LETTERS

Observations from unperturbed closed loop systems cannot indicate causality

Elegant experimentation reported in a recent issue of *The Journal of Physiology* (Loram *et al.* 2005*a*,*b*) showed *in vivo* movements of muscle contractions of the gastrocnemius and soleus during quiet standing. Such measurements are important for the understanding and modelling of mechanisms that stabilize posture. Unfortunately, incorrect open-loop methods were used for data processing such as cross-correlation (XCOR), direct approach (DA) estimation of frequency response functions and time series analysis, which are not applicable for an unperturbed closed-loop system (CLS) such as quiet standing (van der Kooij *et al.* 2005).

The techniques of Loram and colleagues would give unambiguous results for open-loop systems (OLS) in which a stimulus applied to the system under study causes a response. However, the causal relation between two signals within a CLS is principally different than for an OLS. For example, one could argue that changes in EMG activity result in changes in muscle force that will affect body sway. But one could also argue the reverse, that changes in body sway angle are detected by sensors and transmitted to the nervous system that excites the proper muscle groups reflected in EMG changes.

It is a fundamental concept that, in general, cause and effect cannot be distinguished in a CLS. Since balance control is a closed-loop task, there is *always* interference, and the 'physiological sequencing' cannot be distilled from 'time locked averaged' time series data. Since OLS analysis methods were used by the authors, none of the conclusions were drawn in a methodologically correct way. Among these are the major conclusions:

> 'Standing requires the predictive ability to produce the observed muscle movements preceded (110 ± 50 ms) by corresponding changes in integrated EMG signal. We suggest higher level anticipatory control is more plausible.' (Loram *et al.* 2005*a*)

This conclusion is based on the outcome of XCOR analysis of muscle length and EMG. The authors did not taken into account how the estimated XCOR function reflects the activation and contraction dynamics of the muscle, the rigid body and neural system dynamics, and did not recognize that cause and effect cannot be disentangled. Therefore the XCOR function cannot solely be attributed to the nervous system and cannot be used to conclude whether the CNS has 'predictive abilities' or not.

> These alternating, small (30–300 μm) movements provide impulsive, ballistic regulation of CoM movement.' (Loram *et al.* 2005*b*)

This conclusion is based on putting time averaged and synchronized time-series of muscle movements, torque patterns and CoM motion in a 'timetable' (Figs 4, 5, 6 and 7 in Loram *et al.* 2005*b*) and interpreting these patterns as a causal chain, which is not allowed in CLS analysis.

> 'This counter-intuitive result is a consequence of the fact that calf muscles generate tension through a series elastic component (SEC, Achilles tendon and foot) which limits maximal ankle stiffness to 92 ± 20% of that required to balance the body.' (Loram *et al.* 2005*a*)

This conclusion is based on the estimated tendon stiffness derived by correlation of the muscle length and CoM angle and by the DA estimated $H_{\theta 2L}(f)$ as displayed in Fig. 5 (Loram *et al.* 2005*a*). However these measures do not necessarily reflect only the tendon and body dynamics (as in eqn (8) in Loram *et al.* (2005*a*)) but can also reflect the dynamics of the neural system and the contraction dynamics of the muscle.

In conclusion, with the techniques used by Loram and colleagues it is methodologically impossible to isolate the dynamics of one subsystem (e.g. the nervous system) from the others (e.g. muscle tendon dynamics). Instead, one should make use of well defined external perturbation signals in combination with the proper system identification methods (van der Kooij *et al.* 2005).

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