptin: oscillations associated with feeding.

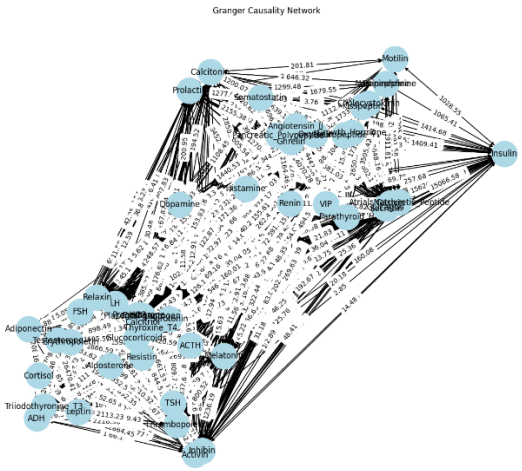

Fig. 4. Hormones Granger causality network

Fig. 4 depicts that Hormones are nodes. A hormone Granger-causes another hormone (i.e., past levels of source improve prediction of target) is shown by directed edges (arrows). Granger test Edge Labels = F-statistic (higher means more substantial predictive influence). All network edges are statistically significant ($p < 0.05$). The graph is highly interconnected, suggesting that many hormones are predictive of one another. This implies that, like endocrine networks, the system is highly interconnected.

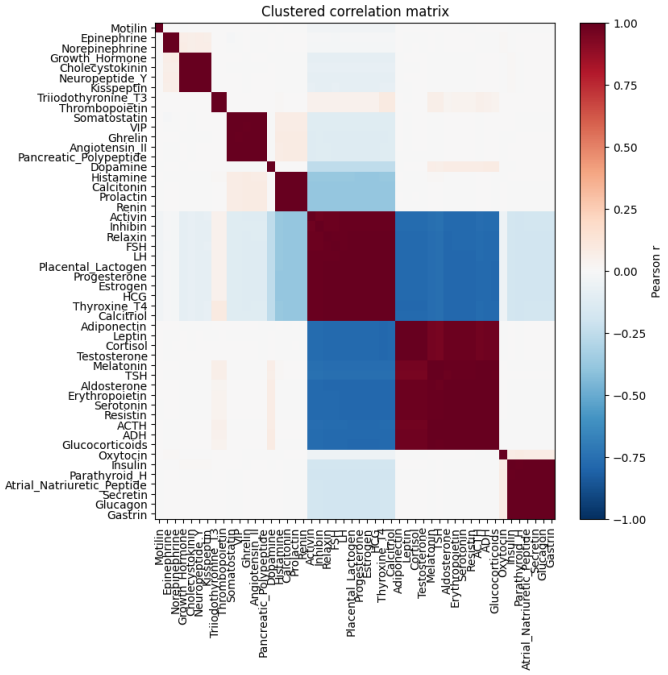

Fig. 5. A clustered correlation matrix of hormones and peptides.

Fig. 5 reveals a clustered correlation matrix of hormones and peptides.

Large red block in the centre: There is a substantial corr elation between many metabolic and reproductive hormo nes (such as leptin, adiponectin, testosterone, oestrogen , cortisol, melatonin, etc.) is,
indicating circadian/seasonal coupling and common cont rol.The blue areas surrounding that block:
Certain hormones exhibit anticorrelation, or opposite tren ds. For instance, There are frequently trade-offs between stress-
related and reproductive/metabolic hormones.
Smaller, isolated groups:
Gut motility plus catecholamines cause motilin, adrenalin e, and norepinephrine to cluster independently.
Triiodothyronine (T3), thyroxine (T4), and TSH cluster (th yroid axis).
Cluster of calcitonin and parathyroid hormone (calcium r egulation).
Pancreatic regulation of glucose is achieved by the insuli n + glucagon + pancreatic polypeptide + somatostatin cl uster.
The endocrine system creates functional clusters of hor mones with strong positive or negative connections, as s een in this image.
Melatonin's function as a global synchronizer is highlight ed by the fact that it clusters with other circadian and me tabolic hormones.

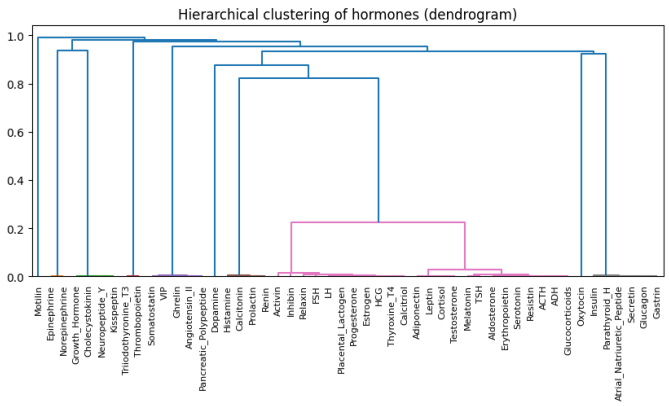

Fig. 6. Hierarchical clustering of hormones

Fig. 6 depicts Hierarchical clustering uses a similarity or distance metric (such as correlation or Euclidean distance) to group related items (in this case, hormones). The connection distance (or dissimilarity) at which clusters combine is shown on the vertical axis. According to the selected characteristics, such as secretion patterns, rhythms, or concentrations, hormones that are closer together horizontally are more comparable. For instance, the tight clustering of FSH, LH, Inhibin, Relaxin, and Activin is probably due to their shared association with

reproductive function. Height of branches (vertical axis) . The degree of difference between two clusters is shown by the height of the branch where they converge. Hormones with lower joins are more comparable. Less comparable hormones result from higher joins. Observable major groupings FSH, LH, estrogen, progesterone, and other reproductive hormones are grouped. The cluster of metabolic and stress hormones includes cortisol, glucagon, insulin, and glucocorticoids. Dopamine, adrenaline, and norepinephrine are catecholamine neurotransmitters.

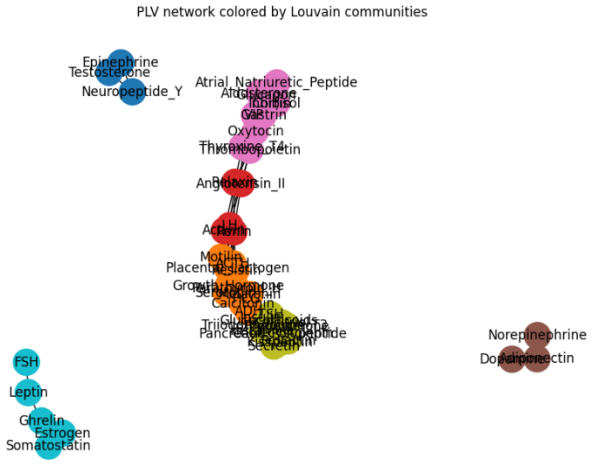

Fig. 7. Phase locking value of different hormones

Fig.7 reveals that the Phase locking values (PLV) were used to create this hormone n etwork graph, which was further divided into Louvain co mmunities—a well-
liked approach for identifying clusters or modules in intric ate networks.
Numerous hormones appear to be closely phase-synchronized, functioning as a global endocrine clock, a ccording to the central supercluster.The specialised subc ircuits that only weakly relate to the primary hormonal rh ythm may be represented by the peripheral tiny clusters (such as norepinephrine/dopamine/adiponectin).In line w ith its function as a master synchronizer of endocrine an d circadian systems, melatonin is located in the central cl uster.

4. Conclusions

A statistic called Phase Locking Value (PLV) is used to measure how consistently the phase discrepancies between two or more oscillatory signals change over time. PLV was first widely used in neuroscience to examine the synchronization between different brain regions, but it now has broader applications in network science, data analytics, time-series analysis, finance, and biomedical engineering. It provides insight into temporal synchronization, noise resilience, nonlinear interactions, and hidden connectivity. Synchronization networks, early warning indicators, cluster formation, and cross-frequency coupling are some of its distinctive features. However, if the 50 hormones in the human body are examined thoroughly, there is a chance that new criteria will be identified.

There is a need for more comprehensive, multi-hormone analyses in this emerging discipline, coupled with AI/ML applications to derive insights into the uncharted research area. To train end-to-end models, future research should compile sizable multimodal datasets (EEG/fMRI + extensive hormone panels throughout time). Investigating the neuronal signatures of understudied hormones (GH, gut peptides, and thyroid hormones) will be crucial. Synthetic database analytics is aimed at the type of information that is plausible to extract for demonstration purposes; however, it may not accurately reflect the real-world scenario. Therefore, this study aims to highlight that the availability of real sample data can provide comprehensive insights into the overall impact of hormones on healthy individuals and patients across different cycles, including those with abnormality. Combining AI/ML with neuroendocrinology offers deep insights into body-brain physiology, but it will necessitate interdisciplinary work and carefully selected data. A broader, data-driven analysis of hormones has the potential to study intersectional domains, viz. Life cycle analysis, Cross-time zone (jet lag, shift work) impact, Hormonal journey mapping, Clinical & lifestyle optimization, and Predictive health & chronobiology.

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