Research · Report NR-01 · 13 September 2026

A body to keep alive: the interoceptive body, arena and insula of the minimal organism

How we gave a simulated organism a regulated body, an environment in which actions have consequences, and an instrument to measure how predictable the body is.

Gioele Chiarolanza Nadirion

Validated 3 test benches · criteria written in advance · causal controls by ablation

9/10	7/7	7.9	5/6
body criteria passed; the only failure is a wrong prediction, left uncorrected	arena criteria: every bodily consequence happens only for the right action	times: how much more predictable the body is than the world in the arena at rest	insula criteria; the noise knobs are not monotonic

SUMMARY

Synthesis v2, the theory these components are meant to test, places the anchor of the self in the interoceptive body: a signal that is always present, predictable and regulated around reference values. Before this work the project had no body. We built three components. The first is a physiological model with baroreflex, chemoreflex, respiratory arrhythmia, exercise, blood glucose, stomach and hypothalamus, which computes a **homeostatic error h**. The second is an **arena** in which eating, moving, resting and meeting a threat change the body. The third is an **insula** with a predictor that is identical for body and world, which measures how predictable each one is. The three test benches pass 9 criteria out of 10, 7 out of 7 and 5 out of 6, and every reflex has a causal control by ablation. In the arena at rest the body is about eight times more predictable than the world, as the theory assumes. The knobs that will have to make the body unpredictable in later tests are not yet monotonic.

1 The question

Synthesis v2, Nadirion's reference theory until 27 September 2026, starts from a principle (P1): the self is anchored to the body because the body is a regulated "internal constant", more predictable than the outside world. Principle P3 defines valence, that is good and bad for the organism, as the expected change in the homeostatic error. Testing these principles requires three things the project did not have:

1. a body that regulates itself and can go into crisis;
2. an environment in which actions change the body, so that the body becomes a consequence of what the organism does;
3. an instrument that measures how predictable body and world are, with the same yardstick for both.

This report describes the three components and their test benches. None of them tests the theory: they prepare the ground for tests F1–F4 (report NR-04).

2 The interoceptive body

Model

The body is a lumped-parameter system of differential equations integrated every 10 ms. It contains six subsystems.

subsystem	contents
cardiovascular	baroreflex (pressure → sympathetic and vagal tone → heart rate, contractility, resistance), baroreflex resetting during exercise, haemorrhage and transfusion
respiratory	chemoreflex on CO_2 and desaturation, alveolar ventilation, Severinghaus curve, respiratory sinus arrhythmia
exercise	central feed-forward command
energy	blood glucose with counter-regulation and insulin-dependent uptake, liver glycogen, gastric emptying
hypothalamus	hunger from the reserve, satiety from gastric distension and persistent satiety (memory of food eaten)
brain	cerebral autoregulation and supply of oxygen and glucose to the metabolic substrate

The regulated state comprises six quantities: mean arterial pressure, arterial CO_2, oxygen saturation, blood glucose, blood volume and energy reserve. Each has a reference value (93 mmHg, 40 mmHg, 97%, 5 mM, 5 L, 0.8) and a tolerance. The homeostatic error is the weighted distance from the reference values: $\mathbf{h} = \|\mathbf{W}(\mathbf{b} - \mathbf{b}^*)\|$, with weights equal to the inverse of the tolerances.

Criteria and results

The criteria were written before running the bench. Every reflex has a **causal control**: the reflex is switched off (gain zero) and the response must change.

criterion	what it checks	outcome
B0 rest	heart rate 78 per minute, breathing 14 per minute, pressure 93 mmHg, saturation 97%, CO_2 40 mmHg, glucose 4.8 mM	passed
B1 baroreflex	0.5 L haemorrhage: pressure drop of 4.0 mmHg with the reflex against 18.8 without	passed
B2 chemoreflex	5% CO_2: +6.9 against +35.6 mmHg; 12% oxygen: saturation 71.9% against 54.2%	passed
B3 respiratory arrhythmia	heart-rate peak at the breathing frequency; atropine abolishes it	passed
B4 energy balance	4-hour fast with stable glucose; three causal ablations	passed
B5 exercise	heart rate +20.7 beats, ventilation 3.3 times, CO_2 unchanged	passed
B6 body → brain	prediction on the drop in brain ATP during hypoxia without chemoreflex	**failed**
B7 homeostatic error	h at rest 0.33; rises under 5 perturbations and returns below 0.5 after all of them	passed
B8 instrument audit	all 45 attributes used; an injected useless attribute is detected	passed
B9 persistent satiety	2 meals in 4 hours against 17 with satiety switched off	passed

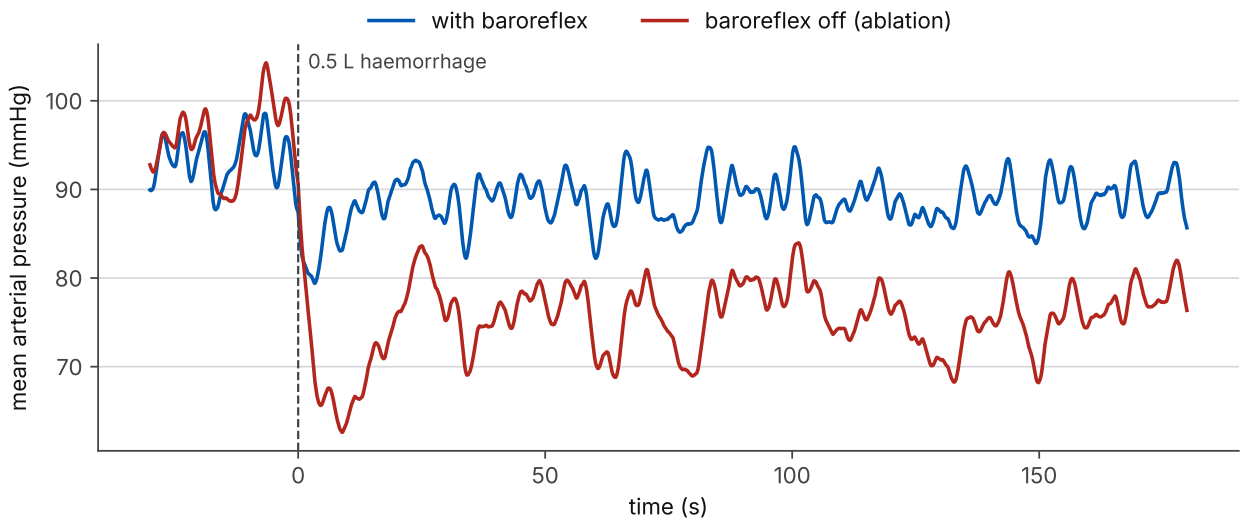


Figure 1. Mean arterial pressure during a 0.5 L haemorrhage, with the baroreflex on and off. Simulation re-run on 28 September 2026 with the current model code (seed 0, after 120 s of settling); the fast oscillations come from breathing. With the reflex the pressure returns close to its reference value; without it, it stays much lower.

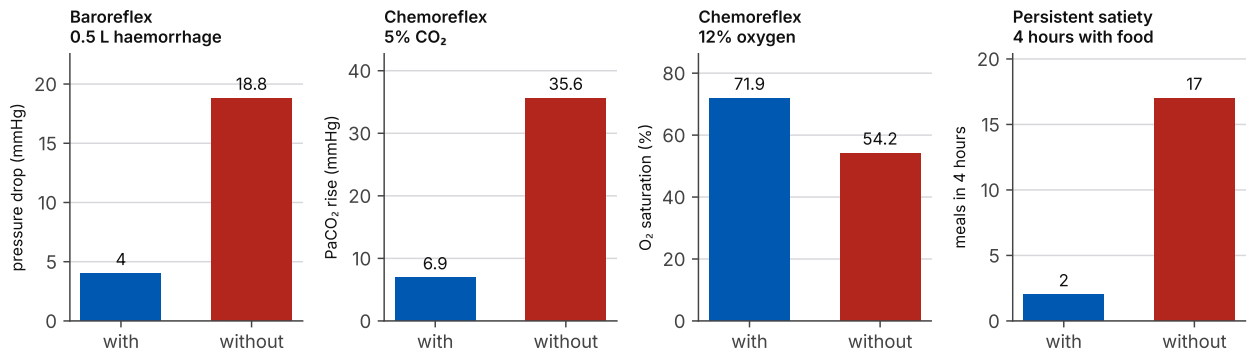


Figure 2. Causal controls of B1, B2 and B9: the same perturbation with the reflex on and off. Values from the log of the V0-BODY bench.

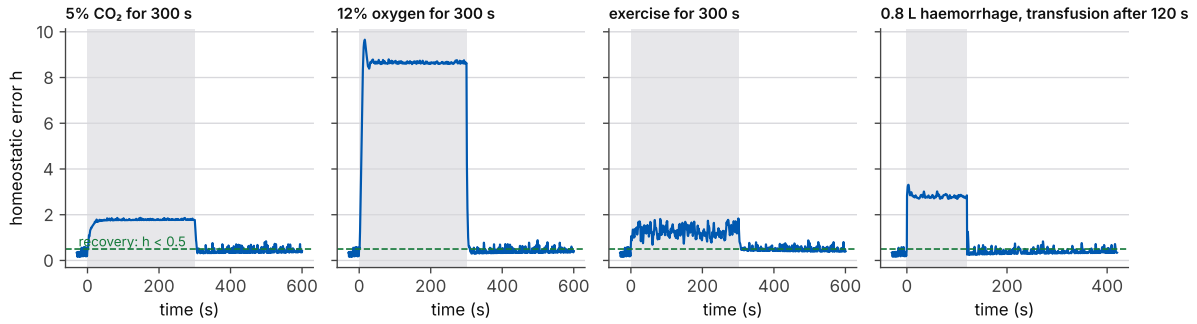


Figure 3. The homeostatic error h under four perturbations (grey area) and after their removal. Simulation re-run on 28 September 2026 with the current code, which includes the revision of the definition of h made on 14 September (see below). In every case h rises during the perturbation and falls back below 0.5 afterwards.

The failure, and why we did not correct it

We had predicted that, without the chemoreflex, hypoxia would lower brain ATP more. The opposite happened: a 1.78% drop without the reflex against 3.63% with it. The explanation is physiological: hyperventilation lowers CO_2 and the cerebral vessels constrict, and in humans the increase in blood flow compensates for the lower oxygen content (Hoiland and colleagues, 2016). The causal link body → brain remains demonstrated (with the body disconnected the ATP drop is 0.00%), but the prediction was wrong. The criterion was not rewritten and the bench stays at 9 out of 10.

Two corrections before the final result

The first run passed 5 criteria out of 9: baroreflex resetting during exercise and sufficient insulin uptake were missing (glucose after a meal 13.8 mM). The corrections come from the literature (Raven, Fadel and Ogoh, 2006). The second run passed 7 out of 9: after fasting h stayed at 0.82 because the model "grazed", with 18 meals in 4 hours. We added persistent satiety, writing criterion B9 to check it **before** implementing it.

On 14 September, while preparing the valence critic (NR-03), a measurement showed that **eating when hungry raised h** for ten minutes: blood glucose after a meal counted as an error. The author

decided two changes: the energy reserve read by the hypothalamus includes the stomach signal, and the glucose tolerance is asymmetric (1 mM below the reference, 3 mM above it, as in the ADA clinical criterion). All benches, re-run with unchanged criteria, gave the same verdicts.

3 The minimal arena

The arena is a one-dimensional corridor with a shelter on the left, food on the right and a threat zone overlapping the food: to eat, the organism must expose itself to danger. The threat is invisible and is announced by a warning signal 3 seconds in advance. Moving costs effort, staying on the food allows meals, the threat causes a haemorrhage and resting in the shelter restores blood volume. There are four actions: left, right, stay, rest. The outside world and the body travel on separate channels, as the insula's predictors require.

criterion	result
A0 reproducibility	identical bit for bit; error in the blood-volume accounting 0.0 L
A1 food → body	135.2 g eaten on the food against 0 g in the shelter
A2 threat → body	0.300 L lost, pressure from 93.4 to 86.6, h 1.34; no damage in the shelter
A3 the signal predicts the threat	129 threats, all preceded by the signal exactly 3.0 s earlier
A4 effort → body	heart rate +20.7 beats, ventilation 3.28 times
A5 channels and operator	5 channels; the operator's pause freezes arena and body
A6 robustness	finite values, no deaths over 6 seeds with a random policy

The first run passed 6 criteria out of 7: the control of A2 required h ≤ 0.6 in the shelter, but the natural variability of h at rest reaches 0.71–0.92 over 180 seconds. It was an error in the threshold, not in the arena; the second protocol compares the control with itself.

4 The insula and the measurement of predictability

Instrument

The insula represents the state of the body with 12 Gaussian units per variable and derives state and h **by decoding the population**, not by reading the body directly. To measure predictability, a recursive linear predictor (RLS with forgetting factor 0.999) predicts the next step of each channel from the current value, the previous one and the action. It is **the same predictor, with the same parameters, for body and world**: so the difference between the two errors comes from the signals, not from the instrument. The ratio ρ = world error / body error says how much more predictable the body is than the world.

Results

criterion	outcome
P0 identical instruments for body and world	passed
P1 known signals	passed: sine wave 0.0000; white noise 1.039; AR(1) process 0.209 against 0.19 in theory
P2 ρ on known mixtures	passed: with both signals noisy ρ = 1.006
P3 noise knobs in the arena	**failed** on monotonicity
P4 insula decoding	passed: error 0.030 tolerances; h from the insula equals h of the body
P5 no information from the future	passed: honest predictor 1.019 on noise; with a deliberate leak 0.0000

In the arena at rest, **ρ = 7.9**: the body is about eight times more predictable than the world. The premise of the theory holds in this organism, at least at rest (report NR-03 shows that the picture changes over 5-second windows and with bodies that really change).

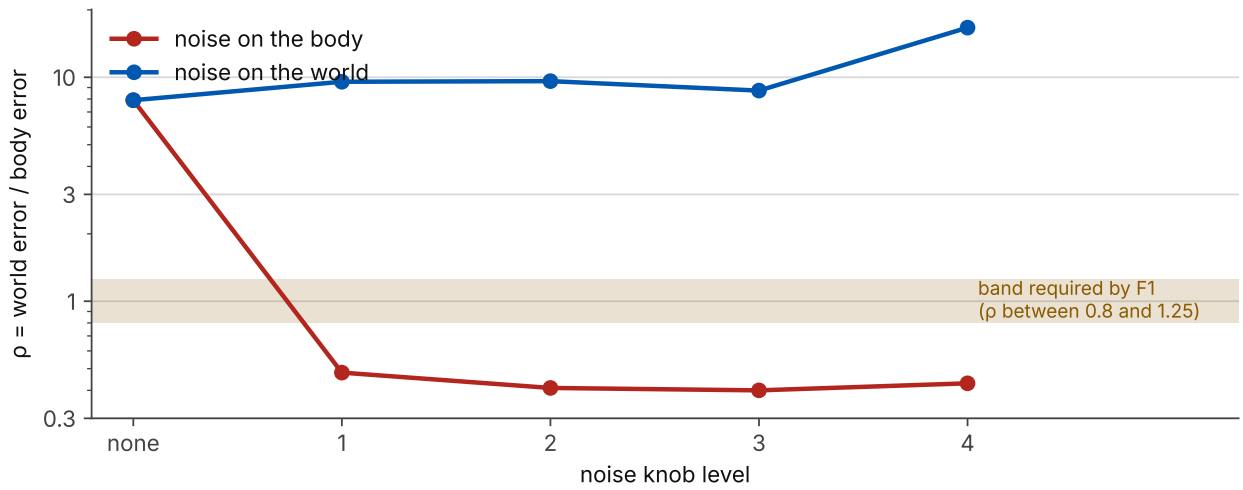


Figure 4. The ratio ρ as noise is added to the body or to the world (mean of 3 seeds, log of the V4-INSULA bench, run 3). Noise on the body makes ρ collapse by about sixteen times already at the first level and then rise slightly; noise on the world makes it rise, but not monotonically. The orange band is the one test F1 needs to reach.

Criterion P3 fails because the curves are not monotonic beyond the 5% tolerance, even though the extreme ratios go the right way (0.05 for the body, 2.11 for the world). In practice the knobs had to be recalibrated with finer levels before F1: we did so in the preparation phase of the tests (NR-04).

Three runs for a reliable instrument

The first run (4 out of 6) used a gradient predictor with step 0.5, which on white noise was wrong by about 50% more than the optimum (1.55 against 1.02). The second (4 out of 6), with a smaller step, no

longer tracked the sine wave. The recursive RLS predictor of the third run resolves the trade-off between tracking and noise. All diagnoses of the second run were made on signals different from those of criterion P1, so as not to tune the instrument on the test.

5 What it shows and what it does not

It shows that the organism has a regulated internal constant with a homeostatic error that behaves as the theory requires, a causal link between body and brain metabolism, an environment in which every bodily consequence happens only for the corresponding action, and a predictability instrument that reproduces the theoretical errors without using information from the future.

It does not show that the body is the anchor of the self: that is the question of tests F1 and F2. It does not show that regulating the body is the same as feeling it. And the value of ρ depends on the predictor chosen: a linear predictor underestimates the predictability of non-linear dynamics.

> **Limitations.** Glycogen is depleted about three times faster than in humans; respiratory arrhythmia does not grow with slow breathing; temperature, thirst and kidneys are missing (restoration in the shelter replaces them). The constants are tuned on the shape of the responses, not on individual data. The arena is a one-dimensional corridor.

References

- Guyton, A. C. and Hall, J. E. *Textbook of Medical Physiology*.
- Severinghaus, J. W. (1979). Simple, accurate equations for human blood O_2 dissociation computations. *J. Appl. Physiol.* 46, 599.
- Raven, P. B., Fadel, P. J. and Ogoh, S. (2006). Arterial baroreflex resetting during exercise. *Exp. Physiol.* 91, 37.
- Hoiland, R. L. and colleagues (2016). Hypoxemia, oxygen content, and the regulation of cerebral blood flow. *Am. J. Physiol. Regul. Integr. Comp. Physiol.* 310, R398.
- Craig, A. D. (2009). How do you feel — now? The anterior insula and human awareness. *Nat. Rev. Neurosci.* 10, 59.
- American Diabetes Association. Diagnostic criteria for glucose tolerance.
- Internal documents: whitepapers WP-01, WP-07, WP-08; records `interoceptive_body`, `minimal_arena`, `insula_predictors`.

How to cite

Chiarolanza, G. (2026). A body to keep alive: the interoceptive body, arena and insula of the minimal organism. Nadirion, research report NR-01, 13 September 2026. https://nadirion.eu/en/research/minimal-organism/

Nadirion technical report, not peer-reviewed. The criteria of every test were written before running it; negative results are reported like positive ones. The tests measure functional roles.