Coordination Dynamics:
Principles and Clinical Applications

Optional interim exam 2014-2015

Closed book exam
17-11-2014
13:30–15:15h
TenT Block 1

Please write on each sheet of paper your name and student number. The exam consists of several open questions, for which 30 points can be earned. Concise answers are highly appreciated and sufficient to earn the points. The Notes section on this page provides additional space to answer questions in case the provided space would be insufficient. Please note that erroneous passages in a lengthy answer may have adverse consequences in that they can lead to diminution of points you received for correct parts in the answer.

Good luck!

Notes

Question 1: Self-organized pattern formation (10 points)

The Haken-Kelso-Bunz (HKB) model of coupled oscillators is one of the foundations of coordination dynamics, an empirically grounded theoretical framework that seeks to understand coordinated behavior in living things. The HKB model was originally formulated in 1985 to account for some novel experimental observations on human bimanual coordination (Kelso, 1995) that revealed fundamental features of self-organization such as multi-stability, phase transitions and symmetry breaking. These features are captured by HKB's

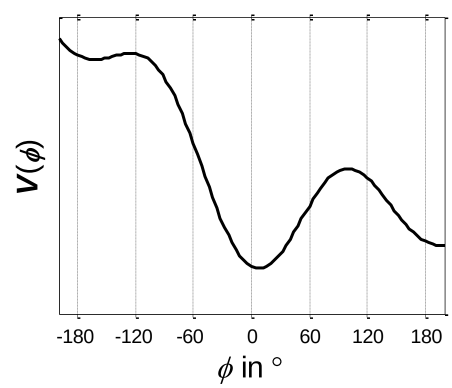
- order parameter dynamics equation: $\dot{\phi} = \Delta\omega - a\sin(\phi) - 2b\sin(2\phi) + \sqrt{Q}\zeta_t$
- potential: $V(\phi) = -\Delta\omega\phi - a\cos(\phi) - b\cos(2\phi)$.

a) What is the frequency relation between the coupled oscillators in a symmetric HKB-model with non-zero *b* and *a*? Explain. **[2 points]**

For a symmetric HKB model Δω=0 and with non-zero a and b there is always at least one stable solution, implying phase locking. Hence, the two oscillators must be frequency locked, in a 1:1 relation (both oscillators move at the same frequency).

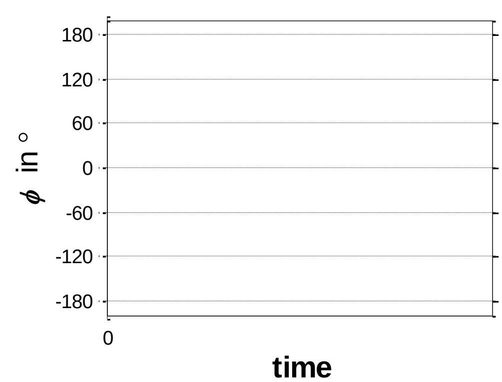
b) In the upper panel of the figure a HBK potential is depicted for a non-zero *Δω* with *b*/*a* = 0.7. Is *Δω* positive or negative in this figure? **[1 point]**

Delta omega is positive, see the first term in the equation for V(phi) representing the linear trend as a function of phi (note the minus sign in front of delta omega)



c) Plot in the lower panel of the figure the evolution of the order parameter ϕ over time for initial values of ϕ: -180°, -120°, -60°, 0°, 60°, 120°, 180°. **[3 points]**

fixed points are located at +10 and at -170 degrees, approximately. Lines should be drawn towards these fixed points as a function of time, starting at the 7 initial values on the vertical axis. 180, 120 and -180 go to -170, -60, 0 and 60 go to 10 and -120 can go both ways (unstable fixed point). Time course is different for +10 (faster) than -170 (slower) attractors



Explain, using $\Delta\omega$, a and b, the difference between a phase transition and relative coordination. **(3 points)**

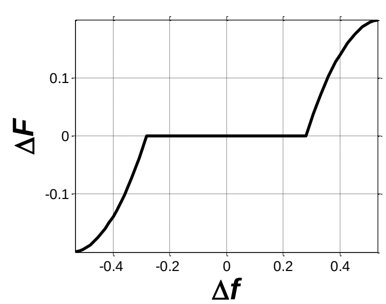
Phase transitions result from scaling the control parameter, hence the ratio b/a, where the order parameter switches from one stable mode to another (within a mode there is absolute coordination, no phase wrapping). In contrast, in relative coordination, there is a continuous competition of coupled oscillators between moving at a joint tempo (magnet effect) and persisting moving at their own preferred pace (maintenance tendency), implying an inherent frequency mismatch between the two oscillators (detuning, Δω, broken symmetry). If a certain values of b/a and Δω, relative coordination starts to occur because fixed points disappear. The order parameter relative phase continuously shifts or wraps, yet it dwells longer in the vicinity of previously stable fixed points (remnants of stability). The difference between relative coordination and a phase transition is that in the former for fixed parameter values the order parameter dynamics can still change. The only requirement is a fairly large Δω value.

d) Is there a single, unique value of ϕ for each combination of $\Delta\omega$, a, b and Q? Explain. **[1 points]**

No. The HKB model is a model with two stable solutions for b/a values > 0.25, indicating that for a given combination of abovementioned parameters, phi can be either in the in-phase mode of coordination or in the antiphase mode of coordination (multistability). Moreover, within a stable mode, phi will vary as well if Q>0 (Noise). In the bistable regime, phi also depends on the direction of parameter changes (hysteresis). Finally, for certain parameter values relative coordination occurs (no stable fixed points), for which phi can result in all possible values (phase wrapping). Ergo, there is not a single unique value for phi for a given set of parameter values.

Question 2: Synchronization (2 points)

Coupled oscillators are seldom identical. Synchronization can be understood as an adjustment of rhythms of oscillating objects due to their weak interaction. Whether or not two non-identical oscillators (having their own frequencies f_1 and f_2) start to oscillate with a common frequency depends on 1) how weak (or strong) the interaction is and 2) how different the uncoupled oscillators are. Consider the schematic *frequency synchronization* vs. *frequency mismatch* plot (ΔF vs. $\Delta f = f_1 - f_2$) for two interacting oscillators. Oscillator 1 has a characteristic frequency f_1 of 1.9Hz while oscillator 2 has f_2 of 2.3Hz.

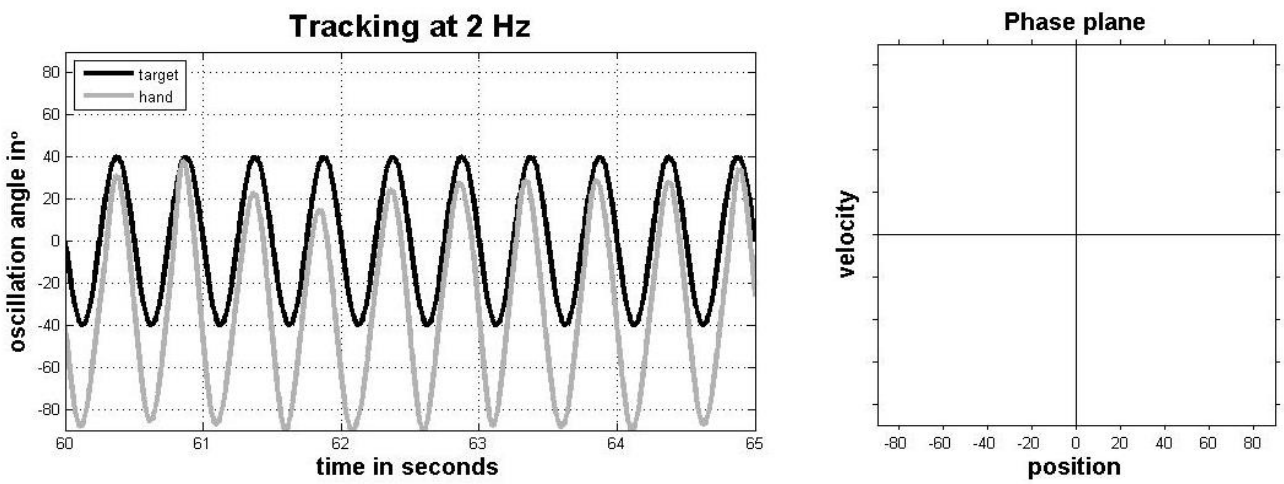


a) Indicate, based on this plot, if the two interacting oscillators will synchronize. **[2 points]**

No they will not. Deltaf is -0.4 and the corresponding value of deltaF is -0.14. Oscillators are only coupled if deltaF is zero, which is for the specified oscillator characteristic frequencies not the case.

Question 3: Phase planes (7 points)

Phase planes are often normalized to maintain a consistent aspect ratio, regardless of oscillation period. In the manuscript by Wimmers et al. (1992), participants performed a visuomotor tracking task. The right-handed participant was instructed to manually track a horizontally oscillating visual target signal in either an in-phase mode or in an antiphase coordination mode. The target signal was presented on a screen in front of the participant. The figure below depicts 10 cycles of visuomotor tracking of hand (grey lines) and target (black lines) oscillations for a target frequency of 2 Hz. Minima represent flexion reversal points of the hand movements and the leftmost reversal points of the target signal.



A) Which coordination mode was performed? (**1 point**)

In-phase tracking

B) Can you infer from the data if the participant is actively steering his/her hand movements to a particular movement reversal point? Explain. **(3 points)**

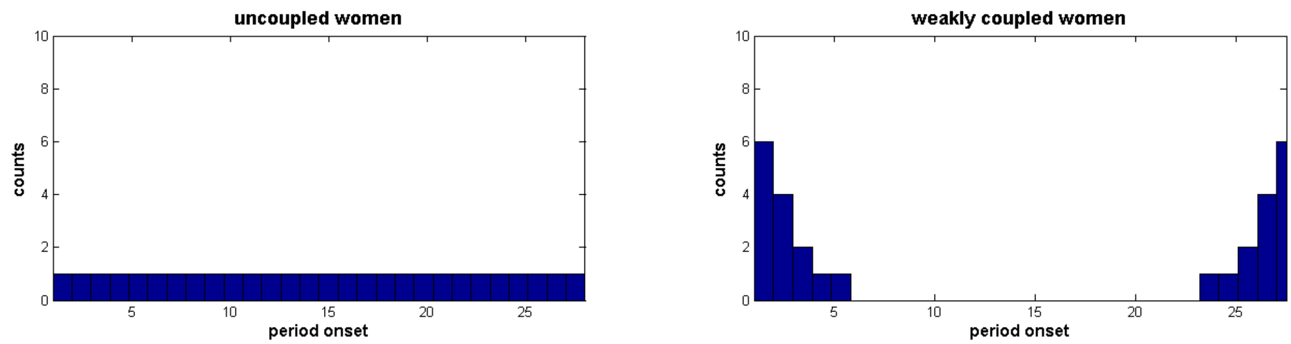
Yes, lower flexion than extension endpoint variability and overall more flexed orientation. Based on these kinematic signatures, the hand is likely steered actively towards peak flexion. Another kinematic signature of anchoring is an asymmetry in peak velocity between the two half-cycles. This is not the case for the presented data.

C) Draw the corresponding phase plane with normalization as applied in Computer Practical 1. Also specify the normalized velocity values on the ticks of the y-axis. **(3 points)**

Circular phase planes with appropriate zero crossings at -85 and +25 degrees. Variability of flexion and extension reversal positions is different, with lower variability for flexion. Note that the amplitude is 55 degrees. Hence, normalized peak velocity should be around -55 and +55 degrees. This is the direct effect of normalization so that the phase planes have a consistent aspect ratio (scaling velocity to amplitude by dividing by 2pi omega, chain rule).

Question 4: Ensembles of weakly coupled oscillators (6 points)

Assume that 28 independent women have a regular 4 week menstrual cycle, with period onsets uniformly distributed across the sample throughout the 28 days, as depicted in the left panel of the figure below. Then they start living together, in other words, the women become weakly coupled. Rumor has it that after a year their period onsets start to converge (right panel).



a) Indicate in the Table below your rough estimates of the mean and the dispersion of period onset days for uncoupled and weakly coupled women using directional and conventional statistics. **[3 points]**

	Directional statistics		**Conventional statistics**	
	uncoupled	***coupled***	***Uncoupled***	***Coupled***
Mean	NaN	1 = 28	14.5	14.5
Dispersion	infinite	2	8	12

b) Pattern formation and pattern change is governed by competition among different sources of information that is meaningful and specific to the pattern(s) in question. Address this competition between informational sources in the context of pattern changes observed in clapping (i.e., audience applause), as demonstrated in Lecture 1 and described in the paper by Neda et al. (2000). **[3 points]**

Two sources of information compete with each other in a rhythmic applause: 1) the clapping noise intensity to express appreciation and 2) synchronization in the clapping phases. Once the audience applauds in a synchronized mode, average noise intensity drops. This may mediate an increase in clapping rate in individual clappers in order to raise the overall noise intensity again. But this goes at the expense of a reduced coupling between the individual clappers and synchronization is likely to be lost. There is competition between clapping together and making as much noise as possible, resulting in switches between synchronized and incoherent clapping modes.

Question 5: Hysteresis (3 points)

Miura et al. (2013) studied whole-body auditory-motor coordination by letting participants bob to the beat of a metronome in either an up-on-the-beat pattern or down-on-the-beat coordination pattern. Hysteresis was a key topic in that study, which was experimentally addressed by asking participants to bob to metronomes that either increased or decreased in frequency (ascending and descending metronome conditions, respectively).

a) What was the dependent variable used to quantify hysteresis? **[1 point]**

Critical frequency

b) What were the main findings for the <u>descending</u> metronome conditions? **[2 points]**

For the down on the beat condition, both dancers and non-dancers preserved the instructed pattern throughout the descending metronome frequency plateaus. For the up on the beat condition, switches were found from down-on-the-beat at high frequencies to up-on-the-beat for low frequencies, which was taken as evidence for hysteresis. The corresponding bifurcation frequency was higher for dancers than for non-dancers, implying that dancers switched earlier from up on the beat to down on the beat in the descending condition.

Question 6: Visually coupled coordination

You have read several papers on visually coupled *between-person coordination* and many of these tests were also performed in the lectures or in the Laboratory, such as two persons wiggling their fingers together with or without seeing each other (Oullier et al. 2008). Furthermore, you have read studies and seen demonstrations of *visuomotor coordination*, such as rhythmic visuomotor tracking (Wimmers et al, 1992, see also Question 3). The precise coupling form differs considerably across these experiments. What is the fundamental difference in oscillator coupling between the experiments of Oullier and colleagues (2008) and Wimmers and colleagues (1992). **[2 points]**

The coupling is based on visual information in both experiments, but differs in directionality. That is, in Wimmers et al the coupling is unidirectional (or unilateral) and only the hand movements can adjust to the visual stimulus and not vice versa whereas in Oullier et al the coupling is bidirectional (bilateral) in that both oscillators can and do adjust their hand movements to each other. (Another difference is that in Oullier et al. the two oscillators are truly autonomous whereas the active oscillator in Wimmers et al is non-autonomous.)