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A model of functional recovery after significant loss of neural tissue: biofeedback based healing of vestibular dysfunction

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Vestibular dysfunction can significantly affect balance, posture, and gait. Hundreds of patients suffering from significant loss of neural (vestibular) tissue were helped with a new treatment using biofeedback – a strip of electrodes feeding head-tilt information onto the tongue surface [1,2]. The success rate is stunning but the neural processes associated with this treatment are, to date, not understood in detail.

We present a model that can explain how a minor fraction of remaining vestibular tissue, trained using biofeedback, regains the ability to balance the modeled organism in an upright position.

Methods

Our model contains 4 populations of rate-coded units with sigmoid activation functions that are either not or fully connected via activity modulated Hebbian synapses (see Figure 1). A vestibular apparatus (VA) senses the tilt level of the modeled organism. VA is connected to a hidden population (HL) connected to a motor control population (BA), generating balancing actions and thereby closing a control loop by influencing the current tilt level. A second loop, the biofeedback, contains a population mimicking the signal of the mentioned tongue strip (TS).

VA and TS create population-coded output because their units are broadly tuned to different preferred tilt levels. HL and BA use winner take all dynamics. All units receive, in addition to the afferent input, a constant amount of white noise. Feedback connections from BA to HL force these populations to commit to a common, converged state.

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Destroyed VA-units reduce the total input to HL. Homeostatic input normalization iteratively strengthens remaining postsynaptic processes to regain the desired input strength.

Results

After destruction of a significant amount of VA-nodes (>90%) the remaining efferent signal does not exceed HL's noise level and the entire system turns non-functional. During homeostatic input normalization the tuning of remaining efferent VA connections broadens and causes the system to settle in a non-functional state.

Biofeedback substitutes missing vestibular data and re-enables BA to generate sensible actions. BA-HL-

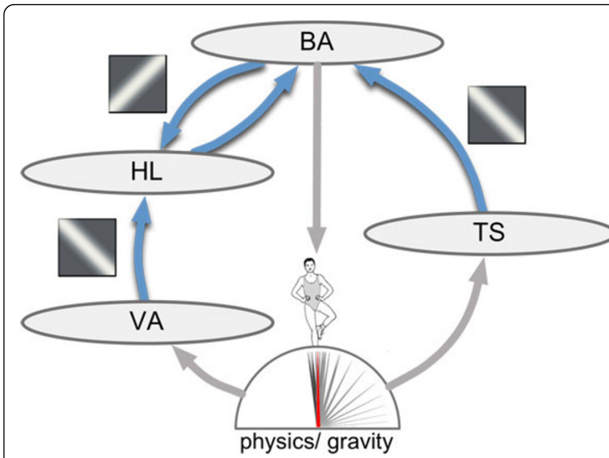

Figure 1 Model architecture. Ellipses: populations; blue (darker) arrows: directed, full connectivity; gray arrows: causal dependencies, i.e., sensing or acting. Abbreviations are explained in the text. Quadratic insets show the initial weight matrices, white coding for high values.

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feedback forces HL's output to be correlated with the sensed tilt angles. Thus, activity modulated Hebbian learning re-sharpens VA's efferent tuning and the modeled organism relearns to balance in an upright position – even without biofeedback. Phenomenologically this effect is also observed in human patients.

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