Coordination dynamics in crew rowing

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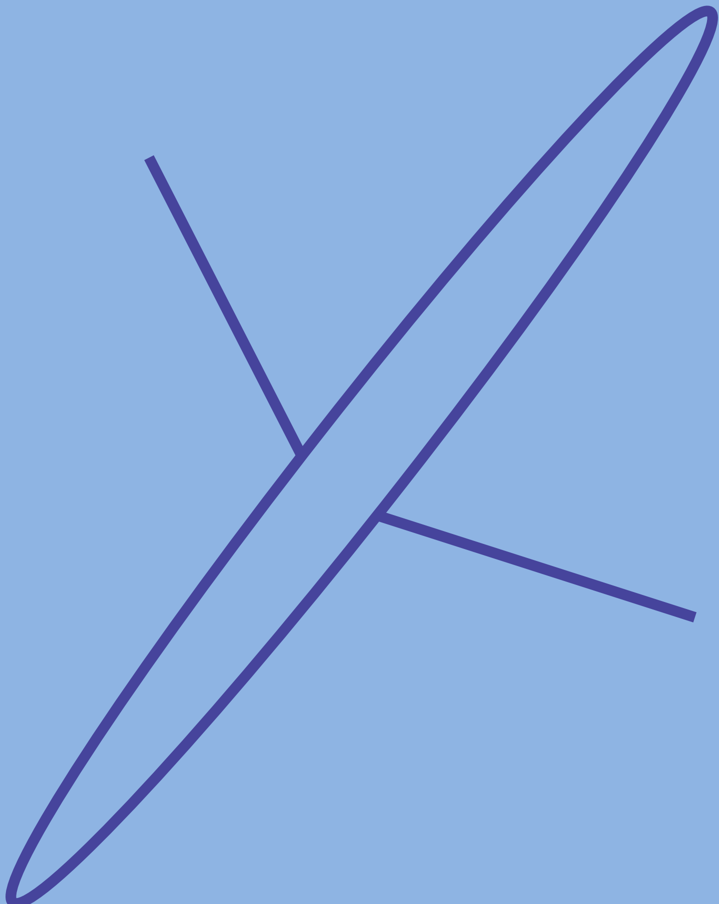
Prologue

Chapter 1



Prologue

I remember the first time I sat in a rowing boat. Trying to maintain my balance in this long and narrow boat, my oars far extended, I noticed that the slightest movement of my hands had a substantial effect on the movements of the boat. At first, it was difficult to maintain balance in a long and narrow boat, pushing off against the blades that also give you stability on the water, let alone levering them above the water during the recover. But after years of training, I became so attuned with my boat that it felt like it had become part of me. I felt how the blades entered the water as if I was touching the water with my hands and despite of ever changing water and wind, I was able to move powerfully and accurately and account for perturbations such as hitting a wave without having to think about it. Later I started rowing with others in a crew, and although this could be a frustrating experience when we were not attuned to each other (being moved around in the boat, perturbed in my motions), I also experienced rowing together with someone else as if we were one. I barely noticed the movements of my partner because our movements were complementing each other perfectly, which felt like the effects of our actions on the boat were amplified. With every stroke, we explored the dynamics of our social-physical system that not only encompassed me and the boat, but also my partner(s) and over many successive strokes it started to feel as if we were all part of the same system.

It is not surprising that crew rowing is often quoted as one of the most expedient examples of team work, joint action and interpersonal coordination. Rowers in a crew are able to coordinate their movements to perfect precision while moving in unison with up to seven others, even when they row at maximum effort and stroke rate. As a spectator, you see one crew, one boat, rather than individual athletes. But how do these individual athletes coordinate their movements with one another? In the case of single scull (individual) rowing, there is one agent that controls the system of rower and boat. In a rowing crew, agency is shared over multiple rowers. There is no hierarchical control, but rather the behaviour of the crew emerges from the interactions of the components (i.e., individual rowers and boat) that constitute the system. An example to illustrate how behaviour in such a system arises can be found in the swirls that emerge in water when boiled in a kettle[1]: the movement of the water emerges both from the individual movements of the molecules that move faster and upwards as they get heatened from the bottom and in return, is the *collective* behaviour of the water molecules that determines the direction of the swirls. As such, the system is self-organising, that is, not dependent on hierarchical control (see e.g., Kelso,

[1] See https://www.youtube.com/watch?v=0xcxumccf8Q&frags=pl,wn

1995). Likewise, the behaviour of the crew emerges from the behaviour of the individual rowers that constitute the crew, and in turn the behaviour of the individual rowers is constrained by the collective behaviour of the crew as a whole. Thus, the behaviour of the crew is self-organising and transcends the individual contributions of the rowers.

As races are often won in margins as close a hundred of a second (O'Brien, 2011), it is evident that simply combining the strongest and most technically skilled rowers is not enough; only a crew that is well attuned to each other can facilitate each other's movements, allowing them to maximize their power output and minimize power losses, so that power is most effectively and efficiently converted into boat speed. As such, it is the behaviour of the crew *as a whole* that determines crew performance. Remarkably, at the start of this research project, scientific studies that focused on crew rowing were rather limited (e.g., Badouin & Hawkins, 2004; De Brouwer, De Poel, & Hofmijster, 2013; Hill, 2002; Hill & Fahrig, 2009; Millar, Oldham, & Renshaw, 2013; Seve, Nordez, Poizat, & Saury, 2011; Wing & Woodburn, 1995). Although since then more studies on crew rowing have appeared (e.g., R'Kiouak, Saury, Durand, & Bourbosson, 2016; Seifert, Lardy, Bourbousson, Adé, Mordez, Thouvarecq, & Saury, 2017; Feigean, R'Kiouak, Bootsma, & Bourbousson, 2017) this is still little in comparison to the body of research that considers individual rowing.

Coordination Dynamics

The example of the water that is boiled in a kettle is a typical example of a dynamical system. In a dynamical system, order emerges from the interactions between the components that constitute the system (hence 'co-oordination'). Synchronisation processes, such as crew rowing, can be modelled as a system of coupled oscillators – which is fitting as a rower repeats the same cyclical movement as well. For synchronisation to arise, the components in a coordinative system need to be coupled, which allows the oscillators to interact with one another and influence each other's movements. In a similar way, the rowers in a crew are coupled, both perceptually (able to perceive each other's movements) and physically (through the boat that they share). As such, a dynamical systems approach, and more specifically, coordination dynamics provides particularly fitting theoretical perspective to study the behaviour of the rowing crew as a whole (Chapter 2).

Haken, Kelso and Bunz (1985) modelled a system of coupled oscillators to capture within-person synchronization processes as observed in Kelso (1984). Kelso observed that when people moved their fingers in in- and antiphase coordination[2], coordinative stability decreased with an increase in movement frequency. At a certain frequency, the antiphase pattern became unstable, resulting in a transition to the still stable in-phase pattern. As this transition was approached, critical fluctuations became apparent, reflected in an increase in variability of relative phase, which signifies the decrease in stability of the coordination pattern (Kelso, Scholz, & Schöner, 1986; Schöner, Haken, & Kelso, 1986). When movement frequency is increased starting in in-phase coordination, no shift towards antiphase occurred, as the system was already in the most stable coordinative state. The dynamics of these observations in Kelso (1984) were captured by the HKB-model, describing the rate of change in relative phase angle ($\dot{\phi}$) between limbs in terms of coupled oscillators (Haken, et al., 1985; Schöner et al., 1986):

$$\dot{\phi} = -a \sin \phi - 2b \sin 2\phi \qquad \text{(Eq. 1.1)}$$

with *a* affecting the attractor strength of in-phase coordination and *b* affecting the attractor strength of both in- and antiphase coordination. People are generally able to stably perform two coordinative modes: in-phase coordination (φ = 0°) and antiphase coordination (φ = 180°). Other coordinative modes are unstable without training (Wilson, Collins, & Bingham, 2005; Kostrubiec, Zanone, Fuchs, & Kelso, 2012; Schöner & Kelso, 1988; Zanone & Kelso, 1992). As such, in- and antiphase coordination may be considered as attractor states of a system, towards which the behaviour of the system is pulled. The attractor strength of both in- and antiphase coordination, is influenced by movement frequency and can be visualised as an attractor landscape with hills that repel, and valleys that attract, certain coordinative states. With an increase in movement frequency, the attractor landscape changes shape: the attraction to in- and antiphase decreases, even more so for antiphase. At a critical frequency, the attractor to antiphase vanishes and the system transitions to the remaining stable in-phase attractor.

It has been shown that coupled oscillator principles not only apply to within- but also to between-person synchronisation processes (e.g., Richardson, Marsh, Isenhower, Goodman, & Schmidt, 2007; Schmidt, Carello, & Turvey, 1990, Schmidt, Bienvenu, Fitzpatrick, & Amazeen, 1998; Schmidt & Richardson, 2008). Laboratory interpersonal tasks demonstrated that when two people are rhythmically coordinating their limbs, they show behavioural phenomena

[2] A coordination pattern (e.g., in- or antiphase) can be expressed by the relative phase (φ) between two rhythmically moving components (Haken et al., 1985). The relative phase indicates the difference in phase (θ) between the rhythmically moving components; a relative phase of 0° indicates no difference in phase and thus perfect synchronisation, while a relative phase of 180° indicates half a cycle difference (i.e., perfect syncopation).

identical to those found in bimanual interlimb coordination, as modelled by the HKB-model (Schmidt & Richardson, 2008). For instance, an experiment in which seated participants were instructed to coordinate their lower legs in in- and antiphase coordination at an increasing frequency (Schmidt, Carello, & Turvey, 1990), showed that the stability of in- and antiphase decreased with movement frequency which at a critical frequency yielded a transition from anti- to in-phase coordination, which is also shown in other laboratory tasks, such as rocking chairs (e.g., Richardson et al., 2007), moving a joystick (e.g., Temporado & Laurent, 2004) and moving fingers rhythmically (e.g., Oullier, De Guzman, Jantzen, Lagarde, & Kelso, 2008). Even without being aware of doing so (i.e., without the explicit instruction to synchronise) people tend to synchronise their movements with each other (Harrison & Richardson, 2009; Schmidt, Fitzpatrick, Caron, & Mergeche, 2011). Participants that were instructed to swing a pendulum back and forth at a comfortable pace while jointly performing a problem-solving task and looking at each other's pendulum movements unintentionally tended to synchronise the swinging of their pendulums in in- and antiphase coordination (Schmidt & O'Brien, 1997). Participants tended to synchronise the rocking of their rocking chair, depending on the perceptual interaction between the participants (Demos, Chaffin, Begosh, Daniels, & Marsh, 2012), even if these rocking chairs have a different eigenfrequency (i.e., preferred movement frequency; Richardson et al., 2007). Together, this demonstrates that the dynamical organising principles as modelled by the HKB-model and extensions thereof transcend within person coordination and extend to social interaction as well, as long as the components (agents) in the (social) system are coupled (i.e., interacting, see Lagarde, 2013).

Crew rowing

Although the generalisability of dynamical organising principles as modelled by the HKB-model to interpersonal coordination is well supported in laboratory tasks (e.g., Richardson et al., 2007; Schmidt et al., 1990; Temprado & Laurent, 2004; Oullier et al., 2008), swinging pendulums and rocking chairs in synchrony remain artificial tasks that are performed in a laboratory environment. An important endeavour would be to test these principles in a naturalistic, real life task, grounded in the natural environment. As crew rowing is a real-life task in which it is *functional*, rather than instructed, to synchronise, it provides an expedient experimental task to study such synchronisation processes further. In the current dissertation, we test crew rowing both in the natural environment on the water (Chapter 3, 6 and 7) and in a more controlled laboratory environment (Chapter 4 and 5), using coupled ergometers on slides to mimic the boat on the water. We aim to test whether dynamical organising principles also hold in natural tasks that are grounded in the environment and for which it is functional to synchronise. The crew rowing task also provides an opportunity to further investigate the effects of coupling between the agents of a social system. In the system of a rowing crew, the rowers are not only perceptually coupled, but also physically through the boat that they share. This means that there is an exchange of forces between the rowers via the boat, much like metronomes that are jointly placed on a moving base[3] (Pantaleone, 2002; see Kapitaniak, Czolczynski, Perlikowski, Stefanski, & Kapitaniak, 2012 for a review). The movements of a metronome set the moving base into motion, and thereby the other metronome as well. Similarly, in the system of a rowing crew, each rower is passively moved by the forces that their crew members apply onto the boat. As such, rowers are not just perceptually (e.g., visually, auditory and haptic/kinaesthetically) coupled, but also mechanically through interaction forces via the boat. While many real life joint action tasks also encompass such force-exchanges between the agents of a social system (e.g., in dance, martial arts, or while moving furniture, see e.g. Lanini, Duburcq, Razavi, Le Goff, IJspeert, 2017; Sofianidis, Elliott, Wing, & Hatzitaki, 2014), most interpersonal coordination dynamics research focuses on perceptual coupling (e.g., Schmidt & Richardson, 2008 and Schmidt et al., 2011), leaving the effect of mechanical coupling relatively unexplored (for notable exceptions, see Harrison & Richardson, 2009 and Marmelat & Delignières, 2012).

In return, coordination dynamics also provides an expedient theoretical framework to further understand the behaviour of a rowing crew, even beyond the conventional in-phase crew coordination (Chapter 2). The interest in the dynamics of different coordination patterns may actually be more relevant for crew rowing than one may initially think. That is, it has been suggested that crew performance may benefit from rowing in an antiphase pattern.

Antiphase crew rowing

Although traditionally crews always row in in-phase coordination, it has been suggested that crews may be able to minimise within cycle velocity fluctuations by rowing in antiphase (e.g., Brearly, DeMestre, & Watson, 1998; Greidanus, Delfos, & Westerweel, 2016). The rowing cycle starts with the placing the blades into the water (the 'catch') after which they propel the boat forward during the drive by applying pressure on the blades. At the end of the drive, the rowers move their blades out of the water (the 'finish') and return to their initial catching position during the recover, while levering the oars above the water. Due to the nature of the rowing cycle, the boat is only propelled forward during half of

[3] An illustration of synchronisation between metronomes can be found here http://www.youtube.com/watch?v = yysnkY4WHyM and here http://www.youtube.com/watch?v = kqFc4wriBvE

the rowing cycle, which causes velocity fluctuations of the boat. By alternating their strokes (and thus propulsive phases), rowers would in theory be able to propel the boat more continuously through the water and minimise power losses due to velocity fluctuations with 5-6% (Hofmijster, Landman, Smidt, & Van Soest, 2007). It has been suggested that for an eight this may result in a gain of more than a boat length on a 2000 *m* race (Brearly et al., 1998). Although over the course of a century, a number of antiphase rowing try-outs were done that were generally regarded successful (see 'Out of phase crew rowing in the past'), it remains unclear whether antiphase rowing indeed works, and, most importantly, *why* it works (or not).

Out of phase crew rowing in the past

Although rowing in antiphase may seem a curious idea, other coordinative patterns than in-phase coordination have been considered in the past. In the 1930's, several experiments were done in England, of which footage[1] is still available. As can be seen in the movie, the crew was divided into four pairs that rowed with a quarter cycle difference from each other. This 'Jazz-rowing', as it was called, was inspired by the four-stroke engine, that is able to produce more power with the pistons moving out of phase. Although the experiments were regarded successful (there were even plans to build a special syncopated boat – which was not realised due to the financial aspect of it, e.g., The Daily News, 1929; Dodd, 2006), they also received a lot of criticism (e.g., Northern Star, 1929; Western Mail, 1929) and finally the experiments were abandoned.

Rumour has it that the Russians also tried the antiphase rowing in the '70's in the Sovjet Union. Although a special boat, the "Dzintars", was built by Latvia in Riga, it was not clear whether the Russians indeed placed the coxswain in the middle to introduce extra space so that the oars would not collide, or that this was simply done to place the center of mass of the coxswain in the middle (Martinova, 2001). When I was visiting Boston, I met Nikolay Kormakov, a former Ukrainian and Sovjet rower (1973-1976) and later coach (1977-1992), who now lives in Boston. At the men's training camp during the rowing season of 1976 in Azerbeidjan (the rowing headquarters at the time), he indeed saw a crew rowing in antiphase in a double scull. Although at the time scientific research was done by the Soviet Rowing Association using a measurement system that could measure boat speed and pressure on the blades and footboard, as far as Kormakov knows, no measurements were done on the antiphase rowing. This is surprising, as they went through the trouble to build a special antiphase boat and given that there was a measurement system available (Cuijpers, 2017).

Conclusions

In the current dissertation, crew rowing is used as an experimental paradigm to gain a deeper understanding of interpersonal synchronisation processes. As crew rowing is a real-life task in which it is functional (and thus meaningful, rather than just instructed) to synchronise movements, it is an expedient experimental task to study interpersonal synchronisation processes. The system of rowers and boat allows for manipulation of different aspects of the system at the level of components (e.g., detuning), the interaction (e.g., coupling strength or modality) and the common level (e.g., different coordination patterns). While the laboratory setup of coupled ergometers (see e.g., Chapter 4) allows more controlled experimentation in the lab, the results obtained in the lab can also be verified in the natural environment on the water. Like many interpersonal tasks, rowing does not only involve perceptual, but also mechanical coupling (i.e., there is a force exchange between the rowers, see Chapter 5).

In return, coordination dynamics (Kelso, 1995) may provide a well-suited theoretical approach to study synchronisation processes in crew rowing, especially given the relevance of coordination dynamics related issues, such as the stability of coordinative patterns, preferred movement frequency and coupling in crew rowing. This may provide a deeper understanding of crew performance, not only for the traditional in-phase, but also for the more experimental antiphase crew coordination. Given the theoretical benefits of rowing in antiphase, it seems worthwhile to study the stability of antiphase crew synchronisation at high movement frequencies and the mediating role of (mechanical) coupling on the stability of antiphase rowing. If the antiphase crew coordination proves to be stable enough at high movement frequencies, this may have major implications for both coordination dynamics and rowing practice. As such, crew rowing as experimental paradigm may provide a deeper understanding of synchronisation processes in coordination dynamics and provide insights for crew rowing practice as well.

Overview of the dissertation

Chapter 2 discusses crew rowing as an archetype for interpersonal coordination, and proposes that the theoretical perspective of coordination dynamics offers expedient tools for analysing crew coordination. Implications from (and for) coordination dynamics for rowing crew coordination are considered such as movement rate, coordinative patterns and switches, individual differences between the rowers (cf., detuning), and coupling.

Chapter 3 addresses the hypothesis that if rowers perfectly synchronize their movements, detrimental boat movements can be minimized, which would result in an optimised conversion of the power that rowers produce into boat speed.

Chapter 4 considers whether increasing stroke rate indeed results in a loss of stability of crew coordination and whether this results in transitions from anti- to in-phase crew coordination.

Chapter 5 proposes that the mechanical coupling through the boat that the rowers share is a rather stringent form of coupling, as the rowers are passively being moved next to the haptic (perceptual) coupling. This is expected to stabilize coordination through an increase in coupling strength.

After promising results from the lab studies in preceding chapters, **Chapter 6** provides a first case study on trying antiphase rowing on-water.

Chapter 7 tests if rowers are able to row in antiphase on the water when trying for the first time and verifies whether rowing in antiphase indeed decreases detrimental movements of the boat and results in faster racing times.

Finally, the implications of these studies for coordination dynamics and crew rowing practice are discussed in **Chapter 7**.