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Case report

Coordination between Crew Members on Flying Multihulls: A Case Study on a Nacra 17

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Abstract
A current trend in sailing sports is the use of boats equipped with hydrofoils, allowing the boats to "fly" over the water surface. In this situation, the handling of the boat requires fine coordination between the crew members to maintain the precarious flight. The purpose of this case study was to analyze the crew activity on a flying multihull and explore the role of the shared sport equipment in the emergence of coordination between crew members. Data were collected during a training session with a crew of expert sailors. A joint analysis of phenomenological and mechanical data was conducted. The aim of the analysis was to categorize the forms of interactions between crew members, boat and environment. Results showed that collective coordination in the studied situation involves six forms of interaction that are associated with stable, unstable or critical states of the flight. Consequently, we discussed the role played by the crew members, the behavior of the boat and the environment in the collective coordination.

Key words: Interpersonal coordination, joint action, course of experience, cognition, water sports.

Introduction

In the last decade, collective coordination in sports has been studied from the perspectives of three main theoretical approaches: the social-cognitive approach, the ecological dynamics approach, and the enactive approach (Araújo and Bourbousson, 2016). Most of the studies referring to these approaches mainly focused on cognitive, behavioral and phenomenological dimensions of the coordination between teammates. By doing so, they underestimated the role of the relations between the system composed of the teammates interacting with a shared sport equipment, and the natural environment of that system. In the present study, we referred to sport equipment as the equipment required for engaging in a sport. In contrast, we referred to the natural environment as the surrounding environment of the athletes-sport equipment system. We referred to "shared" sport equipment when both athletes' bodies are in contact with a same piece of equipment. For example, we considered a boat as a shared sport equipment in sailing, whereas we would not consider a racket as a shared sport equipment in double tennis.

Recently, some authors encouraged the consideration of the role of sport equipment, and more particularly when this equipment is shared and "sensible" to the athletes activity (i.e., when each athlete's activity affects the shared sport equipment) (Millar et al., 2013; R'Kiouak et al., 2016). This is for example the case of a rowing boat that is highly affected by every movements of each rower. In contrast, a soccer field has a limited sensibility to athletes' activity, even though the grass keeps traces of some of the players actions. The aim of the present study was to pursue the exploration of the role of the shared sport equipment in the production of collective coordination in sports. We focused specifically on the study of collective coordination within crews of flying multihull sailboats (i.e., multihulls equipped with hydrofoils). This choice was guided by the fact that the flying boat is a shared sport equipment highly sensible to the crew members movements. Furthermore, wind shifts and water movements also affect speed and balance of the flying boat, constantly challenging the flight. Flying boats can be distinguished from non-flying boats by the capacity of reaching and maintaining a precarious dynamic equilibrium with only a set of appendages (the hydrofoils) remaining in contact with the water (Binns et al., 2017; Heppel, 2015). Because of these singular characteristics of flying multihulls, this situation is particularly relevant to explore interactions between crew members and their shared sport equipment (i.e., the boat equipped with hydrofoils). Indeed, the dynamic behavior of the boat under changing physical environmental constraints requires ongoing individual and collective adjustments of the crew members to maintain flight.

The role of the sport equipment in the explanations of collective coordination in sports

In the domain of sport psychology, the role attributed to sport equipment in collective coordination varies depending on the theoretical assumptions that grounded the studies.

From the social-cognitive perspective, the performance of a team relies on the capacity of each team member to know what his or her teammates are going to do and when they will do it (Eccles and Tenenbaum, 2004). Researchers have studied *shared mental models* (Cannon-Bowers et al., 1993; Eccles and Tenenbaum, 2004) and *team situation awareness* (Cooke et al., 2004). In these approaches, collective coordination relies on each team members knowledge: research on shared mental model primarily focuses on long term team knowledge and research on team situation awareness focuses more on the dynamic aspect of the team's situational knowledge (Cooke et al., 2004). A lack of shared knowledge could lead to weak coordination and reduce the team's ability to adapt to changing environmental demands (Cannon-Bowers et al., 1993). For example, Lausic et al., (2009) speculated in a study on female tennis double teams that winning teams could be

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more attuned to court conditions, such as wind and the speed of the court surface. In this social-cognitive approach, the environment (including sport equipment) is thus essentially considered as an "inert" source of perceptual cues, that can be shared (or not) by the teammates to coordinate one another.

Compared to the previous perspective, the ecological dynamics framework emphasizes more on the role played by the environment (including sport equipment) in collective coordination. This framework articulates key concepts from ecological psychology and non-linear dynamical system theory (Seifert and Davids, 2017). On the one hand, the ecological psychology approach highlights on the continuous coupling of perception and action for individuals. Therefore, in this approach perception is not necessarily mediated by prior knowledge about the world but there is a direct perception, for each individual, of opportunities for action offered by the environment, i.e., affordances (Gibson, 1979). On the other hand, non-linear dynamical system theory provides a conceptual framework for studying self-organization of complex systems and the emergence of coordination tendencies at individual and collective levels (Seifert and Davids, 2017). Studying cooperative social actions, Marsh, Richardson and Schmidt (2009) consider it valid "to conceptualize two people coming together in a 'joint perception-action system' as a new entity with new abilities" (Marsh et al., 2009, p.326). Within this approach, investigations in rowing (Seifert et al., 2017) showed that the behavior of the boat (i.e., changes of the boat velocity) were associated with destabilized collective coordination. Furthermore, the understanding of collective coordination in sports within this approach, takes into consideration not only what the other team members think or know, but also the perception of other actors' affordances. This includes the perception of what actions another actor can provide under a given set of environmental conditions (i.e., affordances for others) and what actions of another actor afford a perceiver (i.e., affordances of others). For example, a ball carrier who perceives a closing gap between defenders, or between a defender and the sideline, is actually detecting a negative affordance for going forward (Silva et al., 2013). Other studies in rowing showed an original way to perform a collective task, highlighting the mediating role of the shared sport equipment in collective coordination. A qualitative study of expert rowers (Millar et al., 2013) showed that collective coordination in pair rowing boats is supported by the perception of the boat's behavior. They have called this type of coordination "extra-personal coordination". These results point out that collective coordination is linked to situational constraints and highlight the role of the sport equipment (including shared sport equipment) in triggering opportunities for joint action. Thus, from the ecological dynamics' perspective, shared sport equipment plays an active role by circumscribing the opportunities for individual and collective actions.

More recently, R'Kiouak et al. (2016) studied the mediation of a shared sport equipment in crew coordination between rowers, beyond the study of Millar et al. (2013). This research was conducted within the "course of action" framework, rooted in an enactive approach of cognition.

This approach considers cognition as an enacted property of the history of the structural coupling of an autonomous organism with its environment (Maturana and Varela 1987). This coupling is asymmetrical in the sense that the autonomous organism regulates its interactions with the world, transforming the world into a place of salience, meaning and value through a "sense-making" activity (Thompson and Stapleton, 2009). In this approach, human coordination emerges from interactions between actors, these interactions affecting individual sense making activity (De Jaegher and Di Paolo, 2007). The enactive approach differs from the previous one by putting emphasis on the study of lived subjective experience to understand human activity (Shear and Varela, 1999). The results showed that rowers were in synch for a large part of the race without simultaneously having a salient, meaningful experience of their joint actions' effectiveness. The authors put emphasis on the mediation of team's coordination by the shared sport equipment (i.e., "extra-personal" regulation processes) referring to the concept of stigmergy (Susi, 2016). This concept was introduced to explain collective coordination observed in groups of social insects: each insect affects the behavior of other insects by indirect communication through the use of material artifacts (Susi, 2016). R'Kiouak et al. (2016) suggested that, despite major differences between the activities of rowers and social insects, in the rowing situation the boat plays a mediating role, as its behavior is affected by each rower's activities.

In the present study, the flying boat presents similarities with a rowing boat as both are highly affected by each crew members' activities. However, on a flying boat the respective activities of each crew member, are very different from those of rowers, depending to their own specific roles on the boat. The constraints of their collective task require a reciprocal interdependence (Saavedra et al., 1993) between helmsman and crew, who regulate specific controls of the boat. Moreover, the flying boat is also highly affected by its natural environment that contributes to its propulsion and dynamic balance, whereas in rowing the natural environment has a less functional role.

Theoretical framework and research purpose

The study was conducted within the course of action theoretical and methodological framework (Theureau, 2003, 2006), that is particularly relevant to analyze human-environment interactions in natural settings such as sports settings (Araújo and Bourbousson, 2016). Studies within this framework have shown how the description of the athletes activity "from the inside" (from the actor point of view), linked to the description of the situated constraints and effects of that activity, provide useful understanding and original insights about sports performance (Poizat et al., 2013; Seifert et al., 2016). The course of action framework relies on a phenomenological approach to human cognition (Shear and Varela, 1999; Varela et al., 1991) that gives primacy to the actor's first-person point of view (i.e., his/her lived experience) in the analysis of his/her activity (i.e., actions, communications, self-talking of the actor). That is, the course of action theoretical framework gives emphasis to the analysis of the actor's own world (Merleau-Ponty, 1962) enacted in the ongoing interactions between an individual and its environment (including other individuals).

Within the course of action framework, the theoretical object representing the construction of the meaning from the actor's perspective is the "course of experience" (Theureau, 2003). The course of experience of an actor is the history of his pre-reflexive activity, i.e., the history of the activity that an actor could tell, show, relate or comment upon at any time during its occurrence. According to the course of action framework, the activity that is meaningful for the actor is a semiotic process, which can then be described as a concatenation of meaningful units, or signs (Theureau, 2003).

From this perspective, we particularly focused on how sailors mutually interact with their partner and the boat to maintain the stability of flight on a foiling multihull. We define flight stability as the tendency of the boat to maintain a steady flight with minimal variations of ride height and heeling, despite the ongoing perturbation of its dynamic equilibrium originated by the crew members actions and the wind, waves and sea current variations. Therefore, flight stability is a central issue in foil sailing (Heppel, 2015): on the one hand, maintaining flight is essential on this kind of boat to produce optimal performance; on the other hand, the flight stability is constantly threatened by environmental changes and crew actions, and requires continuous adjustments of the crew members.

In line with these considerations, and with the previous studies of R'Kiouak et al. (2016), the purpose of the present study was to explore interactions between crew members and the shared sport equipment (the boat), linked to the natural environment of that system.

Methods

Participants and context of the study

This case study is rooted in a collaboration between expert sailors and researchers who were themselves experts in sailing. The sailors of the present study were members of the French national sailing team, training for the Nacra 17 event at the 2020 Olympic Games. The Nacra 17 foiling catamaran is an Olympic multihull for two sailors.

The helmsman was a 34-year-old man, and the crew was a 25-year-old woman. Both sailors had more than 10 years of experience in sailing competition at national and international level. At the time of the study they had been training and competing at international level as a Nacra 17 crew for six years. In this period of time, they have been ranked four times in the top ten at the world championships. The protocol of the study was explained in depth to the sailors and to their coach. They all provided explicit consent to participate in the study. In addition, the study followed the guideline of the university ethics committee.

Sailing activity was studied during a three-hour training session. This session took place during a training session scheduled at the end of the competitive season.

Choice of a specific situation for an in-depth analysis

We selected a nine-minute beam reach leg (i.e., perpendicular to the wind direction) for an extensive analysis of the crew members' activity. On this leg, the boat sailed under jib and mainsail. The helmsman held a stick connected to the rudders and held the mainsheet to act on the mainsail traveler. The crew held the same mainsheet to act on the mainsheet block. When the boat was flying, both crew members were trapezing (when trapezing, sailors are hooked with a waist harness to trapeze lines attached to a point high on the mast). In this position, the sailors had their feet on the gunwale and their bodies fully extended outside the hull. This position gives more leverage to control the heel and opens the possibility of walking along the gunwale to balance the boat's trim.

This sequence was selected because the flight of the boat is particularly unstable on reaches, challenging the crew's coordination. During this sequence, the instruction for the crew was to go as fast as possible, staying on a boat trajectory perpendicular to the wind direction. After the session, the crew members expressed that this sequence was the most salient during the training session from their point of view in terms of perceived difficulty of maintaining flight stability. All these factors created favorable conditions to conduct an instrumental case study on this singular sequence (Baxter and Jack, 2008).

Data collection

Collecting data in situ

Two types of data were gathered in situ: (a) continuous video and audio recordings of the crew members' behavior and verbal communications; and (b) mechanical data about the boat behavior.

Continuous video and audio recordings of the crew members' behavior and verbal communications. The behavior and verbal communications of the crew members were recorded during the entire training session. One camera was filming from the coach's motorboat providing a view from behind of the catamaran and its crew. Both sailors were equipped with a waterproof communication system embedded in the helmets that usually were used during training sessions to communicate with the coach. This communication system was connected to the camera on the boat in order to simultaneously record the onboard conversations and the video of the boat. Another camera was fixed on the mast, providing a view from above of the sailors. This video recorded continuous behavior of the crew such as displacements along the gunwale or actions on the sheets.

Mechanical data about the boat behavior. A research engineer who collaborated in the present study installed an Inertial Measurement Unit (IMU; 5Hz, Yachbot, Igtimi, New Zealand) on the boat. The installation was made using a specifically designed support fixed on the front cross beam. The IMU was calibrated to zero with the boat sitting flat on the ground and measured heel (i.e., the angle of rotation of the boat about its longitudinal axis), trim (i.e., the angle of rotation of the boat about its transversal axis), and yaw (i.e., the angle of rotation of the boat about its vertical axis) angles. In agreement with crew members, trainer and research engineer, heel angles measured by the IMU were chosen in the present study to evaluate flight stability.

Data collection for the analysis of the course of experience

Self-confrontation interviews were conducted immediately after the training session to collect retrospective verbalizations of the sailors lived experience of that studied leg.

A self-confrontation interview is a method consisting of confronting a person with traces of a past episode of his/her activity to "re-live" this episode of activity as it was experienced (Theureau, 2003, 2006; Von Cranach and Harré, 1982). The person interviewed is asked to describe and comment on this lived experience to express the history of his pre-reflexive activity, that is, what he was doing, feeling, thinking, perceiving and self-talking at each moment (Theureau, 2003). The present interviews were conducted individually using the audio-video recording of the session as the traces of the sailor's activity. Each interview lasted approximately one hour. During the interview, the researcher helped the sailor in this description with prompts about his/her sensations, perceptions, focus of attention, concerns, emotions and thoughts. Each interview was recorded in full using a digital camera so that the comments in the self-confrontation interview could be synchronized with events that occurred during the leg, and with collected measurements.

Data analysis

The data analysis was carried out through two main steps: (a) reconstruction and synchronization of the crew members' courses of experience, and (b) identification of episodes of collective coordination and (c) categorization of forms of interaction.

Reconstruction and synchronization of the crew members' courses of experience

The onboard conversations and the verbalizations of the sailors obtained during the self-confrontation interviews were fully transcribed.

The reconstruction of the courses of experience of each sailor consisted of a comprehensive analysis of the verbalizations of the sailors collected during the self-confrontation interviews. During this process, a meticulous investigation of audio-video recordings and measurement data was conducted by the researcher to enrich his interpretation of the verbalization of the sailors.

According to the course of action theoretical framework, a course of experience is a chain of meaningful units of activity from the actor's point of view. By hypothesis, each meaningful unit is composed of six articulated components that, respectively, account for the different phenomena of human experience at each instant of the ongoing activity (Theureau, 2003): (a) involvement in the situation (i.e., the sailor's concerns or intentions); (b) the potential actuality (i.e., the sailor's expectations); (c) the referential (i.e., the practical knowledge mobilized by the sailor during his/her activity); (d) the representamen (i.e., the "perturbations" experienced by the sailor, in terms of meaningful elements of the situation that affect his/her activity); (e) the unit of course of experience (i.e., the fraction of meaningful activity of the sailor); and (f) the interpretant (i.e., the construction or extension of his/her knowledge by the sailor). According to this conceptual model, at each instant, the involvement in the situation, the potential actuality and the referential constitute the "state of preparation" of the course of experience (Theureau, 2003). This state of preparation delimits the possible actions and situational events that are lived as meaningful by the actor. The notion of representamen is comparable to the concept of affordances, considering the following points: in this framework, opportunities of action are not external to the perceiver, they are enacted by the ongoing interactions between the actor and his/her environment, and thus are circumscribed to the possibilities opened by the actor's "state of preparation" at every moment.

After identifying the chains of meaningful units of activity for each actor, the two chains were time synchronized using the video recording as time reference. Such synchronization allowed to examine in detail the collective interlinking of the crew members' courses of experience (Theureau, 2003), i.e., the simultaneous experience of the sailors and their dynamic collective evolution.

Identification of episodes of collective coordination

This step of the analysis was carried out by considering, on one hand, the dynamics of the articulation of the crew members' courses of experience, and on the other hand, the concomitant dynamics of the boat's behavior.

The joint changes of the states of preparation of the sailors were identified in the synchronized courses of experience of the crew members. Each joint change of the states of preparation delimited the closing of an episode (or part of an episode) and the opening of another episode (or part of another episode). An episode could be composed of several parts of discontinuous episodes where the closure was only temporary. In this case the episode already opened was temporarily "put in the background" until it opened again. Thus, 24 collective changes of the states of preparation were identified, corresponding to 14 episodes (Table 1).

The description of the behavior of the boat was based on the analysis of the video-recorded data and heel angles measured by the IMU:

Firstly, based on the video and the self-confrontation interviews, we identified episodes where the flight's viability could be considered as "critical". Critical flights episodes are more about circumstantial evidences that the viability of the flight is being threatened than about measuring the level of stability of the flight. These episodes were identified when (a) the sailors described major perturbations of the flight during the self-confrontation interviews, and (b) observation of the video recording revealed one of the following situation: the boat is flying too high with the tips of the foils about to breach the surface, the boat is flying very low and struggling to maintain the hulls above the water during a lull of wind or the boat suddenly drops down and slams the water. In this way, five critical episodes were identified.

Secondly, for each of the remaining episodes we analyzed the heel angles measured by the IMU to characterize the level of stability of the boat. We conducted this analysis on episodes or parts of episodes that lasted more than 10

Table 1. Overview of the segmentation of the episodes of collective coordination and the corresponding behavior of the boat, by chronological order of apparition.

Episodes of collective coordination	Duration (seconds)	Mean angle of heel (degrees) and standard deviation	Behaviour of the boat
Episode 1: To react to sudden heeling while getting ready to fly	4	11.80 ±3.88	Critical
Episode 2: To coordinate actions on traveler and mainsheet to regulate stability in take-off phase	30	4.59 ± 3.45	Stable
Episode 3(part 1): To anticipate a gust of wind	7	0.94 ± 1.48	Undefined
Episode 4: To react to a loss of control with joint actions with the partner	17	5.58 ± 3.31	Critical
Episode 5 (part 1): To regain flying speed after a strong loss of speed	1	6.03 ± 2.12	Critical
Episode 6 (part 1): To share interpretation about the previous loss of control	17	9.22 ± 3.89	Stable
Episode 5 (part 2): To regain flying speed after a strong loss of speed	17	0.77 ± 4.23	Critical
Episode 6 (part 2): To share interpretation about the previous loss of control	5	7.25 ± 1.07	Undefined
Episode 7: To coordinate actions of traveler and mainsheet to regulate stability in flight	23	3.25 ± 2.65	Stable
Episode 8 (part 1): To optimize lateral stability while maintaining a good reaching angle	91	3.58 ± 4.49	Unstable
Episode 3 (part 2): To anticipate a gust of wind	9	2.46 ± 4.35	Undefined
Episode 8 (part 2): To optimize lateral stability while maintaining a good reaching angle	37	2.80 ± 4.65	Unstable
Episode 5 (part 3): To regain flying speed after a strong loss of speed	5	2.68 ± 7.23	Critical
Episode 9: To anticipate the crossing with another boat	16	4.37 ± 3.08	Stable
Episode 10 (part 1): To argue about the crew position in the trapeze to optimize the stability of the boat while maintaining a good reaching angle	14	2.57 ± 4.53	Unstable
Episode 11 (part 1): To jointly search solutions aimed at solving stability problems while maintaining a good reaching angle	7	4.80 ± 2.73	Undefined
Episode 12: To jointly react to a sudden cavitation of the foils	4	9.18 ± 3.87	Critical
Episode 11 (part 2): To jointly search solutions aimed at solving stability problems while maintaining a good reaching angle	40	8.42 ± 4.46	Unstable
Episode 13 (part 1): To maintain a stable flight	28	5.53 ± 3.37	Stable
Episode 10 (part 2): To argue about the crew position in the trapeze to optimize the stability of the boat while maintaining a good reaching angle	22	4.20 ± 4.24	Unstable
Episode 13 (part 2): To maintain a stable flight	91	2.27 ± 3.49	Stable
Episode 14 (part 1): To react to shifting gusts of wind	7	2.58 ± 2.04	Critical
Episode 3 (part 3): To anticipate a gust of wind	3	7.59 ± 1.65	Undefined
Episode 14 (part 2): To react to shifting gusts of wind	14	4.41 ± 4.54	Critical

seconds, considering the inertia of the boat's movements when rolling from side to side. More precisely, the mean angle of heel was calculated and the Standard Deviation (SD) of this angle was taken into account to evaluate the boat's flight stability. During the whole leg, the SD of the angle of heel was 4.55 and the maximum SD of the angle of heel for a 10 second window SD was 7.88. When the SD of an episode was less than 3.94 (corresponding to the half of the maximum SD of a 10 second window) the flight was considered "stable." Conversely, when the SD of an episode was greater than 3.94, the flight was considered "unstable." This analysis permitted identification of five stable episodes and three unstable episodes. Due to its short duration, one episode could not be characterized in terms of stability of flight. Consequently, this episode was removed from the analysis. For each of the episodes (or parts of episodes), the duration, the mean angle of heel, the SD of the angle of heel, and the cumulated time, are respectively presented in Table 1.

Categorization of forms of interaction

Finally, we identified the forms of interaction between crew members and the boat underlying the control of the boat's flight in relation to environmental constraints. We proceeded by synthesizing the states of preparation, representamen and meaningful units of action of the crew members for each episode. The episodes presenting similarities in terms of state of preparation, representamen and meaningful units of action were grouped in a same category. We then took into consideration the behavior of the boat: when all episodes in the category corresponded to similar behavior of the boat, that category remained unchanged; when one or more episode in the category corresponded to a distinct behavior of the boat, that category was split based on the boat behavior. Six categories were identified, corresponding to the six forms of interaction (Table 2).

Results

The analyses revealed six forms of interaction between the crew members, the boat, and the environment underlying the control of the boat's flight. Table 2 presents an overview of these forms, followed by a description of the characteristics of each one in terms of relations between the crew members' meaningful activity and the boat's behavior.

Form 1: Individual coordination with the boat of the two crew members to maintain flight stability

This form of interaction between the crew members and the boat was characterized by concomitant individual activities

Table 2. **Overview of the forms of interaction.**

Episodes of collective activity	Forms of interaction between the crew members, the boat and the environment
Episode 13	**form 1:** Individual coordination with the boat of the two crew members to maintain flight stability
Episode 3,9	**form 2:** Verbal communications between crew members to share expectations about perturbations of the flight stability
Episodes 2,7	**form 3:** Interpersonal coordination to optimize respective actions directed to the boat to maintain flight stability
Episodes 8,10,11	**form 4:** Interpersonal coordination to find solutions in reaction to the perceived flight instability
Episodes 1,4, 5,12,14	**form 5:** Individual actions of each crew member to a critical flight perturbation to recover control of the boat
Episode 6	**form 6:** Verbal communications to build common explanations of the boat's flight perturbation occurred in the near past

directed to the boat focused on preserving flight stability. There were no meaningful interactions between crew members. The episode 13 represents this kind of interaction in which the behavior of the boat was stable with a standard deviation of the angle of heel of ±3,37 (during the first part of the episode) and ±3,49 (during the second part of the episode).

During these episodes, both crew members had similar states of preparation related to preserving a perceived stable flight. These phases were described as "good phases" by the sailors, e.g.: Crew "*this a good phase, the boat is more stable with the foil that pushes a little bit less (…) I can regulate better.*" The adjustments of each crew member's activity to the movements of the boat occurred without each team member considering his partner's activity. No verbal communication occurred between crew members during these episodes.

Form 2: Verbal communications between crew members to share expectations about perturbations of the flight stability

This form of interaction between the crew members and the boat was characterized by communication between the partners about the perception of their common surrounding environment (i.e., waves and wind to be anticipated or obstacle to be avoided). The episodes 3 and 9 represent this kind of interaction. Due to insufficient duration of the three parts of episode 3, the behavior of the boat was only characterized by mechanical data for episode 9. During this episode, the behavior of the boat was stable with a standard deviation of the angle of heel of ±3,37.

During these episodes, both crew members had similar states of preparation related to the perception of salient changes of environmental conditions, such as incoming gusts of wind, or crossing with other boats. Verbal communication between crew members consisted of short announcements and mutual confirmations of the perceived environmental events, e.g.: Helmsman: "*Big rise in….*"; Crew: "*got it.*" The underlying intentions of these communications for each crew member was to make sure that his/her partner had perceived the perturbation that will potentially require joint action to anticipate and/or react to the perturbation.

Form 3: Interpersonal coordination to optimize respective actions directed to the boat to maintain flight stability

This form of interaction between the crew members and the boat was characterized by activities directed to specific elements of the boat in coordination with the partner's actions on the boat. The episodes 2 and 7 represent this kind of interaction in which the behavior of the boat was stable with a standard deviation of the angle of heel of ±3,45 (episode 2) and ±2,65 (episode 7).

During these episodes, both crew members had congruent states of preparation related to the perception of specific elements of the boat needing joint action to be adjusted. This was, for example, the case for the mainsail that was adjusted by the mainsheet held by both the helmsman (actions on the traveler) and the crew (actions on the blocks). In this case, there was a congruence of the actions of the crew members directed at keeping the boat flat. During these episodes, the relation between the crew members' actions was mutually perceived through shared elements of the boat. For example, in episode 7, the crew expressed during the self-confrontation: *"I told him to pull the traveler, because I was too sheeted on the mainsail. It was to be able to ease [the mainsail] a little bit."* Verbal communications were related to the possibilities of regulation of the mainsail with the shared mainsheet, e.g., Helmsman: "*The mainsheet is very short*"; Crew "*when I go forward, I don't have enough mainsheet*"; "*take it in a little bit more [center the traveler car]"* (episode 7).

Form 4: Interpersonal coordination to find solutions in reaction to the perceived flight instability

This form of interaction between the crew members and the boat was characterized by activities directed to the boat to recover boat stability "here and now" and activities directed to the partner to find solutions to recover flight stability. The episodes 8, 10 and 11 represent this kind of interaction in which the behavior of the boat was unstable with a standard deviation of the angle of heel of ±4,69 (episode 8, part 1), ±4,65 (episode 8, part 2), ±4,53 (episode 10. part 1), ±4,24 (episode 10, part 2), ±5,06 (episode 11, part 1) and ±5,44 (episode 11, part 2).

During these episodes, both crew members had convergent states of preparation directed towards finding a solution to stabilize the flight, involving the partner in the reflection and problem solving. Despite the crew members being involved together in finding a common solution, some conflicts of point of view could occur during their interactions. For example, the analysis of episode 11 revealed a divergence in perceptions of environmental perturbations: in this particular episode, both sailors were perturbed by the lateral instability of the boat. However, leeward heeling was more salient for the helmsman and conversely windward heeling was more salient for the crew. Verbal communications were taking the form of a conflict of points of view with insistent requests and strong argument, e.g. Helmsman: "*Stay flat*"; "*we have a lot of leeward heeling*"; "*Keep easing [the mainsheet], otherwise I can't bear away*"; "*Keep the mainsheet eased, otherwise we go back to closed-hauled*"; Crew: "*we are having too much windward heeling, then I have to haul in*" ; "*Yes but we are down here [on a broad reach]*"; "*With the speed we have for sure we aren't close-hauled.*" During the episodes of this form of interaction, both crew members were at the same time acting on the boat and proposing solutions to keep the boat flat.

Form 5: Individual actions of each crew member to a critical flight perturbation to recover control of the boat

This form of interaction between the crew members and the boat was characterized by activities directed at the boat in reaction to a critical state of flight and communication with the partner to share perceptions of the situation.

The episodes 1, 4, 5, 12 and 14 represent this kind of interaction in which the behavior of the boat was described as critical.

During these episodes, both crew members had a similar state of preparation, directed to the recovery of control of the flight. In these situations, crew members' attention was focused on the critical behavior of the boat and the significant variations in speed and heeling, as well as perceptions of variations of the behavior of the boat through the commands (e.g., meaningful increasing or decreasing of the tension in the mainsheet or vibrations in the rudders' stick). Actions of the crew members were congruent with the behavior of the boat: displacements and actions on the commands were aimed at quickly acting to alter the balance of the boat and keep it flying. For example, in episode 4, video recording showed that as the boat kept accelerating in the gust, the ride height kept increasing to a critical point (when the foils come too close to the water surface they can suddenly lose their lift due to ventilation, which results in a crash), both crew members stepped forward along the gunwale to act on the trim of the boat. Verbal communications were characterized by simple expressions of their perception of phenomena endangering flight viability followed by quick checks of the integrity of the teammate, e.g.: Helmsman "*watch out*"; "*Are you good?*"; Crew: "*Stronger [the gust]*" "*woooo [screaming]*".

Form 6: Verbal communications to build common explanations of the boat's flight perturbation occurred in the near past

This form of interaction between the crew members and the boat was characterized by activities of each crew member directed to his/her partner in the form of a reflexive activity about a near past event. The episode 6 represents this kind of interaction. Due to insufficient duration of episode 6 part 2, the behavior of the boat was only characterized on the basis of mechanical data for episode 6 part 1. During this part of the episode, the behavior of the boat was stable with a standard deviation of the angle of heel of ±3,89.

During these episodes both crew members had similar states of preparation, related to communicating explanations to the teammate about actions taken during a past event in order to better anticipate similar events in the future. The perceived perturbations by crew members were similar and consisted of memories of what happened and what they had said during a past event. Verbal communication consisted of the developed expression of experienced difficulties during the past event and argumentation about alternative solutions to resolve an eventual future similar situation, e.g.: Helmsman: "*here [before, during the gust], I think if I broach we cartwheel*"; Crew: "*but no, well, if you went progressively I don't think so*".

Discussion

The purpose of the present study was to describe the role of a shared sport equipment in the emergence of collective coordination in flight multihulls in sailing, and more broadly in team sports in which performance is highly equipment-dependent. The results of this study reveal a set of six forms of interaction between the crew members and the boat, interacting with natural environmental conditions. From the perspective of the crew members' coordination, three main functional states appear, each of which can respectively be associated with distinct cognitive and interactive processes: (a) extra-personal coordination processes to maintain or restore flight stability; (b) interpersonal coordination processes to maintain or restore flight stability; and (c) reflective interpersonal coordination processes to anticipate environmental events or to understand past events. We discuss each of these three functional states in the following subsections.

Extra-personal coordination processes to maintain or restore flight stability

The extra-personal coordination processes to maintain or restore the flight stability are represented by the forms 1 and 5. From each crew member's experience, the meaningful interactions are primarily between his/her own activity and the flight stability. Two contrasting cases, however, must be distinguished: in form 1, the actions of the crew members are aimed at maintaining an existing stable flight, whereas in form 5 crew members react to a sudden critical perturbation of the flight.

In these two cases, from each crew member's experience, his/her teammate is non-meaningful in the situation, as if each crew member was alone on the boat. This form of interaction is similar to what some authors describe as extra-personal coordination (Millar et al., 2013; R'Kiouak et al., 2016). In these studies, in rowing, the boat is described as a mediator of an activity of synchronization of movements between two rowers. Taking this consideration to an extreme, we could consider that in this kind of situation each actor "simply" regulates his relations with an object, as in individual human-object interactions (Adé et al., 2017). However, certain differentiated constraints on the activity of teammates in these two sports must be considered. On a rowing boat, the movements of both teammates are fundamentally the same: pulling on the oar and making the same movement in synchronization. Therefore, if one of rower breaks the synchronization (for example by accelerating the recovery part of the stroke and making the catch of the following stroke earlier than his teammate), the other rower will feel it indirectly through the boat. On a flying boat, ongoing modifications of the boat's behavior are caused by the activities of each teammates as well as environmental constraints such as wind and waves. Therefore, the behavior of the boat is partly independent from the behavior of the teammates. In other words, the boat "takes life" as it is activated by its natural environment and the crew members. In both forms 1 and 5, the crew members seem to act in a coordinated manner, but the behavior of the boat is radically different (stable versus critical). From his/her experience, the activity of regulation of each crew member is the activity of regulation of the boat. But in these forms of interaction, the boat cannot be considered only as a mediating structure, as it is described in rowing (R'Kiouak et al., 2016). It could instead be considered an "interacting agent" in which the teammate is embodied. Therefore, despite the observable phenomena being similar (teammates coordinate their actions without considering themselves respectively, only based on their individual continuous adjustments to the boat's behavior) we hypothesize that the boat plays a different role: a mediating structure in rowing, an interacting agent on foiling boats. The implications are that whereas in rowing, "rowing with the boat" is a condition both necessary and sufficient to be coordinated with the partner (Millar et al., 2013 ; R'Kiouak et al., 2016), on flying boats being coordinated with the partner not necessarily implies a stable flight, and "sailing with the boat" may not necessarily lead to a maintained coordination between the partners.

Interpersonal coordination processes to maintain or restore the flight stability

The interpersonal coordination processes to maintain or restore flight stability are represented by forms 3 and 4, in which crew members are collectively interacting with the boat's flight stability, and both the collective action and its relationship with the flight stability of the boat are meaningful for the crew members.

In form 3, the flight is stable; however, a "need" for interpersonal coordination is perceived by each teammate to act on the boat efficiently. Form 4 is closely related to form 3 with the difference that in this case, flight is unstable. In the following discussion, we suggest that in both cases, the interpersonal coordination processes are aimed at constantly updating team situational awareness about mutual affordances, allowing the crew members to jointly maintain or restore flight stability.

As it has been observed in team sports, collective coordination relies on shared affordances (Silva et al., 2013). In the situation we studied, we can consider that there is a direct perception by the crew members of their mutual opportunities of action. Each crew member plays the role of an affordance (i.e., affordance of the other) to contribute to actions involving regulating the boat's controls. In the same way, one teammate can act on the boat to expand his/her partner's opportunities for action (i.e., affordance for the other). From this point of view, the stability of the flight could rely on the congruence of the respective affordances for each crew member, i.e., when desirable affordances (Kimmel and Rogler, 2018) for the crew are congruent with desirable affordances for the helmsman.

In some cases, the crew members individually perceive affordances, but cannot act on their own, because of their mutual and reciprocal interdependence (Saavedra et al., 1993). In such cases, verbal communication between the crew members allows everyone to ask the partner to act to open up opportunities for himself/herself. We hypothesize that if this action opens affordances for the partner, the flight remains stable. In contrast, if this action reduces affordances for the partner, the flight becomes unstable. Because of the reciprocal interdependence between the crew members' actions on the boat, mutual affordances are comodulated. Kimmel and Roger (2018) have introduced the notion of "zero-sum coupling" of affordances in dyads of opponents: "A's desirable affordances equal B's undesirable affordances" (p. 210). In the case of cooperative dyads, verbal communication between teammates can be conceptualized as the main process to update a team's situation awareness about mutually desirable affordances, allowing the crew members to jointly maintain or restore the flight stability. According to this idea, if situation awareness is shared by the crew members about their respective desirable affordances, crew members work as partners and the flight is stable. For example, in episode 7 (form 3), when the crew asks the helmsman to pull the traveler, and the helmsman does so, it opens the possibility for the crew to ease the mainsail increasing her capacity to regulate the stability of the boat. At the same time, pulling the traveler to some extent doesn't reduce the regulation capacity of the helmsman. In this case, the possibilities for the boat to become unstable are reduced as the crew members increase their capacity of regulation. Conversely, if this situation awareness is not shared, crew members may work as unintentional opponents, which can lead to flight instability. For example, in episode 8 (form 4), the boat keeps rolling side to side and windward heeling is more salient for the crew whereas leeward heeling is more salient for the helmsman. As the helmsman asks the crew to ease the mainsail to maintain the point of sail, he reduces her capacity to act on windward heeling, in the same way, when the crew sheets the mainsail to act on windward heeling she reduces the possibilities for the helmsman to maintain the point of sail without increasing windward heeling. As both crew members reduce each other's capacities of actions, the boat remains unstable. Thus, flight instability can be linked to differences in situation awareness of the crew members. Previous studies have yet showed a high frequency of poor mutual situation awareness between expert teammates in team sports (e.g., Poizat et al., 2009).

Reflective interpersonal coordination processes to anticipate an environmental event or to understand past events

The reflective interpersonal coordination processes for anticipating environmental events or understanding past events are represented by the forms 2 and 6. In these, there are meaningful interactions between the crew members, as well as between each crew member and the environment. In both situations, the interactions between crew members consist of verbal communications traducing a reflective activity of both crew members, based on past events, to anticipate future action and create new shared knowledge. In form 2, these communications occur under time pressure due to the incoming perceived perturbations of the environment. Their purpose is to share expectations about perturbations of flight stability that can occur in the immediate or near future. In form 6, there is no time pressure, as the communications between crew members are aimed at building common explanations of flight perturbations that occurred in the near past, in order to share alternative solutions to resolve an eventual future similar situation.

These results suggest that, in the crew members' experience, onboard coordination does not always involve a meaningful relation with the boat. In forms 2 and 6, the boat is non-meaningful in the lived situation of the crew members. In both cases, the flight is stable, and this stable behavior of the boat seems to open opportunities for crew members to focus on meaningful elements of the surrounding natural environment (form 2) or on memories of past events (form 6). In form 2, the meaningful relations for each crew member are with both the surrounding environment and his/her teammate. The perceptions of salient changes of the environment (e.g., wind gusts) trigger verbal communication between crew members aiming at sharing contextual information (Poizat et al., 2009). As we have noted in the previous sections, situation awareness is not always shared by both crew members. When a salient change in the environment is perceived by one of the crew members, with a potential impact on the future stability of the flight, verbal communication is necessary to ensure similarity in the states of preparation of both crew members, i.e., to share expectations about the possible evolution of flight stability. We suggest that the stability of the boat opens opportunities for the crew members to explore the environment and anticipate collective actions. Thus, this situation can be seen as a discrete point of connection (Gatewood, 1985) sufficient for teammates to adjust to one another and act in a coordinated fashion (Poizat et al., 2009). Form 6 is similar but instead of connecting with a "shared environment," teammates connect to a "shared history" in order to validate/invalidate previous shared knowledge, or to construct new shared knowledge (Bourbousson, Poizat, Saury, & Sève, 2011). The underlying phenomena are fundamentally similar in that it is the stable behavior of the boat that allows each teammate to "evade the here and now" to recall and discuss past actions and anticipate future actions. In this case, the goal is also to create congruent states of preparation, in terms of shared knowledge (i.e., shared mental models) in the eventuality of a similar event in the future (Bourbousson et al., 2011; Cannon-Bowers et al., 1993; Mohammed et al., 2010).

Conclusion

The results of the present study complement results of previous studies in rowing (R'Kiouak et al., 2016; Sève et al., 2013): firstly, our results provide a detailed description of six complementary forms of interaction between crew members and the boat in natural environmental conditions. These findings contribute to understand collective coordination on flying boats and more generally collective coordination in sports situations in which equipment is shared by teammates, and in which performance is highly equipment-dependent. Secondly, the discussion emphasizes the distinction in the role played by the boat in collective coordination in rowing versus in hydrofoil sailing: from a mediating structure in rowing to an interacting agent on flying boats.

Further research should be undertaken to solve methodological and technical challenges for the study of flying multihulls such as the Nacra 17. Indeed, this study participates to reinforce the importance of jointly considering the crew members lived experience and the boat movements. However, a methodological limitation of this study remains in the objectivation of the behavior of the boat. Further studies should focus on the validation of a stability index to distinguish stable, unstable or critical behaviors of the boat. In our view, technical innovation is required to take in consideration the relation between the boat and its environment by measuring moment to moment windspeed, wind direction and waves height, without constraining the boat/crew activity with the measurement systems. In line with previous studies (Cuijpers et al., 2017), our conclusions should encourage collaborative work between researchers, engineers, coaches and sailors to develop easy-to-use measurement systems that provide information about indicators that "make sense" for the crew, such as boat stability. Regarding the role of shared sport equipment in coordination in sports, the present case study was an in-depth analysis of a limited number of expert participants (two crew members on one boat) on a specific leg of a training race, Therefore, further case studies should be undertaken to enrich or contrast the description of the forms of interaction and validate the generic nature of these forms of interaction in sailing, and other sports.

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Key points

- Coordination between crew members on a flying sailing boat includes six forms of interaction going from individual interactions of each crew members with the boat and the boat environment to social interactions between crew members.
- On flying boats, as in rowing, the shared sport equipment actively participates in collective coordination. Similarities and differences in the role played by the boat are discussed in this paper.
- This study encourages joint consideration of experiential data from the athletes and measurement data from the shared sport equipment to understand collective coordination in highly equipment-dependent sports.

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