Comparison of Physiological Markers: Sympathetic, Dorsal Vagal, and Ventral Vagal States

Autonomic State	Key Physiological Markers	Measurement Methods / Indices	Functional/Clinical Notes	Citations
Sympathetic	- Increased heart rate (HR) - Increased blood pressure (BP) - Reduced heart rate variability (HRV) - Increased low-frequency (LF) HRV (but not specific) - Increased muscle sympathetic nerve activity (MSNA) - Increased electrodermal activity (EDA) - Increased plasma norepinephrine	- Direct MSNA (microneurography) - EDA (skin conductance) - LF HRV (limited specificity) - Plasma norepinephrine	- LF HRV is not a reliable marker of pure sympathetic activity - EDA and MSNA are more specific - Sympathetic activation is associated with stress, arousal, and "fight or flight" responses	(Thomas et al., 2019; Furlan et al., 1990; Ghiasi et al., 2020; Valenza et al., 2018; Tobaldini et al., 2020; Ernst, 2017; Grassi et al., 2018; Malliani et al., 1991; Nardelli et al., 2023; Eckberg et al., 1985; Porter et al., 1990; Spiesshoefer et al., 2022)
Dorsal Vagal	- Bradycardia (slowed HR) - Hypotension - Reduced HRV - Vasovagal syncope - Reduced metabolic activity - Fainting, immobilization	- HRV (reduced overall) - Clinical observation (e.g., syncope) - Baroreflex sensitivity	- Dorsal vagal activation is associated with "shutdown" or immobilization responses - Difficult to isolate with noninvasive markers; often inferred from clinical context	(Ghiasi et al., 2020; Wu et al., 2021; Machhada et al., 2015; Korsak et al., 2023; Machhada et al., 2017; Moreira et al., 2018; Coote, 2013)
Ventral Vagal	- Increased high-frequency (HF) HRV - Increased root mean square of successive differences (RMSSD) - Respiratory sinus arrhythmia (RSA) - Calm, steady HR - Social engagement behaviors	- HF HRV (0.15–0.4 Hz) - RMSSD - RSA - Direct vagal nerve recordings (rare)	- Ventral vagal activation supports social engagement, calm states, and flexible emotional regulation - RMSSD and HF HRV are reliable noninvasive markers of ventral vagal tone	(Thomas et al., 2019; Furlan et al., 1990; Ghiasi et al., 2020; Valenza et al., 2018; Cooper et al., 2015; Matuz et al., 2021; Ernst, 2017; Papadopoulos et al., 2024; Hornung et al., 2024; Valenza et al., 2019; Machhada et al., 2017; Park al., 2022; Kirby et

Autonomic State	Key Physiological Markers	Measurement Methods / Indices	Functional/Clinical Notes	Citations
				al., 2017; Laborde et al., 2017; Movius & Allen, 2005)

FIGURE 1 Comparison of physiological markers for sympathetic, dorsal vagal, and ventral vagal states.

Key Takeaways:

- **Sympathetic activity** is best measured by direct MSNA and EDA; LF HRV is not specific.
- **Dorsal vagal state** is challenging to measure directly; clinical signs and reduced HRV are suggestive.
- **Ventral vagal activity** is reliably indexed by HF HRV, RMSSD, and RSA, reflecting calm and social engagement.

For clinical and research purposes, combining multiple physiological markers and considering context is essential for accurate autonomic state assessment (Thomas et al., 2019; Furlan et al., 1990; Ghiasi et al., 2020; Valenza et al., 2018; Ernst, 2017; Nardelli et al., 2023; Machhada et al., 2017; Park et al., 2022; Kirby et al., 2017; Laborde et al., 2017; Movius & Allen, 2005).

These papers were sourced and synthesized using Consensus, an AI-powered search engine for research. Try it at https://consensus.app

References

Thomas, B., Claassen, N., Becker, P., & Viljoen, M. (2019). Validity of Commonly Used Heart Rate Variability Markers of Autonomic Nervous System Function. *Neuropsychobiology*, 78, 14 - 26. https://doi.org/10.1159/000495519

Furlan, R., Guzzetti, S., Crivellaro, W., Dassi, S., Tinelli, M., Baselli, G., Cerutti, S., Lombardi, F., Pagani, M., & Malliani, A. (1990). Continuous 24-hour assessment of the neural regulation of systemic arterial pressure and RR variabilities in ambulant subjects.. *Circulation*, 81 2, 537-47. https://doi.org/10.1161/01.CIR.81.2.537

Ghiasi, S., Greco, A., Barbieri, R., Scilingo, E., & Valenza, G. (2020). Assessing Autonomic Function from Electrodermal Activity and Heart Rate Variability During Cold-Pressor Test and Emotional Challenge. *Scientific Reports*, 10. https://doi.org/10.1038/s41598-020-62225-2

Valenza, G., Valenza, G., Citi, L., Saul, J., Barbieri, R., & Barbieri, R. (2018). Measures of sympathetic and parasympathetic autonomic outflow from heartbeat dynamics.. *Journal of applied physiology*, 125 1, 19-39. https://doi.org/10.1152/japplphysiol.00842.2017

Wu, L., Bo, J., Zheng, F., Zhang, F., Chen, Q., Li, Y., Kang, Y., & Zhu, G. (2021). Salusin-β in Intermediate Dorsal Motor Nucleus of the Vagus Regulates Sympathetic-Parasympathetic Balance and Blood Pressure. *Biomedicines*, 9. https://doi.org/10.3390/biomedicines9091118

Cooper, T., Mckinley, P., Seeman, T., Choo, T., Lee, S., & Sloan, R. (2015). Heart rate variability predicts levels of inflammatory markers: Evidence for the vagal anti-inflammatory pathway. *Brain, Behavior, and Immunity*, 49, 94-100. https://doi.org/10.1016/j.bbi.2014.12.017

Tobaldini, E., Rodrigues, G., Mantoan, G., Monti, A., Zelati, G., Cirelli, C., Tarsia, P., Morlacchi, L., Rossetti, V., Righi, I., Nosotti, M., Da S Soares, P., Montano, N., Aliberti, S., & Blasi, F. (2020). Sympatho–Vagal Dysfunction in Patients with End-Stage Lung Disease Awaiting Lung Transplantation. *Journal of Clinical Medicine*, 9. https://doi.org/10.3390/jcm9041146

Matuz, A., Van Der Linden, D., Kisander, Z., Hernádi, I., Kázmér, K., & Csathó, Á. (2021). Enhanced cardiac vagal tone in mental fatigue: Analysis of heart rate variability in Time-on-Task, recovery, and reactivity. *PLoS ONE*, 16. https://doi.org/10.1371/journal.pone.0238670

Machhada, A., Ang, R., Ackland, G., Ninkina, N., Buchman, V., Lythgoe, M., Trapp, S., Tinker, A., Marina, N., & Gourine, A. (2015). Control of ventricular excitability by neurons of the dorsal motor nucleus of the vagus nerve. *Heart Rhythm*, 12, 2285 - 2293. https://doi.org/10.1016/j.hrthm.2015.06.005

Korsak, A., Kellett, D., Aziz, Q., Anderson, C., D'Souza, A., Tinker, A., Ackland, G., & Gourine, A. (2023). Immediate and sustained increases in the activity of vagal preganglionic neurons during exercise and after exercise training. *Cardiovascular Research*, 119, 2329 - 2341. https://doi.org/10.1093/cvr/cvad115

Ernst, G. (2017). Heart-Rate Variability—More than Heart Beats?. *Frontiers in Public Health*, 5. https://doi.org/10.3389/fpubh.2017.00240

Grassi, G., Pisano, A., Bolignano, D., Seravalle, G., D'Arrigo, G., Quarti-Trevano, F., Mallamaci, F., Zoccali, C., & Mancia, G. (2018). Sympathetic Nerve Traffic Activation in Essential Hypertension and Its Correlates: Systematic Reviews and Meta-Analyses. *Hypertension*, 72, 483–491. https://doi.org/10.1161/HYPERTENSIONAHA.118.11038

Papadopoulos, G., Balomenou, F., Sakellariou, X., Tassopoulos, C., Nikas, D., Giapros, V., & Kolettis, T. (2024). Autonomic Function in Obese Children and Adolescents: Systematic Review and Meta-Analysis. *Journal of Clinical Medicine*, 13. https://doi.org/10.3390/jcm13071854

Hornung, E., Robbins, S., Srivastava, A., Achanta, S., Chen, J., Cheng, Z., Schwaber, J., & Vadigepalli, R. (2024). Neuromodulatory co-expression in cardiac vagal motor neurons of the dorsal motor nucleus of the vagus. *iScience*, 27. https://doi.org/10.1016/j.isci.2024.110549

Valenza, G., Sclocco, R., Duggento, A., Passamonti, L., Napadow, V., Barbieri, R., & Toschi, N. (2019). The central autonomic network at rest: Uncovering functional MRI correlates of time-varying autonomic outflow. *NeuroImage*, 197, 383-390. https://doi.org/10.1016/j.neuroimage.2019.04.075

Malliani, A., Pagani, M., Lombardi, F., & Cerutti, S. (1991). Cardiovascular Neural Regulation Explored in the Frequency Domain. *Circulation*, 84, 482–492. https://doi.org/10.1161/01.CIR.84.2.482

Nardelli, M., Citi, L., Barbieri, R., & Valenza, G. (2023). Characterization of autonomic states by complex sympathetic and parasympathetic dynamics. *Physiological Measurement*, 44. https://doi.org/10.1088/1361-6579/acbc07

Machhada, A., Trapp, S., Marina, N., Stephens, R., Whittle, J., Lythgoe, M., Kasparov, S., Ackland, G., & Gourine, A. (2017). Vagal determinants of exercise capacity. *Nature Communications*, 8. https://doi.org/10.1038/ncomms15097

Park, C., Youn, I., & Han, S. (2022). Single-lead ECG based autonomic nervous system assessment for meditation monitoring. *Scientific Reports*, 12. https://doi.org/10.1038/s41598-022-27121-x

Kirby, J., Doty, J., Petrocchi, N., & Gilbert, P. (2017). The Current and Future Role of Heart Rate Variability for Assessing and Training Compassion. *Frontiers in Public Health*, 5. https://doi.org/10.3389/fpubh.2017.00040

Eckberg, D., Nerhed, C., & Wallin, B. (1985). Respiratory modulation of muscle sympathetic and vagal cardiac outflow in man.. *The Journal of Physiology*, 365. https://doi.org/10.1113/jphysiol.1985.sp015766

Moreira, T., Antunes, V., Falquetto, B., & Marina, N. (2018). Long-term stimulation of cardiac vagal preganglionic neurons reduces blood pressure in the spontaneously hypertensive rat. *Journal of Hypertension*, 36, 2444–2452. https://doi.org/10.1097/HJH.0000000000001871

Coote, J. (2013). Myths and realities of the cardiac vagus. *The Journal of Physiology*, 591. https://doi.org/10.1113/jphysiol.2013.257758

Porter, T., Eckberg, D., Fritsch, J., Rea, R., Beightol, L., Schmedtje, J., & Mohanty, P. (1990). Autonomic pathophysiology in heart failure patients. Sympathetic-cholinergic interrelations.. *The Journal of clinical investigation*, 85 5, 1362-71. https://doi.org/10.1172/JCI114580

Spiesshoefer, J., Regmi, B., Ottaviani, M., Kahles, F., Giannoni, A., Borrelli, C., Passino, C., Macefield, V., & Dreher, M. (2022). Sympathetic and Vagal Nerve Activity in COPD: Pathophysiology, Presumed Determinants and Underappreciated Therapeutic Potential. *Frontiers in Physiology*, 13. https://doi.org/10.3389/fphys.2022.919422

Laborde, S., Mosley, E., & Thayer, J. (2017). Heart Rate Variability and Cardiac Vagal Tone in Psychophysiological Research – Recommendations for Experiment Planning, Data Analysis, and Data Reporting. *Frontiers in Psychology*, 8. https://doi.org/10.3389/fpsyg.2017.00213

Movius, H., & Allen, J. (2005). Cardiac Vagal Tone, defensiveness, and motivational style. *Biological Psychology*, 68, 147-162. https://doi.org/10.1016/j.biopsycho.2004.03.019