Pedal control of perturbed stable loads: Does ankle rotation feedback make control more automatic?

Cristiano Spiga, Ian Loram
IRM, Manchester Metropolitan University, John Dalton Building, Oxford Road, Manchester, M1 5GD, UK
c.spiga@mmu.ac.uk

INTRODUCTION

Control of external loads is affected by the properties of the load and by the source and modality of sensory information. Previous work has shown that visual manual control of stable and unstable 2nd order (massy) loads is intentional rather than automatic, according to the time delay of > 180 ms, the low frequency bandwidth of 2 Hz and control over direction as well as amplitude of response [1]. Here we are interested to know whether adding joint rotation feedback alters this result and interpretation. Although familiar, human posture is a specific pedal control, in which mechanical and sensory feedback from ankle rotation has a predominant role. That feedback has several different routes: instant mechanical, spinal and brain stem of short and medium short latency (50-70ms), functional stretch reflexes (100ms), and intentional responses (>150ms). For pedally, balancing perturbed stable loads, our main question is: how does the latency of EMG responses change when the source of sensory information is altered? Here we present three conditions of sensory feedback (i) ankle rotation only, (ii) ankle rotation and vision, (iii) vision only.

METHODS

The task is to balance, against an unpredictable disturbance, a virtual, 2nd order stable load. The load had a moment of inertia equivalent to a standing human and was controlled by modulating left ankle moment. A periodic, multisine disturbance, with equal power at all frequencies (0.1, 0.2, 0.3... 10 Hz), was added to the ankle moment and applied to the load. Sensory information which represents movement of the load was available from either the rotating footplate, or a luminous dot on an oscilloscope or both. Under PID control, the rotationally actuated footplate has a time delay of 10 ms and faithful response up 10 Hz.

Thirteen participants, strapped to a vertical board with ankle coaxial with the footplate axis of rotation, were instructed to minimize motion of the load from the centre position on the screen and/or rotation of the footplate from the initial horizontal position. Trials lasted 230 seconds.

RESULTS AND DISCUSSION

Considering sensory conditions in order of progression from full reliance on vision to full reliance on ankle rotation, the following changes were seen. Participants controlled the load with rms sway of 1.33 ± 0.38 degs, 0.85 ± 0.17 degs, and 1.94 ± 1.85 degs (mean ± s.d.) respectively for vision only, combined, and ankle rotation only conditions. For vision only, and for muscles soleus, gastrocnemius medialis and gastrocnemius lateralis respectively, the first significant activation
occurred at time-lags of 250ms, 220ms and 190ms (Figure 2, top row). For the combined condition, significant activity only from soleus at 150ms (Figure 2, central row). For the ankle rotation only condition, and for soleus, gastrocnemius medialis and gastrocnemius lateralis respectively, first significant involvement took place at latencies of 160ms, 270ms and 240ms (Figure 2, bottom row). As a spatially organised sense, vision alone allowed good spatial isometric control. Isometric pedal balance was significantly correlated with muscle responses which appeared to have a more dominant role in gastrocnemii and which were relatively late beyond 190ms. Such time-lags describe intentional control as it may be expected because there was no ankle rotation.

Adding ankle rotation to vision produced a high reduction in load sway ($t=16.9, \ p<0.05$). Nevertheless no reflexes were significantly involved as consistent with [2]; indeed significant soleus muscle activity was only after 150 ms.

Relying on ankle rotation alone without visual guide, appeared to reduce position sense, since load position sway was higher than it was with the combined condition ($t=4.45, \ p<0.05$). Soleus, significantly activated 10ms later than the combined condition, showed generally more significant activity than gastrocnemii. Latencies were more consistent with intentional (i.e. allowing choice over direction as well as amplitude [1]) rather than automatic reactions even in the ankle rotation only feedback condition.

**CONCLUSIONS**

When somatosensory feedback was removed no mechanical responses and no reflexive reactions originated. This was valid for visually guided control over perturbed 2nd order stable loads, either with hand [1] or ankle moment. For isometric pedal tasks, gastrocnemii provide the most significant muscle activity.

However, even though intrinsic ankle stiffness and reflex mechanisms are available for pedal control using ankle rotation, pedal control was governed by long time delays consistent with intentional rather than automatic reflex control, and with prevalent activity in soleus.

### Figure 2. Latency of EMG responses when varying kinds of feedback

Plots show statistical significance (1-p value, Wilcoxon signed rank, n=13) of the median cross correlation between disturbance and EMG signals for different time lags. Left, central, and right columns show soleus, gastrocnemius medialis and lateralis respectively. Top, central, and bottom rows show visual only, combined visual and ankle rotation, and ankle rotation only feedback, respectively. Red indicates significance at $P=0.05$.

### REFERENCES
