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# Plastic CPG-based Robot Controllers for Human-Robot Rhythmic Interactions

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### III. RESULTS

The experiment can be divided into four observed main phases (see Figure 2, the different phases are delimited).

**Learning phase (from  $t = 1.7$  s to  $t = 7$  s):** The human starts waving slowly and the  $\sigma_s$  instantly decrease.

**Slow waving - permanent phase (from  $t = 7.5$  s to  $t = 21$  s):** The human partner is still waving slowly,  $\sigma_s$  is stable around 12 which corresponds to an intrinsic frequency of 0.5 Hz for the CPG. Both CPG outputs are also in phase with the optical flow detected.

**Fast waving (from  $t = 21$  s to  $t = 41$  s):** The human partner accelerates the waving. The  $\sigma_s$  adapt and start increasing. The new stability value is around 40 (intrinsic frequency of 1 Hz for the CPG).

**No waving (from  $t = 41$  s to  $t = 50$  s):** The waving has ceased. Both  $\sigma_s$  remain stable, showing that the CPG retains the new frequency learned.

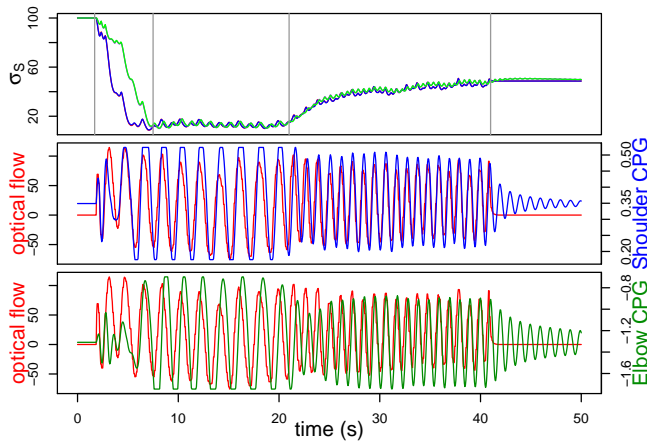


Fig. 2. Above, evolution of  $\sigma_s$ : in red and blue for the shoulder CPG; in green and purple for the elbow CPG. Note that the extensor and flexor curves are merged for both CPGs. Below, in red, the optical flow detected. In blue, the position command sent to the shoulder joint. In green, the position command sent to the elbow joint.

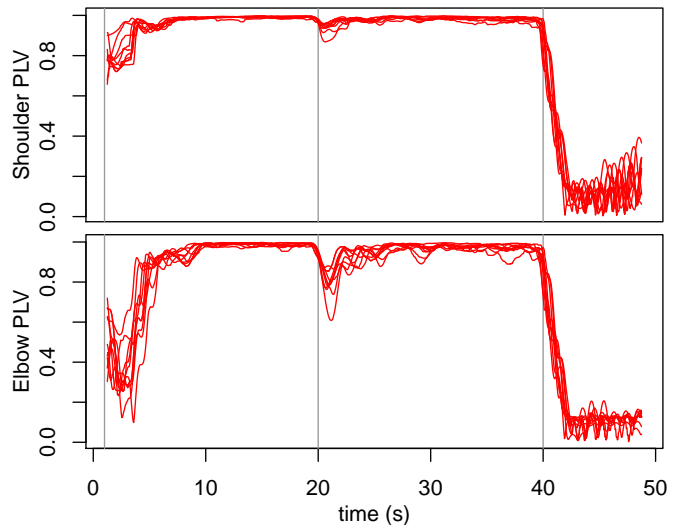
#### A. Evaluation of Coordination

The Phase Locking Value (PLV) has been introduced by [5] to measure coordination in brain signals.

Figure 3 represents the superimposed PLV for the ten interactions. It can be plainly observed that though the shoulder joint quickly coordinates with the optical flow ( $t = 7$  s), the elbow joint experiences a longer transition phase before achieving coordination ( $t = 9.7$  s). Similarly, at  $t = 20$  s, when the waving frequency changes, the transition is more distinct for the elbow joint than for the shoulder joint. Waving in the higher frequency appears less stable and with more variability than for the lower frequency, especially for the elbow joint.

### IV. CONCLUSION

CPG-based controllers endowed with plasticity mechanisms are able to synchronize with an external visual signal. This synchronization property enables motor synchronization



**Figure 3.** Top, PLV for the shoulder joint and the optical flow; Bottom, PLV for the elbow joint and the optical flow. The PLV for ten interactions are superimposed.

which in turn, triggers the emergence of social synchronization between the robot and the human. This was achieved by analyzing the synchronization between the optical flow and articular command values across ten different interactions thanks to the PLV. Despite the obvious human variability in the different interactions, results show an interesting coherence with signals often overlapping. Thus, the coordination observed previously is not merely due to chance but the controller indeed triggers the emergence of coordination (the PLV tends to reach 1.0) after a transitory phase where the system adapts to the new input information.

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