Student name : **Student number :**

Coordination Dynamics: Principles and Applications

Model answers

Written closed-book exam 2016-2017

19-12-2016, 8:45–11:00h

WN-F619/637/647

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 pages 9 and 10 provide additional space to answer questions in case the provided space is 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. Dictionaries and calculators are not allowed. **Good luck!**

Reference list course literature

1. Bank PJM, Roerdink M & Peper CE (2011). Comparing the efficacy of metronome beeps and stepping stones to adjust gait: Steps to follow! *Experimental Brain Research* **209**, 159-169.
2. Blikslager & de Poel (in press). Sync or separate? No compelling evidence for unintentional interpersonal coordination between Usain Bolt and Tyson Gay on the 100 m world record race. *Journal of Experimental Psychology: Human Perception & Performance*.
3. Cuijpers LS, Zaal FTJM, & De Poel HJ (2015). Rowing crew coordination dynamics at increasing stroke rates. *PloS ONE* **10**, e0133527
4. Dingwell JB, Cusumano JP (2010). Re-interpreting detrended fluctuation analyses of stride-to-stride variability in human walking. *Gait & Posture* **32**, 348-353.
5. Goldberger AL (2006). Complex systems. *Proceedings of the American Thoracic Society*, **3**, 467-472.
6. Harrison SJ & Richardson MJ (2009). Horsing around: Spontaneous four-legged coordination. *Journal of Motor Behavior* **41**, 519-524.
7. Kelso JA (1995). *Dynamic Patterns: the self-organization of brain and behavior*. A Bradford Book, MIT Press, Cambridge, MA.
   Chapter 1: How nature handles complexity (pp 1-17, except "*Turing instabilities*" and "*Some other dynamic patterns*" sections)
   Chapter 2: Self-organization of behavior (pp 37-67; starting at "*Are actions self-organized? If so: how?*")
   Chapter 3: Self-organization of behavior: first steps of generalization (pp 93-95, Starting at "*Social coordination*")
   Chapter 4: Extending the basic picture: breaking away (pp. 97-110).
8. Kelso JA (2016). On the Self-Organizing Origins of Agency. *Trends in Cognitive Sciences*, **20**, 490-499.
9. Kennedy DM, Wang C, Panzer S, Shea CH (2016). Continuous scanning trials: Transitioning through the attractor landscape. *Neuroscience Letters* **610**, 66-72.
10. McGarry T, de Poel HJ (2016). Interpersonal coordination in competitive sports contests: Racket sports. In: *Interpersonal coordination and performance in social systems*, Eds: Passos P, Davids K, & Chow JY. Routledge, 2016
11. Miura A, Kudo K, Nakazawa K (2013). Action-perception coordination dynamics of whole-body rhythmic movement in stance: a comparison study of street dancers and non-dancers. *Neuroscience Letters* **544**,157-162.
12. Néda Z, Ravasz E, Brechet Y, Vicsek T, Barabási AL (2000). The sound of many hands clapping. *Nature* **403**, 849-850.
13. Oullier O, de Guzman GC, Jantzen KJ, Lagarde J, & Kelso JA (2008). Social coordination dynamics: measuring human bonding. *Social Neuroscience* **3**, 178-192.
14. Peper CE, Van Loon EC, Van de Rijt A, Salverda A, van Kuijk AA (2013). Bimanual training for children with cerebral palsy: exploring the effects of Lissajous-based computer gaming. *Developmental Neurorehabilitation* **16**, 255-265.
15. Pikovsky A, Rosenblum M & Kurths J (2001). *Synchronization: A universal concept in nonlinear sciences.* University Press, Cambridge UK; Chapter 1: Introduction, pp. 1-14
16. Roerdink M, Lamoth CJC, van Kordelaar J, Elich P, Konijnenbelt M, Kwakkel G & Beek PJ (2009). Rhythm perturbations in acoustically-paced treadmill walking after stroke. *Neurorehabilitation and Neural Repair* **23**, 668-678.
17. Roerdink M, Bank PJ, Peper CL, Beek PJ (2011). Walking to the beat of different drums: practical implications for the use of acoustic rhythms in gait rehabilitation. *Gait & Posture* **33**, 690-694.
18. Schöner G, Kelso JA (1988). Dynamic pattern generation in behavioral and neural systems. *Science*, **239**, 1513-1520 (except "*Pattern Generation in Neurobiological Systems*" section).
19. Sparto PJ & Schor RH (2004). Directional Statistics; In Stergiou N. (Ed), *Innovative Analysis of Human Movement*, Human Kinetics, Leeds, UK pp. 123-128.
20. van Ulzen NR, Lamoth CJ, Daffertshofer A, Semin GR, Beek PJ (2010). Stability and variability of acoustically specified coordination patterns while walking side-by-side on a treadmill: does the seagull effect hold? *Neuroscience Letters* **474**, 79-83.
21. Varlet M, Marin L, Capdevielle D, Del-Monte J, Schmidt RC, Salesse RN, Boulenger JP, Bardy BG, Raffard S (2014). Difficulty leading interpersonal coordination: towards an embodied signature of social anxiety disorder. *Frontiers in Behavioral Neuroscience*, **8**, 29.
22. Varlet M, & Richardson MJ (2015). What would be Usain Bolt's 100-meter sprint world record without Tyson Gay? Unintentional interpersonal synchronization between the two sprinters. *Journal of Experimental Psychology: Human Perception & Performance* **41**, 36-41.
23. Varoqui D, Froger J, Lagarde J, Pélissier JY, Bardy BG (2010). Changes in preferred postural patterns following stroke during intentional ankle/hip coordination. *Gait and Posture* **32**, 34-38.
24. Wimmers RH, Beek PJ & van Wieringen PCW (1992). Phase transitions in rhythmic tracking movements: A case of unilateral coupling. *Human Movement Science* **11**, 217-226.

Question 1: Coordination dynamics and the 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 emerge, adapt, persist, and change in natural systems consisting of multiple interacting subsystems.

A) A collective variable may be defined as a variable that characterizes the dynamics of patterns of coordination in systems consisting of multiple interacting subsystems. Describe the time-scale relation between the dynamics of the collective variable and that of the interacting subsystems, and give an example. **[2 points]**

Hallmark feature of coordination dynamics is that the collective variable evolves orders of magnitudes slower than the constituent processes (1 point). Many examples possible; at least the constituent processes and the collective variable should be specified, including a specification of the time-scale separation in the dynamics (1 point).

B) What is the name for an abrupt change from one collective state to another, as induced by scaling an unspecific control parameter? **[1 point]**

Phase transition

The Haken-Kelso-Bunz (HKB) model of coupled oscillators is one of the foundations of coordination dynamics. The potential of the symmetric HKB model and its order parameter dynamics equation were originally defined as $V(\phi) = -a\cos(\phi) - b\cos(2\phi)$ and $\dot{\phi} = -a\sin(\phi) - 2b\sin(2\phi) + \sqrt{Q}\zeta_t$, respectively.

C) The symmetric potential was later modified by adding a parameter in order to deal with asymmetries in intrinsic frequencies of the subsystems. What is the general name for this asymmetry? Also, specify the modified potential function ($V(\phi) = \ldots$). **[2 points]**

The general name for this asymmetry is detuning (1 point)
The potential should be modified as follows: $V(\phi) = -\Delta\omega\phi - a\cos(\phi) - b\cos(2\phi)$

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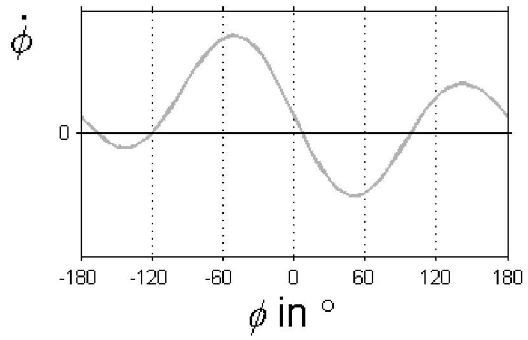
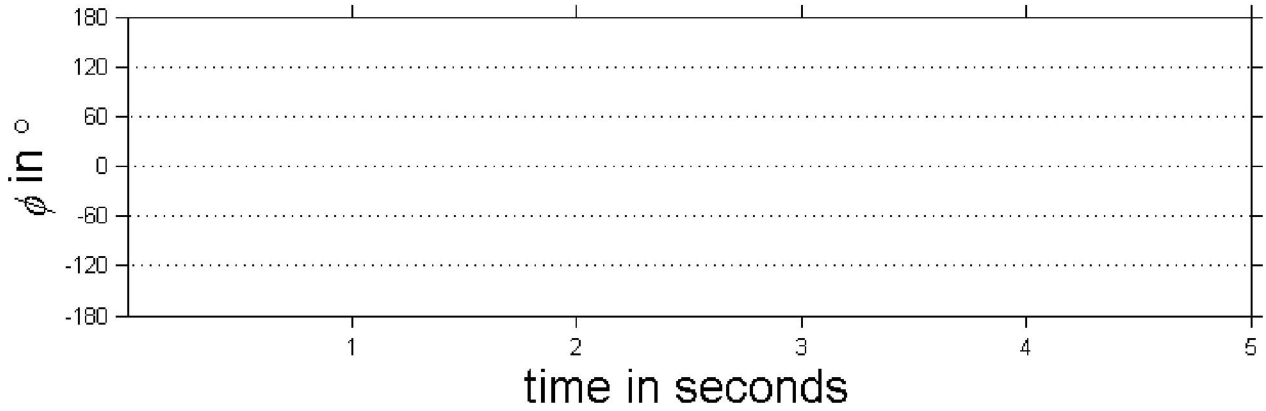
D) In the figure on the right, the order parameter dynamics function is given for a certain parameter setting. Sketch in the figure panel below the time evolution of the order parameter ϕ, starting at $\phi = 120°$ and with Q > 0. **[2 points]**



From 120 to 180 (dphi/dt > 0), then from -180 to about -170 (where dphi/dt = 0 with negative slope). Noisy around -170 because Q>0

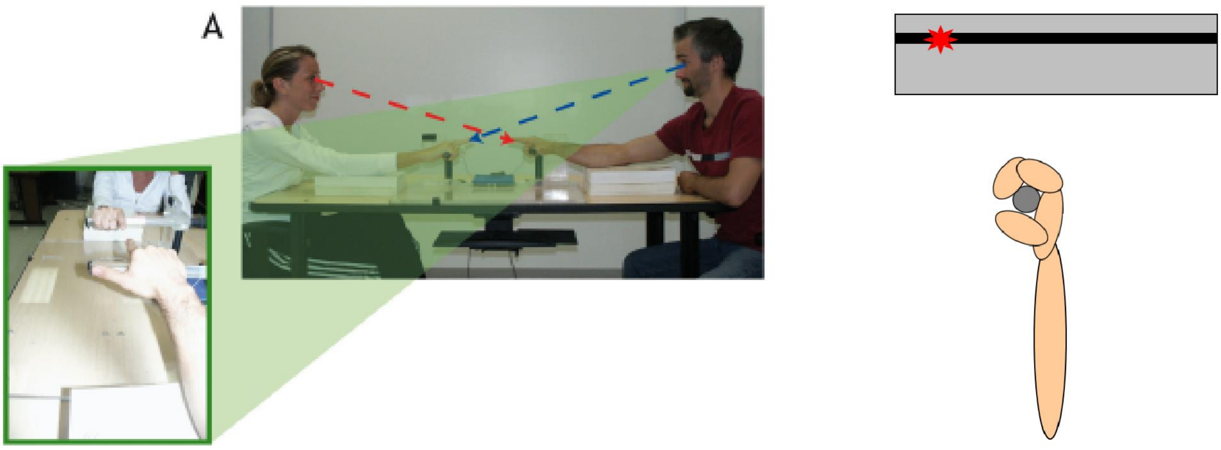


E) With regard to the HKB model, describe the three model-parameter requirements under which we can observe critical fluctuations for in-phase coordination. **[3 points]**

We need a non-zero Q (1 point), a big delta omega (1 point), and we need to scale the b/a ratio to a very low value such that the stable in-phase fixed point disappears (1 point). At and around this vanishing fixed point, fluctuations will grow because the driving force towards phidot is zero vanishes.

Question 2: Sensorimotor coordination (4 points)

We have seen many examples of sensorimotor coordination in this course, mostly auditory-motor and visuomotor coordination. With regard to the latter, we have witnessed an inter-personal finger-wiggling task (see the left panels in the figure below; picture from Oullier et al. 2008) and a tracking task in which participants had to follow a rhythmically oscillating visual stimulus with their hand (as schematically represented in the right part of the figure below; based on Wimmers et al. 1992).



A) These two examples of visuomotor coordination differ in terms of coupling in two regards. Explain. **[2 points]**

The coupling differs in two ways: in directionality and autonomy. In the interpersonal finger wiggling task, both persons can autonomously adjust their tempo and phasing (bidirectional autonomous coupling). In the tracking task with a visual metronome, only the person can adjust, so the coupling is unidirectional and non-autonomous (time dependent).

B) Give an example of an undirected form of auditory-motor coordination that emerges from 'the bottom up'. **[1 point]**

Episodes of synchronized clapping in an audience. No one is in charge (no conductor, director, commander), but synchronized clapping emerges spontaneously (self-organized) from interactions among subsystems (everybody can adjust their tempo and phasing to each other). Neda et al. 2000

C) Define syncopation (in the context of sensorimotor coordination) and give an example. **[1 point]**

Syncopation is to perform a rhythmic action in between rhythmic external events. Example: clap in between the beat.

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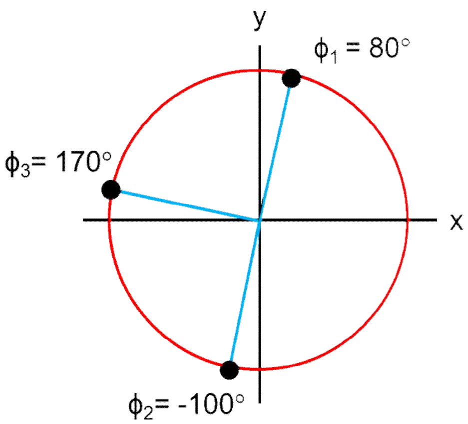
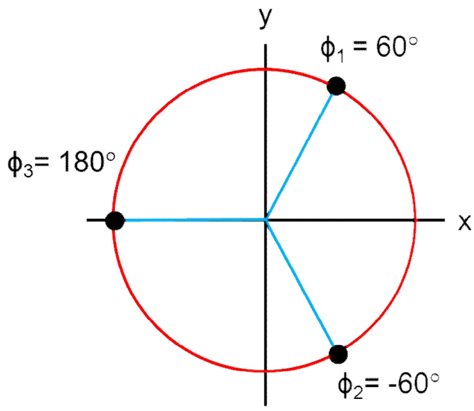
Question 3: Circular statistics and complex variability (7 points)

A) Within the coordination dynamics literature, circular (a.k.a. directional) statistics is often used to quantify the mean relative phase and its variability. In Sparto and Schor (2004) and in the Computer Practicals, circular plots were introduced in which each value of relative phase is plotted in polar coordinates on a unit circle. Typically, a vector is included in this plot to represent the mean relative phase as well as its dispersion. The direction of the vector is a measure of central tendency of the relative phase data ϕ and its length is inversely related to the dispersion of the relative phase data. Determine for the relative phase data ϕ of the two circular plots depicted below the mean vector direction and its length. **[4 points]**

Mean direction: 170° Mean length: 0.33 Mean direction: NaN Mean length: 0





B) The temporal ordering in physiological time series is informative, as shown by Goldberger (2006) in the context of fractal physiology and by Dingwell and Cusumano (2010) in the context of the control processes underlying gait-parameter fluctuations. Explain, on the basis of particular features in such time series, how tightly controlled processes can be identified. **[2 points]**

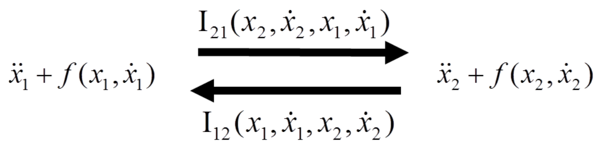
This question refers to long-range correlations in data, of which two types exist: persistent and anti-persistent correlational structure. The latter represents that deviations in a certain direction are statistically more likely to be followed by deviations in the opposite direction, a distinct feature of tightly controlled processes.

C) Relative phase data of stationary bimanual coordination exhibits fluctuations, which is typically quantified by taking the standard deviation of the relative phase time series. Does the temporal ordering of relative phase data points matter in that regard? Briefly explain. **[1 point]**

No, SD of relative phase is a measure quantifying the average squared deviation from the mean value, and hence the temporal ordering of the data points does not matter (is averaged out).

Question 4: Coupling relations (5 points)

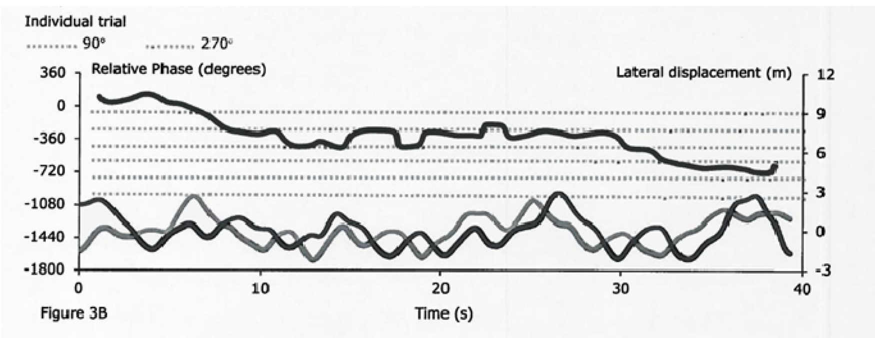
In his guest lecture, Dr. de Poel introduced asymmetric and inverse coupling between two oscillators. He visualized this by modifying the coupling relation I_{12} (the extent to which oscillator 1 is influenced by its own dynamics and by that of oscillator 2) in a system of symmetrically coupled oscillators, as reproduced here on the right.

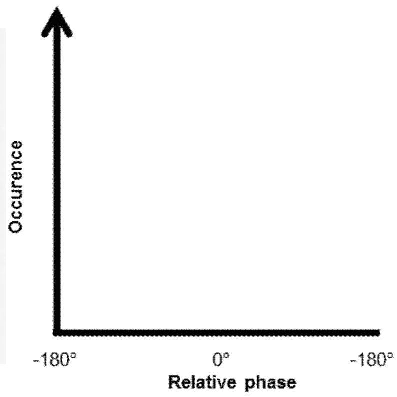


A) Give, in the context of interpersonal coordination, an example of asymmetric coupling. Also, indicate how the coupling relation I_{12} should change to represent asymmetric coupling. **[2 points]**

Many examples possible. For example the horsing around study with mechanical coupling and vision: the front person has a stronger influence on the back person than vice versa. By adding a positive constant c with a value smaller than 1 in front of I_{12} the degree to which oscillator 1 is influenced by oscillator 2 can be scaled.

B) In the left panel of the figure below, copied from McGarry and de Poel (2016), lateral displacement data of two squash players (the lower two time series) are depicted, along with the corresponding relative phase data of the rally (upper time series). Sketch in the right panel the histogram of the relative phase data, name the type of coupling involved, and indicate how the coupling relation I_{12} should be changed to account for such a distribution. **[3 points]**





Histogram has peaks at -90 (=270) and + 90 degrees, suggesting an antagonistic or inverse coupling relation. I12 should be changed by adding negative signs to x_2 and $xdot_2$ to represent this inverse coupling relation (or placing a negative constant c in front of the relation).

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Question 5: Interpersonal coordination (4 points)

In lecture 9, we discussed the manuscript by Varlet et al. (2014) addressing a coordination-dynamics experiment on inter-personal rhythmic pendulum swinging in persons with social anxiety disorder (SAD) and in healthy controls (Control). The figure on the right provides the group results of the intentional coordination conditions for the different pendulum combinations.

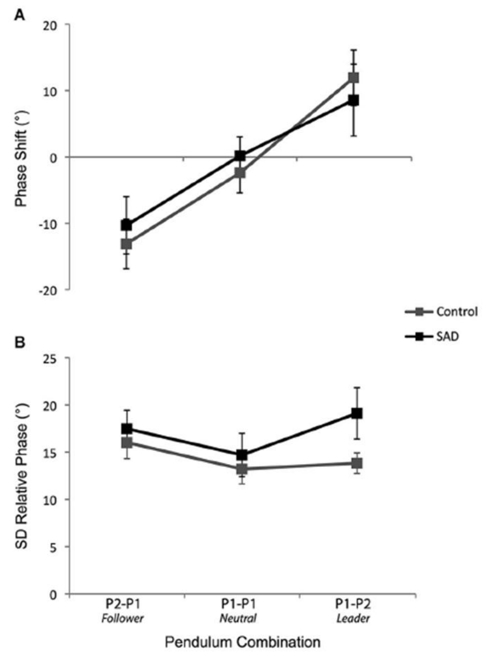


FIGURE 2 | The phase shift from the intended coordination **(A)** and the standard deviation of relative phase **(B)** for the control and SAD groups as a function of the pendulum combination. The error bars represent the standard error of the mean.

A) Describe what is meant with P2-P1 (follower), P1-P1 (neutral) and P1-P2 (leader) pendulum combinations? **[2 points]**

Participants were holding pendulums (P1 or P2), for which the intrinsic frequency varied (frequency P1 < P2). Participants of the two groups were matched with a synchronization partner, with either matching (P1–P1) or dismatching pendulum pairs (P2-P1 and P1-P2). In the P2-P1 condition, the participant had to couple his swinging (P1) to a person with an intrinsically faster frequency (P2); as a consequence the participant has the tendency to follow. Vice versa, for the P1-P2 condition, the participant (P2) is the intrinsically faster oscillator with the tendency to lead over the intrinsically slower oscillator (P1).

B) The authors summarized their findings as follows: "*The results demonstrated that the coordination dynamics were disrupted in the SAD group when the coordination was intended and the SAD participant had to lead the coordination*". Which of the two outcome measures depicted in their Figure 2 (see above) supports this statement? Explain. **[1 point]**

SD relative phase (1 point). As can be seen in Fig 2B, the SAD group had higher SD relative phase than the controls in the P1-P2 (leader) condition (Interaction effect), representing poorer (less stable) coordination (1 point).

C) In addition to intentional coordination, the authors also examined group differences with regard to unintentional coordination. Summarize the group findings in that regard. **[1 point]**

There were no differences between groups, suggesting that unintentional social coordination was not disrupted in the SAD group.

Question 6: Lissajous planes and relative phase (5 points)

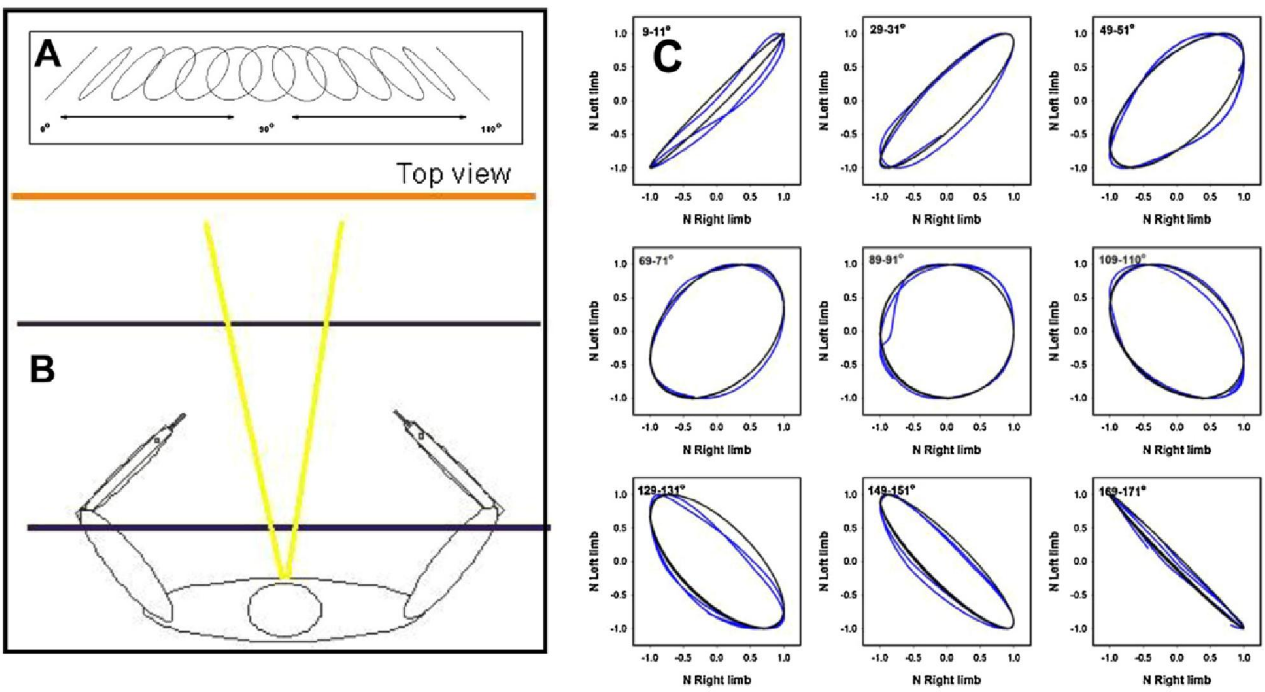
Lissajous planes are efficient ways to visualize coordination patterns, while the mean relative phase is often used to quantify coordination patterns. In the realm of coordination dynamics, both have been used extensively, such as in studies on bimanual coordination and ankle-hip postural coordination.

A) In lectures and computer practicals, two types of relative phase were introduced. Name the two types of relative phase and <u>explain</u> which type corresponds to the following equation, as used by Varlet and Richardson (2015) in their study on unintentional interpersonal synchronization between two sprinters (Bolt, Gay). **[2 points]**

$$\phi = \frac{t_B - t_G}{T_B} \times 360^\circ$$

The two types of relative phase are 1) point estimate of relative phase and 2) continuous relative phase (1 point). This equation deals with a point estimate of relative phase because the time indices of foot contact of Bolt and Gay were used as reference points (1 point).

B) The results of Kennedy et al. (2016) clearly indicated that with direct Lissajous feedback participants can produce a large range of intrinsically unstable interlimb coordination patterns. Draw arrows in the nine Lissajous planes in the figure of Kennedy et al. (2016) below to indicate the direction of evolution, taking into account that the right limb was always leading. **[1 point]**



Counterclockwise for all panels (right is already at its extreme, left arrives at the extreme later)

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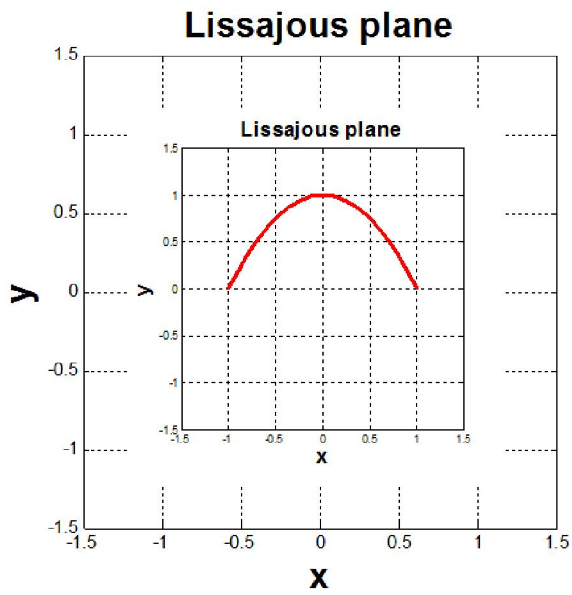
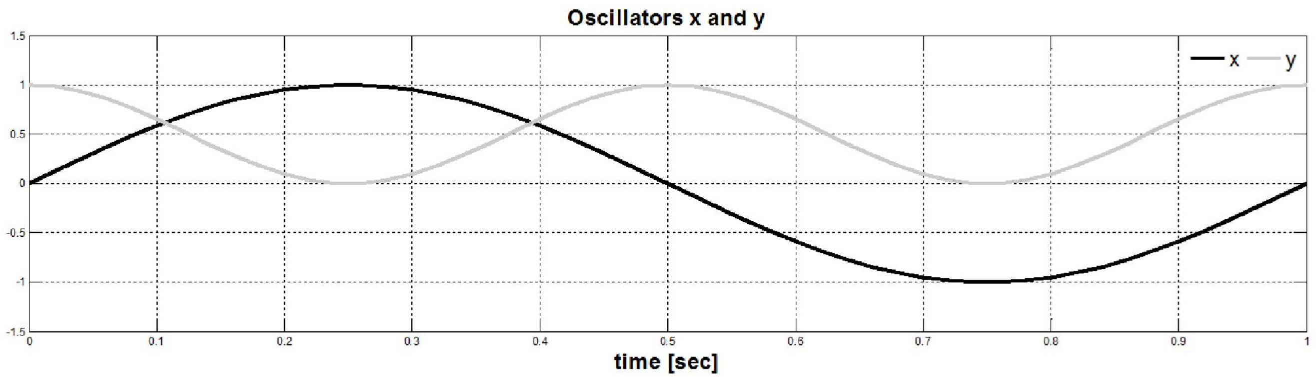
C) In the figure below, positions of oscillators **x** and **y** are depicted as a function of time. Draw the corresponding Lissajous plane in the panel on the right. **[2 points]**





Notes:

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