Student name : **Student number :**

Coordination Dynamics: Principles and Applications

Written closed-book exam 2015-2016

14-12-2015, 8:45–11:30h

RAI Block 9

Please write on each sheet of paper your name and student number. The exam consists of six open questions, for which 35 points can be earned. Concise answers are highly appreciated and sufficient to earn the points. The Notes sections on this page and on page 8 provide 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 it can lead to diminution of points you received for correct parts in the answer.

Good luck!

Notes

Question 1: Coordination dynamics and HKB model (10 points)

Coordination dynamics may be defined as a set of context-dependent laws and rules that describe, explain, and predict how patterns of coordination form, adapt, persist, and change in natural systems consisting of multiple interacting subsystems. The relative phase is often used as the collective variable that characterizes the dynamics of patterns of coordination.

A) The coexistence of several collective states for the same value of the control parameter is called ... **[1 point]**

Multistability

B) Relative coordination is special form of coordination. How can we identify relative coordination from relative phase time series? **[2 points]**

Hallmark feature of relative coordination in terms of relative phase is a relative phase distribution in which all values of relative phase are visited (e.g., due to the phase wrapping or cycle slips) but with a greater probability of finding relative phase values near previously stable fixed points (remnants of stability).

The Haken-Kelso-Bunz (HKB) model of coupled oscillators is one of the foundations of coordination dynamics, represented by HKB's

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

C) The order parameter ϕ is continuously perturbed by the noise term $\sqrt{Q}\zeta_t$. For a fixed value of the control parameter, what will be the effect of detuning on the variability in ϕ? Explain. **[2 points]**

Slopes at zero crossings in order parameter dynamics plot become less steep with detuning, hence driving force towards the attractor becomes smaller and noise has a greater impact on the dynamics (i.e., greater SD of phi).

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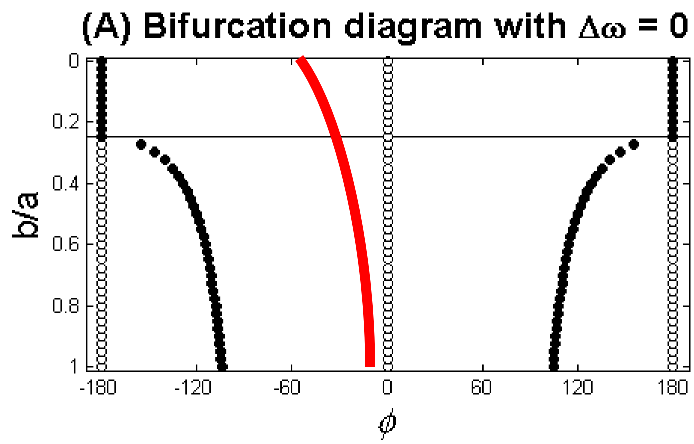
D) In the figure on the right, the bifurcation diagram for the symmetric HKB model is given. Describe what black and white dots represent. **[1 point]**

The black dots represent repellors (unstable fixed points) while white dots represent attractors (stable fixed points).



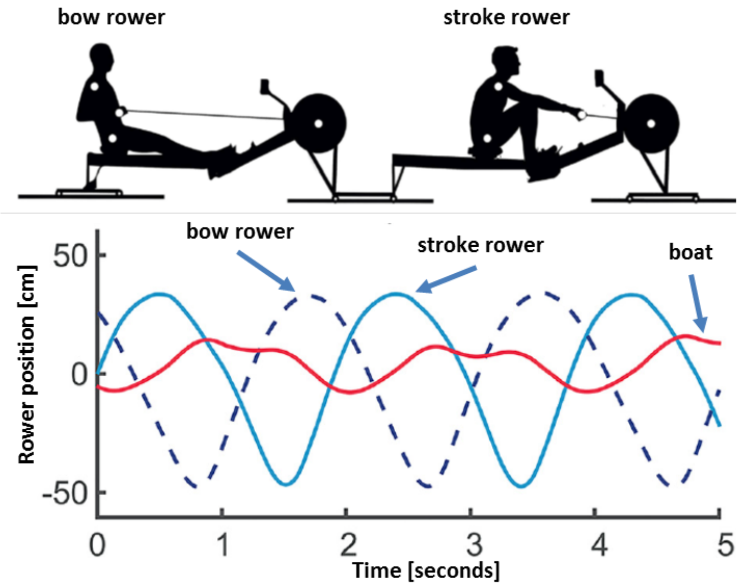
E) Sketch in the figure above the fixed points for in-phase (absolute) coordination for a negative value of $\Delta\omega$. **[1 point]**
See red line in figure

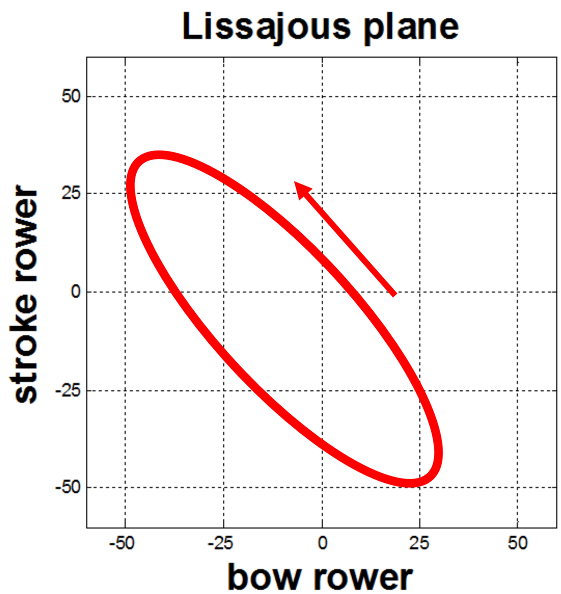
F) What is the name of the procedure to experimentally examine the seagull effect? What are the corresponding independent and dependent variables. **[3 points]**

The procedure is called the scanning procedure (1 point). The corresponding independent variable is the imposed phase relationship (1 point) (ranging from -180 to 180 degrees), the dependent variables are the performed phase relationship and its standard deviation (1 point)

Question 2: Lissajous planes of coupled oscillators (6 points)

Lissajous planes are frequently used in coordination dynamics literature to visualize frequency and phase relationships between two oscillators. Examples were horse-rider dynamics, postural coordination dynamics and bimanual coordination. Another example for which Lissajous planes may be used to visualize frequency and phase relationships is crew rowing. Cuijpers et al. studied rowing crew coordination using mechanically coupled ergometers. In the figure below, the rowers' positions are depicted over an episode of 5 seconds.





A) What is the coordination pattern between the rowers? **[1 point]**
Antiphase

B) Explain which rower is leading. **[1 point]**
The stroke rower is leading the antiphase pattern as evidenced by the observation that positional maxima (minima) of the stroke rower are reached earlier in time than the minima (maxima) of the bow rower.

C) Draw the corresponding Lissajous plane and indicate the direction of evolution. **[3 points]**
See figure

D) Are the rowers unidirectionally, asymmetrically or bidirectionally coupled? Explain. **[1 point]**

Asymmetrically: the two rowers are mechanically coupled (very strong bidirectional coupling), but the bow rower is also visually coupled to the stroke rower (relatively weak unidirectional coupling).

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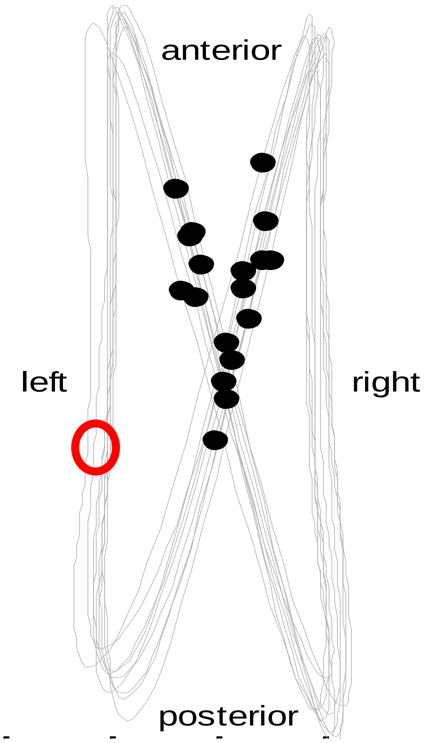
Question 3: Rhythm perturbations (5 points)



The figure on the right shows a gaitogram, that is a Lissajous plane of medio-lateral and anterior-posterior center-of-pressure time series during walking on an instrumented treadmill. The black dots indicate metronome onsets.

A) What is the frequency relationship between anterior-posterior and mediolateral center-of-pressure time series? **[1 point]**

2 (AP) : 1 (ML)

B) Sketch in the depicted gaitogram a metronome onset corresponding to a 60° phase-advance perturbation of the metronome beat pacing the right footfall. Explain your answer. [**2 points]**

General: test insight in gaitogram, direction of evolution, speed differences in gaitogram, and important gait event indications. Also note this subject anticipates the beat, as footfalls happen slightly before metronome. With regard to a phase advance perturbation for metronome onset pacing right footfall it is important to indicate that the right footfall occurs in the lower-left part of the butterfly. With phase-advance perturbation, the beat arrives earlier than expected, 1/6th of the gait cycle earlier. So beat onset should be indicated somewhere in the single support phase of the left leg (prior to FCright; note that the speed varies over the gaitogram, going much slower in the single than in the double support phase).

C) Roerdink et al. (2009) and Bank et al. (2011) used rhythm perturbations to examine pattern stability of auditory-motor synchronization in acoustically paced treadmill walking in stroke patients and healthy elderly, respectively. They did this at participants' preferred cadence. What was the associated outcome measure? **[1 point]**

Outcome measure for pattern stability of auditory-motor synchronization: Nreturn, the smaller Nreturn, the stronger gait is coupled to the beat.

D) Do you expect that this outcome measure of question 3C will change with metronome rates set at a slower-than-preferred pace? Explain your expectation. **[1 point]**

Expectations: Nreturn will likely increase for slower than preferred metronome tempi (indicating weaker coupling) because Roerdink et al. (2011) found that the coupling between gait and the beat reduced for metronome rates other than the preferred cadence.

Question 4: Variability, DFA and surrogate analysis (5 points)

A) Two time series can differ in "variability" even when they exhibit similar means and standard deviations. Explain and give an example. **[1 point]**

Variability is an ambiguous term. In this context, variability should not be equated with SD but refers to the way in which the points are ordered over time. See Goldberger (2006), Figures 1 and 2; spread around the mean (SD) can be the same but the points can be ordered differently as a function of time between two time series, such as rather periodically for a patient suffering from sleep apnea versus a more complex type of variability for a heart rate time series of a healthy person (many examples possible)

B) The scaling exponent α of detrended fluctuation analysis (DFA) is often used to quantify the correlational structure in stride times, stride lengths and stride speeds. Dingwell and Cusumano (2010) randomly shuffled stride speed (SS) time series to test the hypothesis that original stride speeds were temporarily independent from previous strides. Did their experiment verify or falsify this hypothesis? Explain. **[2 points]**

They falsified this hypothesis. The reported alpha from the original stride speed time series was significantly different (lower) from that of the randomly shuffled stride speed time series (Figure 2), suggesting that the temporal ordering of stride speeds is not independent (uncorrelated, as is the case for shuffled surrogates) but structured over time (i.e., in an anti-persistent manner).

C) In Lecture 5, an experiment was discussed in which participants walked on a treadmill with constrained walking areas: small, intermediate and large. What was the effect of this walking area manipulation on the correlational structure of stride speed fluctuations and what was the corresponding interpretation of this effect? **[2 points]**

The degree of antipersistence in the stride speed fluctuations changes with walking area manipulation: the smaller the walking area the stronger the antipersistence in stride speeds. This effect was interpreted as follows: the more stringent the walking area constraint, the tighter the stride speeds should be regulated (to minimize positional variations over the treadmill). A more relaxed constraint increases the maneuverability range and hence a smaller need to tightly regulate stride speeds (some positional variation over the treadmill is allowed, resulting in a lower degree of antipersistence). Alpha < 0.5 not necessarily a marker of disease, as has been the prevailing interpretation for a long time.

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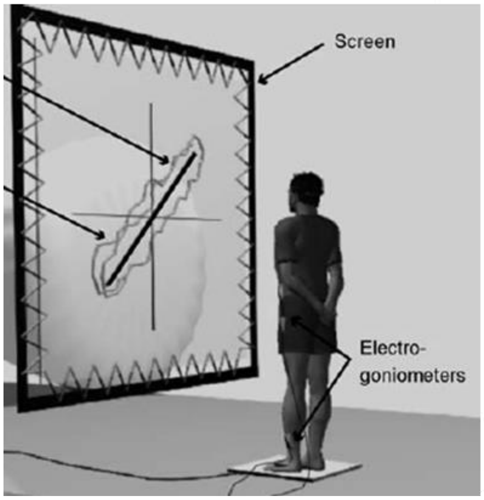
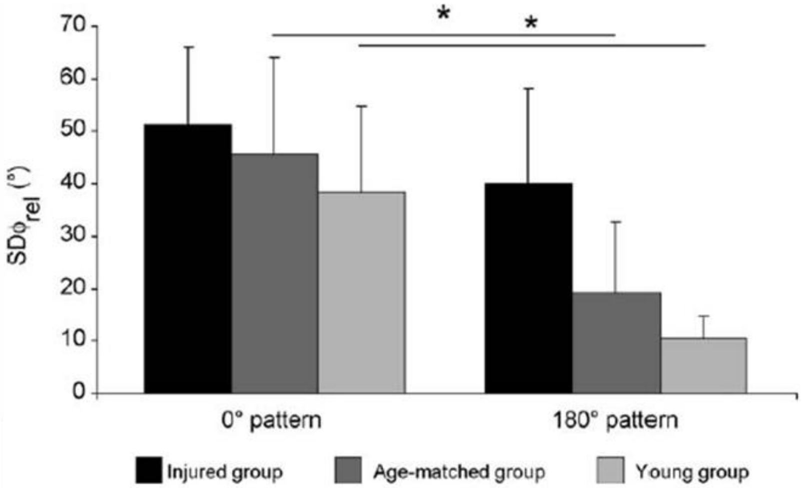
Question 5: Postural coordination dynamics (4 points)

In lecture 7, we discussed and experimented with postural coordination dynamics, in which participants were instructed to perform different postural coordination patterns (i.e., in the case of Varoqui et al. (2010) guided by Lissajous feedback; see the left panel in the figure below). In the right panel of this figure the pattern stability results of Varoqui et al. (2010) are reproduced.





A) As you can appreciate from the figure, pattern stability differed between 0° and 180° postural coordination patterns for healthy young and healthy elderly adults (as indicated by the * symbols). Explain which pattern was most stable. **[1 point]**

The 180 degrees pattern was most stable for these groups, as evidenced by a lower standard deviation of the relative phase between hip and ankle angles.

B) For the stroke patients (injured group), no stability difference was observed between the two imposed postural coordination patterns. Explain why. **[1 point]**

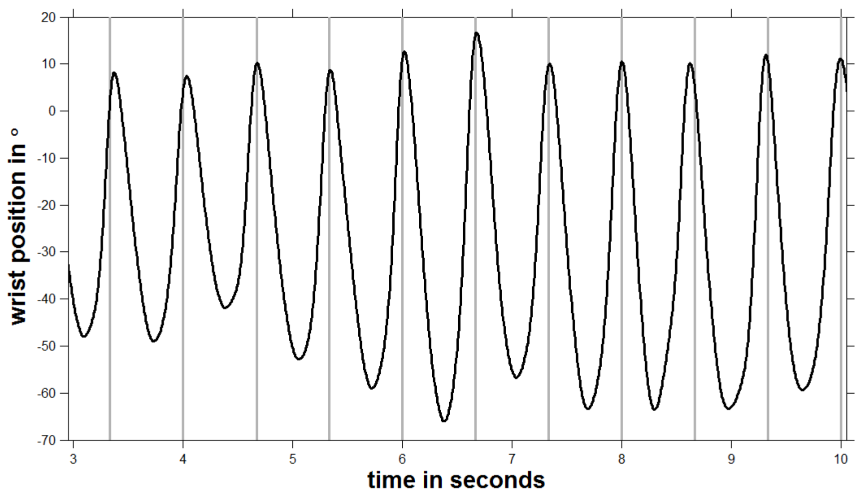
Stroke patients were unable to perform the 0 degrees pattern and performed the 180 degrees pattern instead in the 0 degrees pattern condition. The reported SDrel in that condition thus largely corresponds to the 180 degrees postural coordination pattern

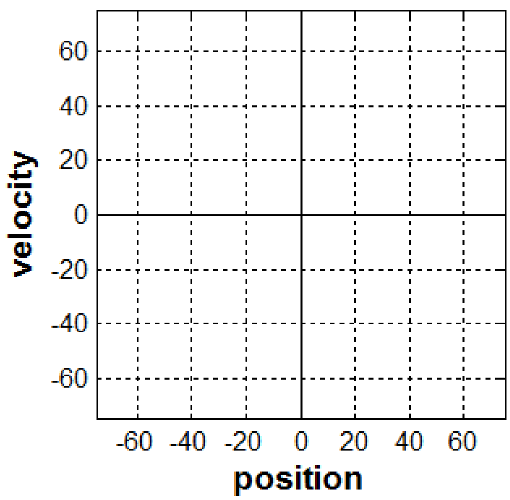
C) Varoqui et al. (2010) also reported a main effect of pattern (0° or 180°) on the movement frequency of the postural coordination patterns. Indicate which pattern was performed at a higher movement frequency and explain how this effect of pattern on movement frequency may have influenced the observed pattern stability findings. **[2 points]**

Movement frequency was higher in the 180 degrees pattern than in the 0 degrees pattern. Pattern stability typically varies as a function of movement frequency => the higher the movement frequency, the lower the pattern stability. So, when compared at similar movement frequencies, the differences in pattern stability may become more pronounced.

Question 6: Phase planes of sensorimotor coordination (5 points)

In Laboratory 1, various unimanual synchronization and syncopation conditions were performed with the right wrist, paced by a metronome. Wrist position time series of a participant who was 'cheating' in the flex-in-between-the-beat condition is depicted in the left panel. Grey vertical lines represent metronome beep onsets. Draw the corresponding normalized phase plane in the right panel. **[3 points]**
Use arrows to specify in what direction the trajectory evolves as a function of time. **[1 point]**
Also depict the beep onsets using dots. **[1 point]**





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Phase plane, running clockwise, with greater variability at peak flexion (around -50) than at peak extension (around 10) and greater peak velocity in the extension phase (+40 or so) than in the flexion phase (-20 or so). Beep onsets at and around the peak extension crossings.

Notes:

This is the end of the exam. Thank you for participating in the coordination dynamics course. The course and exam evaluation poll is now available online (VUnet). Your feedback to help improve the course is very much appreciated! I wish you happy holidays! Best regards, Melvyn Roerdink