Coordination dynamics in crew rowing

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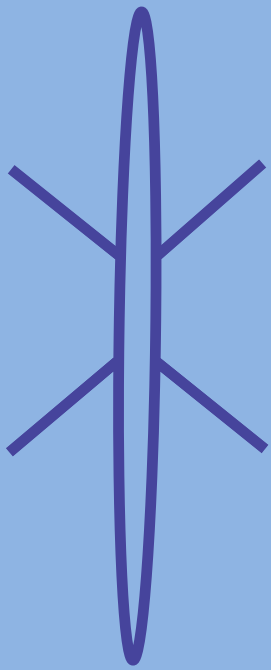
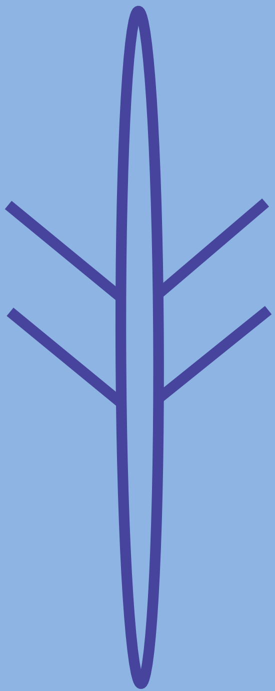
Epilogue

Chapter 8





Epilogue

Crew rowing is a naturalistic task in which it is functional to synchronise, and which is often quoted as the archetypical example of interpersonal coordination and synchronisation processes (e.g., Keller, 2008; Marsh, Richardson, & Schmidt, 2009; Richardson, Marsh, Isenhower, Goodman, & Schmidt, 2007). In the preceding chapters of this dissertation, we used crew rowing as a model task and considered a rowing crew as a system of coupled oscillators to gain a deeper understanding of interpersonal coordination dynamics. The first step was to test crew rowing in the more controlled laboratory situation, using coupled ergometers on slides to mimic the boat on the water. Next, we verified the obtained results in the naturalistic environment on the water, showing that coupled oscillator principles apply to a real-life task outside the laboratory situation. We verified coupled oscillator principles, such as effects of movement frequency, differential pattern stability, breakdowns in coordination and (mechanical) coupling, showing that crew rowing is more than a mere metaphorical example of interpersonal coordination. In return, by considering crew rowing from a coordination dynamics perspective, the obtained results provide insights for crew rowing, both for the traditional in-phase as the more experimental antiphase crew rowing.

Main experimental findings

Before discussing the results of this dissertation more in-depth, a brief overview of the main experimental findings and how these findings fuelled new research questions is given. We started this research project on the water, addressing the general hypothesis held both in science and in practice, namely that if rowers perfectly synchronise their movements in in-phase crew coordination, detrimental boat movements can be minimised, which would result in an optimised conversion of the power that rowers produce into boat speed (Chapter 3). As movement frequency (or stroke rate) was expected to affect both the stability of coordination and movements of the boat, we tested the relation between crew coordination variability and movements of the boat at different stroke rates, varying from 18-34 *spm* (strokes per minute). The results indicated that variability of crew coordination is indeed related to surge velocity fluctuations of the boat for coordination around the catch, but counter to the direction that was expected. That is, less variable crew coordination actually involved more surge velocity fluctuations. In line with expectations, less variable crew coordination was related to less roll, which is indicative of better lateral balance of the boat. The results showed that more stable crew coordination indeed is related to improved lateral balance but also suggested that deviating from perfect

in-phase synchronisation may contribute to less velocity fluctuations of the boat and hence, less hydrodynamic drag.
In the subsequent studies (Chapters 4-7), we therefore also tested antiphase crew coordination, which is less conventional for rowing but a well-studied pattern in coordination dynamics. As most coordination dynamics studies generally show that the stability of coordination decreases with an increase in movement frequency (e.g., Kelso, 1984; Schmidt, Carello, & Turvey, 1990), which in the case of antiphase coordination may yield transitions to in-phase coordination, we tested whether rowers would be able to row in in- and antiphase crew coordination at increasing stroke rates, starting at 30 *spm* and increasing movement frequency until they could not increase stroke rate any further (Chapter 4). We did so in the lab, using an experimental setup of coupled ergometers to reflect the movements of the boat with respect to the water and to mimic the physical connection between rowers via the boat that they share. The results showed rowers were well able to row in antiphase coordination, even at high stroke rates and the less displacement of the ergometer system suggested that the antiphase coordination pattern indeed reduces velocity fluctuations of the boat, compared to in-phase crew coordination.

As clearly shown in the supplementary material video's in Chapter 5, the ergometer system moves back and forth while rowing in in-phase coordination and remains at more or less the same position in space when rowing in antiphase coordination. The observation that if antiphase coordination breaks down, the ergometer system starts oscillating at larger amplitudes (see 'Coordinative breakdown.mp4') led us to question whether the mechanical coupling through the boat (or ergometer system) that the rowers share may perhaps explain the occurrence of coordinative breakdowns as observed in Chapter 4. Therefore, in Chapter 5 we tested crews rowing in in- and antiphase at 20 and 30 *spm* on ergometers with and without mechanical coupling. Although the results showed no significant difference between the with and without mechanical coupling conditions in the occurrence of coordinative breakdowns, the stabilising effect of mechanical coupling was clearly reflected in the lower variability of both in- and antiphase crew coordination in the mechanical compared to the no mechanical coupling condition.

Given the promising results obtained in the lab that showed that rowers are able to row in antiphase, even at high stroke rates as in racing, and given that rowing in antiphase involves less movements of the ergometer system, we set out to test the antiphase rowing on the water. After a promising first case study in Chapter 6 in which the crew was able to perform four 1000 *m* trials in in- and antiphase at 20 and 30 *spm* without breakdowns in coordination, we repeated the experiment with more pairs in Chapter 7. Again, even though it was the very first time these rowers performed the antiphase pattern, they were well able to row in antiphase: all pairs rowed at least one antiphase trial without breaking down coordination. Rowing in antiphase crew coordination indeed reduced velocity fluctuations of the boat, but did not result in faster racing times in comparison to rowing in in-phase crew coordination.

Implications for coordination dynamics

The above-described overview discusses the main experimental findings of the experiments in this research project. In these experiments, we tested predictions based on coupled oscillator models, more specifically, the particularly relevant HKB-model (Haken, Kelso, & Bunz, 1985). In the next paragraphs, the results obtained in this dissertation are discussed more specifically in relation to and in terms of implications for coordination dynamics.

Movement frequency

A general held hypothesis is that the stability of both in- and antiphase coordination decreases with an increase in movement frequency (e.g., Kelso, 1984; Schmidt et al., 1990). Remarkably, the results of our studies did not align with this hypothesis, showing higher coordinative variability at 20 compared to 30 *spm*, for both in- and antiphase crew coordination (Chapter 3, 5-7). Although we initially thought that this effect might have been due to the mechanical coupling between the rowers (see Chapter 5), we found that regardless of whether the rowers were mechanically coupled or not, both patterns were more stable at the higher compared to the lower movement frequency.

At first glance, our finding that coordinative variability was higher at the lower rather than the higher movement frequency may seem contradictory to predictions from the HKB-model. However, they are not. Note that the model predicts that the attractor strength of in-phase (reflected by a and b in Equation 1.1) and antiphase (reflected by b in Equation 1.1) decreases with coupling strength between the oscillators. To account for the observations in Kelso (1984), Haken et al. (1985) proposed that the attractor strength of both in- and antiphase decreases with movement frequency, with antiphase stability decreasing faster than in-phase stability. Hence, $\frac{b}{a}$ reflects the change in differential pattern stability (i.e., the difference in stability between in- and antiphase). The proposed assumption was well supported by experimental studies for both intra- and interpersonal coordination (e.g., Schmidt et al., 1990), albeit for a limited range of movement frequencies. Hence, the observations that coordinative stability decreases with an increase in movement frequency does not necessarily extrapolate to movement frequencies beyond that experimentally tested frequency range. Indeed, an interpersonal pendulum swinging experiment, in which participants had to synchronise the swinging of their pendula at a range of

.6 to 2 *Hz* showed that coordinative variability increased above, but also *below* 1 *Hz* (Schmidt, Bienvenu, Fitzpatrick, & Amazeen, 1998; for bimanual coordination see also Monno, Temprado, Zanone, & Laurent, 2002). This suggests that at lower movement frequencies, coupling strength (and, hence, attractor strengths) may actually increase with an increase in movement frequency. Although this hypothesis needs to be tested further, the experimental findings observed in this dissertation (considering movement frequencies between .3 - .6 *Hz*, i.e., 18-36 *spm*) provide an initial support to investigate the evolvement of attractor strength over movement frequency over a broader frequency range further and in other tasks.

Interestingly, the movement frequency in the study of Schmidt et al. (1998) at which coordination was most stable was close to the eigenfrequencies (the natural oscillation frequency) of the pendula that the participants were swinging. This suggests that coordinative stability may be related to the eigenfrequency of the components that constitute the system, even if that component is not an agent/passive (e.g., Treffner & Turvey, 1996; Schmidt & Richardson, 2008). The system of a rowing crew consists of relatively high inertia components in comparison to other coordination dynamics tasks and not only includes two agents, but also a boat with its own inertial characteristics. Possibly, characteristics such as the rigging settings of the boat (i.e., the length of the oars may be adjusted to change the lever of the oars) may influence coordinative stability like the eigenfrequencies of the pendula in Schmidt et al. (1998). In the laboratory set up, a higher resistance of the flywheels implies that rowers may need more time to move through the drive phase given a fixed power output. Alternatively, they can maintain the same drive duration by increasing power output to overcome the higher resistance of the ergometer flywheels (or the oars on water). Moreover, although rowers are able to move at a range of movement frequencies, research of Sparrow, Hughes, Russell, and Le Rossignol (1999) suggested that rowers may possess an individual preferred stroke rate for a given power output. Rowers can produce that given output also at stroke rates above and below their preferred stroke rate, but this leads to an increase in metabolic cost. As such, crew rowing may provide an interesting experimental task to study the effects of component characteristics in relation to coordinative stability, as the task allows manipulations of the characteristics of the boat/ergometer system (e.g., through rigger and flywheel settings), but also by manipulating power output (e.g., constraining compensatory strategies by fixating power output).

Differential pattern stability

An empirically established prediction of the HKB-model is the intrinsically higher stability of in-phase compared to antiphase coordination (Haken et al., 1985). Indeed, we found that breakdowns in crew coordination, reflecting a loss of stability in the system, only occurred in the antiphase pattern (Chapters 4, 5 and 7). As previously discussed in these chapters, the intrinsically higher stability of the in-phase pattern may also be attributed to the extensive experience of the rowers rowing in in-phase (and not in antiphase).

The HKB-model holds that with a decrease in $\frac{b}{a}$ (Equation 1.1), the *difference between* the in- and antiphase attractor strengths increases. Thus, as the attractor strength of in-phase coordination is affected by both *a* and *b*, while the attractor strength of antiphase coordination is only affected by *b*, this implies that the stability of the antiphase pattern decreases faster than the in-phase pattern (Haken et al., 1985; Fuchs & Jirsa, 2008). Experimentally, this is reflected in the decrease in both in- and antiphase coordination with an increase in movement frequency, until in-phase is the only remaining stable pattern (hence, the observed transitions from anti- to in-phase at a critical movement frequency; e.g., Kelso, 1984; Schmidt et al., 1990). This suggests that an increase in coupling strength (increasing attractor strengths) relates to a decrease in differential pattern stability. Simply put: as in- and antiphase become more stable, the difference in stability between the two patterns decreases (Haken et al., 1985). As discussed in the previous paragraph on movement frequency, we found a higher variability of in- and antiphase crew coordination at the lower compared to the higher movement frequencies, which suggests that coupling strength increases with movement frequency for the range of frequencies (.33 vs. .5 *Hz*, corresponding to 20 vs. 30 *spm*) that we tested in Chapters 4 - 7. In line, we found that the differential pattern stability was larger at the lower compared to the higher movement frequency, supporting the prediction that differential pattern stability decrease with coupling strength, as in crew rowing. Hence, our findings confirm that natural, functional synchronisation tasks like crew rowing abide by coupled oscillators dynamics.

Breakdowns in coordination

A typical feature of the system's loss of stability in the HKB-model is the occurrence of transitions, which in most coordination dynamics studies happened at a critical frequency at which the antiphase pattern became unstable, causing the system to transition to the remaining stable in-phase pattern (e.g., Kelso, 1984; Schmidt et al., 1990). In order for such a clean change from one coordination pattern to the next to occur (and not to return back to the previous pattern), it is critical that the participants are instructed to "not resist if they would feel they would slip into another pattern” (e.g., see Kelso, 1984, 1995; Schmidt et al., 1990; Lee, Blandin, & Proteau, 1996). In the experimental studies (Chapters 4-7) that also considered the antiphase pattern, we specifically instructed participants to return to the instructed pattern if they were slipping out of the instructed pattern. This may explain why the ‘transitions’ that occurred in the present study resulted in a temporary change of the antiphase pattern, after which the rowers tried (and were often able) to restore their antiphase coordination. We quantified these short deviations from the instructed pattern as coordinative breakdowns.

The breakdowns in coordination did not seem related to a movement frequency-induced loss of stability (Chapters 4, 5, and 7). Rather, the occurrence of coordinative breakdowns seemed to be following perturbations, such as hitting a wave with the blade or a temporary loss of attention. Regarding the latter, various studies have shown that the degree of attention devoted to the movements of the other agent affects the stability of coordination for both inter- and intrapersonal coordination (e.g., Richardson et al., 2007; Temprado & Laurent, 2004). Although the coupling may remain relatively stable for a certain task or situation (e.g., the movements of the rower in front remain visible over the course of a race), the degree to which agents attend to the perceptual coupling may change, e.g., depending on other attentional demands, such as steering the boat in the crew rowing task. Note that the mechanical coupling seems a more stringent form of coupling, in that the rowers are moved by the force exchange, regardless of whether they attend to the mechanical coupling or not (Chapter 5). This makes crew rowing an interesting task to study the effects of attention on coordinative stability, also to verify whether the breakdowns in coordination observed in this dissertation indeed result from perturbations such as temporary loss of attention. Given the intrinsically lower stability of the pattern, antiphase coordination remains more prone to such perturbations, which is indeed supported by the observation that coordinative breakdowns only occurred in antiphase crew coordination.

Interpersonal coupling

Instigated by the observation that the ergometer system starts oscillating at larger amplitude once the crew breaks down from antiphase coordination (Chapter 4), we tested the effect of mechanical coupling on the occurrence of coordinative breakdowns and the stability of crew coordination. Given the prediction from coupled oscillator models that an increase in coupling strength stabilises coordination (e.g., Fuchs & Jirsa, 2008), we expected that the stringent nature of mechanical coupling (i.e., agents are passively moved by the other agent(s) in the system) in addition to the perceptual coupling (such as seeing the movements of the stroke rower and hearing the sounds of the ergometer flywheels) may strengthen the coupling between the rowers in comparison to perceptual coupling alone. As such, we hypothesised that the additional mechanical coupling possibly stabilises crew coordination to such a degree that breakdowns in coordination (following a decrease in stability) are prevented. Although the occurrence of coordinative breakdowns was not statistically affected by whether the rowers were mechanically connected or not[18], the results clearly showed the stabilizing effect of mechanical coupling on in- and especially on antiphase crew coordination (Chapter 5). The latter suggests that mechanical coupling may have a larger stabilising effect on antiphase than on in-phase coordination, which may be so as antiphase is intrinsically less stable than in-phase (simply put: there may be a larger potency to enhance stability of a pattern when it is less stable). Thus, the mechanical coupling through the boat that the rowers share may contribute to the observed decrease in differential pattern stability as well.

As mentioned in Chapter 5, the effect of the mechanical coupling is dependent on the mechanical configuration of the task (see Kapitaniak, Czolczynski, Perlikowski, Stefanski, & Kapitaniak, 2012). Given that many interpersonal coordination tasks, such as moving furniture together, dance, and martial arts (e.g., see Lanini, Duburcq, Razavi, Le Goff, IJspeert, 2017; Sofianidis, Elliott, Wing, & Hatzitaki, 2014) involve mechanical coupling, while not many interpersonal coordination dynamics studies considered the effects of mechanical coupling on coordinative performance (for notable exceptions, see Harrison & Richardson, 2009 and Marmelat & Delignières, 2012), the current dissertation provides a first step in gaining insight into the effects of mechanical coupling, showing a stabilising effect on coordination for this particular task and mechanical configuration. Next to further investigating the effects of mechanical coupling in other interpersonal tasks, the ergometer setup in our experiments provide more possibilities to further explore effects of mechanical configurations within the rowing task, for instance using servo-motors that may act as dampers affecting the force-exchange between the rowers (see De Brouwer, De Poel, & Hofmijster, 2013). To illustrate, ergometers that are fixated to the ground can be considered to have ‘maximum’ damping, allowing no force exchange between the ergometers. As such, changing the degree to which the ergometers can move with respect to the ground may provide more detailed insight into the effects of mechanical coupling on interpersonal coordination dynamics (similar to what is already shown in mechanically coupled non-biological systems, see Kapitaniak et al., 2012 for a review).

[18] Seven antiphase breakdowns without mechanical coupling and four with mechanical coupling were observed in Chapter 5. Although this difference was not statistically significant, this may also have been a matter of statistical power.

Implications for crew rowing

The above-described aspects illustrate the expediency of crew rowing as a model task to provide a deeper understanding of interpersonal coordination dynamics. Next to insights relevant for coordination dynamics, the obtained results in this dissertation also provide insights for crew rowing, both for the traditional in-phase as the more experimental antiphase crew rowing. Considering the rowing crew as one coordinative system, we tested crew performance in the more controlled laboratory setting and verified the obtained results in the natural setting in which crew rowing takes place: on the water.

In-phase crew rowing

Both in science and in practice (e.g., O'Brien, 2011; Wing & Woodburn, 1995), the general idea is that if rowers move perfectly in sync, they can minimise detrimental movements of the boat, such as heave, roll, pitch and, most importantly, surge velocity fluctuations. Minimising these boat movements would result in an optimised conversion of the power that the rowers produce into forward speed and, evidently, faster racing times. In Chapter 3 we aimed to address this hypothesis directly, measuring 15 pairs rowing at various stroke rates on the water in a double scull. We found that the consistency of crew coordination was lower for 18-26 *spm* compared to 26-30 *spm*. Inspired by coordination dynamics, we quantified the degree of crew synchronisation in terms of relative phase, taking cycle duration into account, whereas most crew rowing studies consider crew synchronisation in units of absolute time (e.g., Hill, 2002). Although the decrease in difference between the rowers around the catch and finish in terms of absolute timing indeed suggested that rowers became more accurate with an increase in stroke rate, measures in terms of relative phase showed that coordinative accuracy increase with stroke rate for the catch, but actually decreased for the finish. This endorses the importance of taking cycle duration into account when compared over different stroke rates.

Further, the findings on coordinative accuracy suggests that rowers primarily use the catch as an anchor point (a specific point within the cycle at which the control of the movement is based; e.g., Beek, 1989) to stabilise crew coordination, especially at higher stroke rates. While both the catch and the finish are clear distinct points in the movement cycle, it may be easier to accurately time the catch than the finish. Hypothetically, a rower can catch at any moment as the blades move freely above the water during the recover, while the finish is preceded by the drive phase at which the blades are more constrained in the water. With an increase in stroke rate, surge, heave and pitch increased, while roll was not affected by stroke rate. Most importantly, we found that lower variability of crew coordination (i.e., closer to perfect synchronisation) was actually related to *more* surge, heave and pitch, while pitch (reflecting lateral balance) was indeed related to less variability of crew coordination. Thus, the strive to row in perfect in-phase synchrony may benefit crew performance by enhancing lateral balance (and potentially facilitate power production, see Chapter 3), but not necessarily by minimising drag-increasing surge velocity fluctuations of the boat as often assumed (see e.g., O'Brien, 2011; Wing & Woodburn, 1995).

The lower variability in in-phase crew coordination when the rowers are rowing at mechanically coupled ergometers vs. at separate ergometers in the lab (Chapter 5) suggests that the mechanical coupling between rowers is important to take into account when replacing on-water crew practice with training on the ergometer. More broadly, this finding endorses the idea that people pick up task-relevant information from the environment (Gibson, 1979/1986). To illustrate this point, practising crew synchronisation on ergometers that are placed next to each other instead of behind each other may facilitate rowers to synchronise with their opponents in the lane next to them, instead of their crew member(s) seated behind or in front of them. Thus, the more consistent crew coordination when rowers are rowing on mechanically coupled in comparison to separately moving ergometers, stresses the importance of taking the (constraints of) the task seriously in practice. A similar principle holds for selecting rowers in a crew; as emphasised throughout this dissertation, it is not the sum of the individual rowers, but the collective behaviour of the crew as a whole that determines crew performance (e.g., Chapter 2). Although individual testing on ergometers may provide insights into individual power production, it does not directly inform about rowing efficiency on water (e.g., Hofmijster, Van Soest, & De Koning, 2008; Lamb, 1989), let alone on the ability to row well with others in a crew. Fortunately, in the last few years measurement systems to measure crew coordination on-water become more available (e.g., the *Powerline* system of Peach Innovations, Cambridge, UK; see e.g., Sève, Nordez, Poizat, & Saury, 2011 – although measuring power production on the water remains challenging, see e.g., Hofmijster, Lintmeijer, Beek, & Van Soest, 2018), which may enable coaches to select and monitor crew rowers in the natural environment on the water.

Antiphase crew coordination

In the current dissertation, we tested rowing in antiphase coordination experimentally, both in the lab and on the water. The theoretical idea behind rowing in antiphase is that if rowers alternate their strokes, velocity fluctuations of the boat are minimised, which may reduce power losses due to hydrodynamics drag with 5-6% (Brearly, DeMestre, & Watson, 1998; Greidanus, Delfos, & Westerweel, 2016; Hill & Fahrig, 2009; Hofmijster, Landman, Smidt, & Van Soest, 2007), which suggests that rowing in antiphase may reduce race times compared to the traditional in-phase rowing (Brearly et al., 1998).

Rowers, who never rowed in antiphase coordination before, were able to row in antiphase without problems, both in the lab and on the water, at various stroke rates (Chapters 4-7). An interesting next step would be to study the evolution of coordinative stability both in the well trained in-phase as in the new antiphase coordination pattern, to see, e.g., whether practising the new antiphase pattern also improves the well trained in-phase pattern, as practising movements in different movement patterns may improve motor performance (see e.g., Frank, Michelbrink, Beckmann, & Schöllhorn, 2008). An interesting additional endeavour might be to train novice rowers in in- and antiphase and study the evolvement of both coordination patterns with practice. As such, the crew rowing task may be a suitable task to study motor learning of a new pattern and the degree of transfer from one pattern to the next.

Both in the lab and on the water, we verified that rowing in antiphase indeed reduces velocity fluctuations of the boat (or in the case of the laboratory setup, movements of the ergometer system; Chapters 4-7). While surge velocity fluctuations for in-phase rowing clearly increased with stroke rate, for antiphase surge velocity fluctuations were lower at 30 compared to 20 *spm*. Although in the experiments in the current dissertation, the reduction in velocity fluctuations while rowing in antiphase did not result in faster racing times compared to in-phase rowing, one pair (World Cup level) managed to row only 4 *s* slower in anti- compared to in-phase coordination at 30 *spm*, which is a very small difference, given that this is the very first time for them to row in antiphase (Chapter 7). Given the promising first indications from this dissertation, it seems worthwhile to study the potential benefits of antiphase rowing further. Possibly, antiphase rowing may be improved through practice and optimisation of antiphase rowing technique, as well as through the optimisation of rigging and design of the boat. More insight into the biomechanics of antiphase rowing, such as into the difference in hydrodynamics around the blades and the change in air resistance in comparison to in-phase rowing may contribute to find out if rowing in antiphase can be truly faster than rowing in in-phase (or not). Regardless of the latter, researching antiphase rowing may also contribute to a better understanding of in-phase rowing, both in science and in practice.

Conclusions

The current dissertation considered crew rowing from a coordination dynamics perspective, providing a first step in verifying and testing coupled oscillator principles in a naturalistic task to provide a deeper understanding of interpersonal coordination dynamics. The results indicate that predictions from coupled oscillator models and more specifically the HKB-model apply to crew rowing, both in the lab and on the water.

The higher observed differential pattern stability and findings that in- and antiphase crew coordination are more variable at 20 compared to 30 *spm* both suggest that in the crew rowing task and for the range of movement frequencies that we tested, an increase in movement frequency involves enhanced attractor strengths, while the difference between in- and antiphase stability diminishes. As such, the results provide an initial incentive to further investigate the evolution of attractor strength over a broader frequency range and in other tasks. The lower variability in both in- and antiphase crew coordination with in comparison to without mechanical coupling, are indicative of the potential stabilising effect of mechanical coupling in other interpersonal coordination dynamics tasks and provide an incentive to further study interpersonal tasks that involve mechanical coupling (such as dance, martial arts and moving furniture). The finding that coordinative breakdowns only occurred in antiphase and the suggestion that these breakdowns were following from temporary perturbations, such as a loss of attention instead of a frequency-induced loss of stability, needs to be investigated further, e.g., through the use of a dual-task, for which crew rowing seems to be a suitable task, given the possibility to study the effect on attention alongside manipulations in coupling (e.g., in relation to the stabilising effect of mechanical coupling). Together, this dissertation provides a first step in taking crew rowing from a mere metaphorical example to a model task to study interpersonal coordination dynamics processes, and its suitability for testing coupled oscillator predictions though experimentation, both in the lab and on-water. The current dissertation offers incentives for further research in interpersonal coordination, more specifically on the role of attention and perturbations, manipulations of interaction sources (mechanical coupling in particular) and preferred movement frequencies, also in social systems larger than two agents (e.g., Zhang, Kelso, & Tognoli, 2018), for instance crews of four or eight rowers (e.g. Hill & Fahrig, 2009; Wing & Woodburn, 1995).

In return, the obtained results provide insights for the traditional in-phase as the more experimental antiphase crew rowing, showing the importance of taking cycle duration and task constraints into account when quantifying and practicing crew synchronisation. The findings endorse the importance of considering the crew as one coordinative system, both in science as in crew rowing practice. Given the promising first indications from this dissertation, it seems worthwhile to study the potential benefits of antiphase rowing further, regardless of whether rowing in antiphase ultimately proves to be faster or not: researching antiphase rowing may also contribute to a better understanding of in-phase rowing, both in science and in practice.