Student name : **Student number :**

Coordination Dynamics: Principles and Clinical Applications

Exam 2012-2013

Open book exam
17-12-2012
08:45–11:30h
WN-F619, F637, F647

Model Answers

Please write on each sheet of paper your name and student number to earn the first 10 points of the total of 80 points. The exam consists of several open questions, for which 70 points can be earned. Concise answers are highly appreciated, but you are allowed to use and refer to the “notes” sections on page 9 and 10 if the space provided is insufficient. Note, however, that erroneous passages in a lengthy answer can lead to diminution of points you received for correct parts in that answer.

Caution: there may not be enough time to look up every question!

Good luck!

PS: the exam with model answers will be available on BlackBoard ASAP.

Question 1: HKB-model of coordination dynamics (15 points)

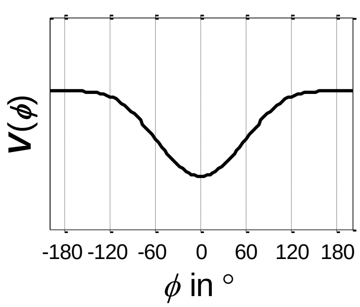
The Haken-Kelso-Bunz (HKB) model of coupled oscillators is one of the foundations of coordination dynamics, an empirically grounded theoretical framework that seeks to understand coordinated behavior in living things. The HKB model was formulated to account for some novel experimental observations on human bimanual coordination (e.g., see also Kelso, 1984, 1995) that revealed fundamental features of self-organization such as multi-stability, phase transitions, symmetry breaking, and hysteresis. These features are captured by HKB's

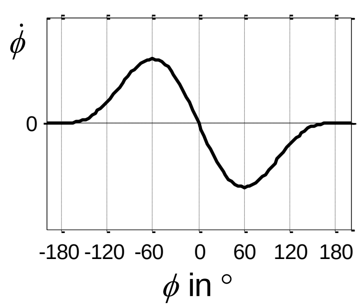
- order parameter dynamics equation: $\dot{\phi} = \Delta\omega - a\sin(\phi) - 2b\sin(2\phi) + \sqrt{Q}\zeta_t$
- potential: $V(\phi) = -\Delta\omega\phi - a\cos(\phi) - b\cos(2\phi)$.

A) What is the general name for a parameter that drives a system of coupled oscillators through different patterns of coordination? Furthermore, specify this parameter for the HKB-model as well as its meaning in the context of rhythmic finger wiggling. **(5 points)**

The general name for such a parameter is: control parameter or control variable.
The control parameter in the HKB model is b/a, which is inversely related to movement frequency in the context of rhythmic finger wiggling.

B) Select for the depicted HKB-potential and the corresponding order parameter dynamics plot a combination of appropriate *Δω*, *a*, and *b* parameter values from the options listed in the Table below. Briefly motivate your answer. **(4 points)**





parameter value options				
Δω	*0*	*1*	*2*	*3*
a	*1*	*2*	*3*	*4*
b	*1*	*2*	*3*	*4*

Δω = 0, the potential and order parameter dynamics are symmetric.
The ratio b/a should be 0.25 (graphs correspond to critical state with slope 0 at phi is +/- 180 degrees), which is only possible with the listed values b = 1 and a = 4 (many students identified the b/a = 0.25 but then strangely claimed b to be 4 and a to be 1… ???)

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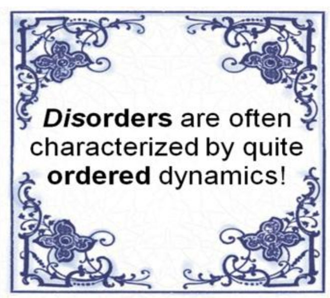
C) What is meant by differential stability? List four experimental procedures to assess differential stability in rhythmic bimanual coordination and specify the corresponding outcome measure. **(6 points)**

Differential stability indicates that the attractors in a multistable system are not equally strong.
Four experimental procedures to assess differential stability are:

- *Stationary trials for the different states: examine their stability with the standard deviation of relative phase*
- *Perturbations: perturb the relative phase for the different states and examine how fast relative phase is restored (recovery time)*
- *Switching: ask the participant to voluntarily switch from one state to the other and examine the relative duration of the switch (switching time)*
- *Transition trials for the different states: increase movement frequency for the states and determine transitions between states and/or the critical frequency for coordination loss.*

Question 2: Complex systems (5 points)



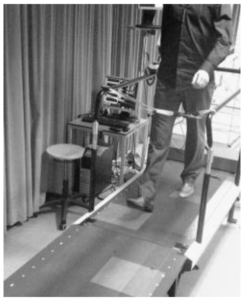
Ary L. Goldberger became famous for his quote “Disorders are often characterized by quite ordered dynamics”. Explain what he meant by this quote and elaborate on the practical relevance of this quote for bedside diagnosis in the clinic.

With this quote, Goldberger refers to the fact that pathological behavior is often characterized by a loss of complexity in that disorders instead become recognizable by repeating, periodic symptoms (many examples in Goldberger1996). As such the name disorder is somewhat of a misnomer. Bedside diagnosis would be impossible without the loss of complexity and the emergence of pathological periodicities, which allow clinicians to identify and classify many pathological features of their patients

Question 3: DFA and surrogate analysis (10 points)

A) Dingwell and Cusumano (2010) randomly shuffled stride length (SL) time series to test the hypothesis that original stride lengths were temporarily independent from previous strides. Did their experiment verify or falsify this hypothesis? Explain. **(5 points)**

They falsified this hypothesis. The reported alpha from the original stride length time series was significantly different from that of the randomly shuffled stride length time series (Figure 2, left panel), suggesting that the temporal ordering of stride lengths is not independent (as is the case for shuffled surrogates) but structured over time (persistence).



B) In Laboratory 2 participants walked on a treadmill to a sequence of visual stepping stones. Compared to normal treadmill walking, what will be the effect of visually cued walking on the scaling exponent α (derived from detrended fluctuation analysis) of stride length (SL), stride time (ST) and stride speed (SS) time series? Explain. **(5 points)**

Dingwell and Cusumano (2010) showed that ST and SL time series exhibited statistical persistence, whereas SS showed anti-persistence. Their interpretation was that the latter parameter was under tight control because persistent deviations in SS may result in dangerous position shifts on the treadmill. When walking to a sequence of stepping stones, stride lengths will be tightly controlled, such that deviations in this variable will be followed by rapid corrections. Alpha for SL will thus likely change qualitatively from the persistent (alpha > 0.5) to the antipersistent regime (< 0.5). SS and ST will either both become persistent (but correlated) because they are not controlled and when correlated the SS remain bounded as well. Alternatively, also SS and ST will show antipersistence (as SL and SS are tightly controlled, ST will be constrained similarly as well).

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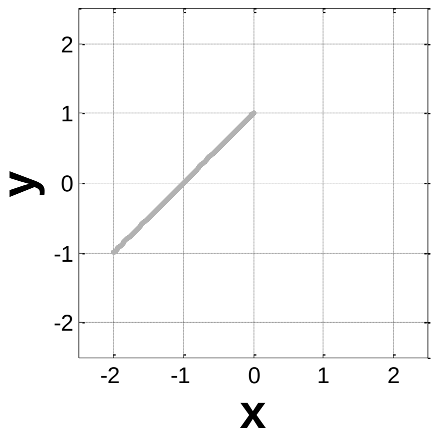
Question 4: Lissajous planes (10 points)

Lissajous planes are frequently used in coordination dynamics literature to visualize frequency and phase relationships between two oscillators (e.g., hands/fingers, body segments; see e.g. Kelso 1984; Varoqui et al. 2010). The figures below depict 3 Lissajous planes for oscillators $x = O_x + A_x \cdot \sin(360° \cdot \omega_x \cdot t + \varphi_x)$ and $y = O_y + A_y \cdot \sin(360° \cdot \omega_y \cdot t + \varphi_y)$.



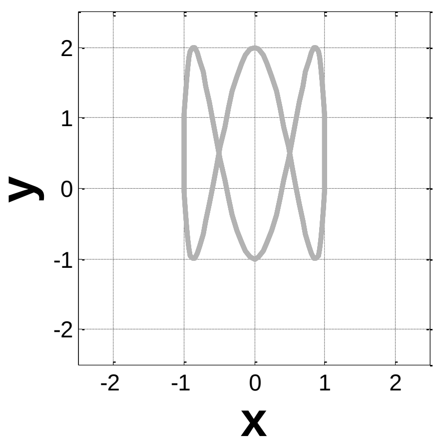
3A: Indicate O_x, O_y, A_x, A_y, ω_y and φ_y at t = 0 sec given that ω_x = 3 Hz and φ_x = 0° at t = 0 sec **(3 points)**

O_x = -1 O_y = 0

A_x = 1 A_y = 1

ω_y = 3

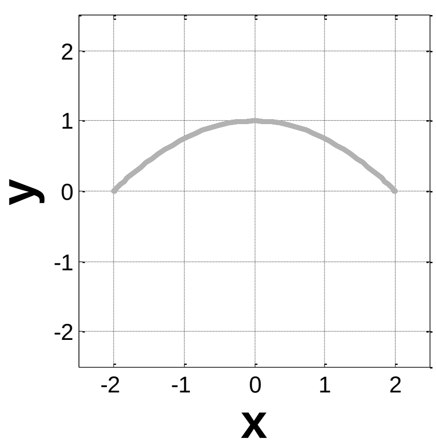
φ_y = 0 (at t = 0 sec)



3B: Indicate whether or not the following parameter combination statements correspond to the depicted Lissajous plane **(2 points)**

$\omega_y = 2 \cdot \omega_x$ **[True/False]**
$A_x = A_y$ **[True/False]**
$O_x \neq O_y$ **[True/False]**

3C) Report the two initial values for φ_y at t = 0 sec given that φ_x is then 0° **(2 points)** 90 and 270 degrees



3D: Indicate O_y, A_y, ω_y and φ_y at t = 0 sec given that $x = 2 \cdot \sin(360° \cdot 3 \cdot t + 180°)$ **(3 points)**

O_y = 0.5
A_y = 0.5
ω_y = 6 Hz (2 times 3Hz)

φ_y = 90° (at t = 0: x for phi = 180 degrees = 0; for t > 0, x then becomes negative). The corresponding value of y is then 1 and becomes smaller than 1 if time evolves. Hence, phi y is 90 degrees.)

Question 5: Environmental coupling (10 points)

A) The coupling between two oscillators is either unidirectional or bidirectional and can operate over multiple informational modalities (e.g., visual, auditory, mechanical, et cetera). Can you give an example of a system of coupled oscillators for which there is an asymmetry in the coupling function, such that the two oscillators are bidirectionally coupled for one informational modality and unidirectionally for another? **(3 points)**

Many examples possible, such as the horsing around example of Harrison and Richardson 2009 where the two oscillators are mechanically coupled bidirectionally whereas only the rear 'oscillator' can visually see the other one and not vice versa and as such coupling for the visual modality is unidirectional (only the rear person can adjust based on visual info picked up from the person walking in front of him/her). Note: unidirectional and bidirectional does not refer to the number of modalities involved in the interaction.

B) Rhythmic unimanual visuomotor tracking (cf. Wimmers et al. 1992; Laboratory 1) and walking to a sequence of stepping stones (cf. Bank et al. 2011; Laboratory 2) are both examples of coordination with environmental coupling. The collective variable to describe coordination was in both cases the relative phase between the participant's movement and the environmental stimulus. To assess coordinative stability both studies perturbed the collective variable. Explain how. (**3 points**)

Coordinative stability of the collective variable was assessed by perturbing the movement itself (Wimmers et al. suddenly arrested one arm for a little while by applying a torque to the lever) or by perturbing the visual stimulus (Bank et al. the visual stepping stones were suddenly shifted either in the direction of the participant or away from the participant). In both cases this resulted in a phase shift between the visual target and the hand movement and the 'recovery time' was assessed as a marker of stability.

C) In Bank et al. the direction of the perturbation varied. Would this also be possible with the setup of Wimmers et al.? Motivate your answer. (**4 points**)

Yes, by suddenly accelerating the arm with the motor instead of arresting it. In this way, a shift is introduced in the relative phase in the opposite direction. (alternatively: Yes, use perturbations in the visual target signal instead of the mechanical perturbations)

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Question 6: Interlimb interactions (10 points)

Three sources of interlimb interactions are assumed to be involved in rhythmic bimanual coordination, namely 1) integrated timing (IT), 2) error correction based on afferent feedback (EC) and 3) phase entrainment by contralateral afference (PE). To study the contribution of these three sources of interlimb interactions to bimanual coordination and pattern stability, several experimental test conditions are required: rhythmic unimanual movements paced by a metronome (UN), unimanual movements paced by a metronome with a passively moved (phase-shifted) contralateral hand as a distracter (UNm), active bimanual movements paced by a metronome (AB), and kinesthetic tracking of a passively moved contralateral hand (KT).

A) Which of these experimental test conditions are required to isolate the contribution of integrated timing (IT)? Explain. What is the outcome measure used to quantify this contribution? Indicate how this outcome measure will change over the selected conditions. **(5 points)**

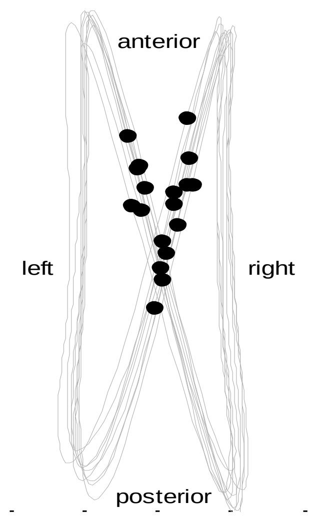
Active bimanual movements (AB) and kinesthetic tracking (KT). Integrated timing (IT) is present in active bimanual movements (AB; next to EC and PE), but not in kinesthetic tracking (KT, only EC and PE are present), which has a positive effect on pattern stability. To quantify the contribution of IT on pattern stability, the standard deviation of the relative phase between both hands is compared between AB and KT. This standard deviation is generally lower for AB than KT.

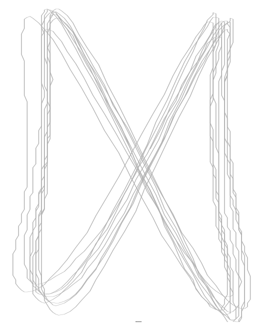
B) Describe how you can experimentally test for phase entrainment (PE) and what outcome measure you would need to quantify the contribution of PE on bimanual coordination? Explain. **(5 points)**

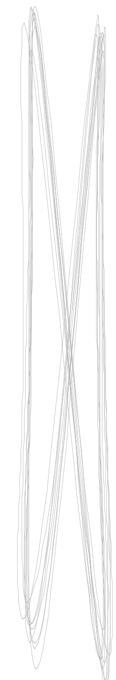
With unimanual movements paced by a metronome with a passively moved, phase shifted contralateral hand as distractor (UNm; here PE is the only present source of interlimb interaction). Compare the relative phase before and after the phase shift between motor and metronome => the unintentional contribution of PE presents itself by a phase shift in the relative phase between the hand and the motor/metronome, such that the relative phase will follow the distracter hand instead of the metronome.

Question 7: Walkograms and metronome beats (10 points)

A person is walking on an instrumented treadmill at his preferred walking speed of 1 m/s. Then a metronome is presented to pace his left and right footfalls with a metronome rate of 120 beats per minute, which corresponds to his preferred cadence. The related walkogram is depicted in the left panel, with metronome onsets indicated by black dots. The other two walkograms reflect conditions in which the same participant was asked to walk with a different step length than preferred, again at a walking speed of 1 m/s.







A) Indicate the beat onsets in the center and right walkogram (assuming that the double support phase lasts equally long for all depicted walkograms). Motivate your answer. (**5 points**)

In the center panel, the participant walks with shorter steps and hence takes more steps per minute than preferred (i.e., fixed speed). In the right panel, the participant takes large steps and hence takes fewer steps per minute than preferred. In Roerdink et al. (2011) the relation between cadence and relative phase shift between heel strike and metronome onsets was described for acoustically paced treadmill walking, showing smaller phase leads with increasing pacing frequencies. Likewise, the black dots should shift in the direction of heel strike (minima in the butterfly) for the center panel and towards the tops for the right butterfly.

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B) Step width differs considerably for the depicted three walkograms. This can be attributed to changes in coordination between the femur, pelvis and thorax. Explain. **(5 points)**

With long steps (right panel) the walkogram is narrower than with short steps (center panel). Huang et al. (2010) showed that stride length is accountable for changes in pelvis-thorax coordination. Specifically, increasing stride length (with lower frequency) led to larger spinal rotations, larger thorax–pelvis relative phase, and lower pelvis–leg relative phase, while the thorax continued to counterrotate with respect to the leg. This means that the pelvis follows the leg movement, a phenomenon known as the pelvis step. This pelvic step helps to lengthen the stride but also results in a narrower stride in that due to the in-phase rotations between pelvis and femur the feet are placed more in front of each other (opposite reasoning for walking with small steps, pelvis counterrotates relative to the femur).

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