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► **To cite this version:**

Eric Terrien, Benoît Huet, Jacques Saury. Controlling the flight on double-handed foiling catamarans: The role of shared equipment on the crew members' mutual modes of regulation. *Psychology of Sport and Exercise*, 2022, 61, pp.102204. 10.1016/j.psychsport.2022.102204 . hal-03989963

HAL Id: hal-03989963

<https://hal.science/hal-03989963>

Submitted on 15 Feb 2023

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1 **Controlling the flight on double-handed foiling catamarans: the role of shared**
2 **equipment on the crew members' mutual modes of regulation**

3
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8
9 **Abstract**

10 The purpose of this study was to contribute to the understanding of the role of shared sport
11 equipment in the collective coordination of a team. It was conducted within an enactive
12 approach of human cognition by mobilizing the methodological tools and methods of the
13 Course of Action framework. Six crew members of hydrofoil sailing catamarans participated
14 in this study. Data collection consisted in video-recording training sessions followed by
15 individual self-confrontation interviews. A qualitative analysis of the data allowed typical
16 modes of regulation of the flight to be characterized from each crew member's perspective.
17 Three main modes of regulation were identified. All of them involved either salient perception
18 of the boat's movements, or actions directed to regulating the boat's movement. In the
19 discussion, we propose a distinction between three types of collective sport situations, regarding
20 the role of the material environment of athletes in their coordination. This distinction opens new
21 perspectives both for future research on team coordination, and for pedagogical and training
22 implications.

23 **Keywords:** Enaction, Team Coordination, Course of Action, Sport Equipment, Hydrofoil
24 Sailing

1 **Highlights**

- 2 • **Shared sport equipment plays an active role in the process of collective**
- 3 **coordination;**
- 4 • **In the sailing of double-handed foiling catamarans, the boat can be considered as**
- 5 **a “third partner”;**
- 6 • **Research on team coordination in sports should take into consideration different**
- 7 **levels of implication of the material environment.**

8

9 **Introduction**

10 Understanding the dynamic perceptual and cognitive processes underlying teammates’
11 coordination and their collective behavior in real time is currently a significant challenge in the
12 field of sports psychology (e.g., Passos et al., 2016). The present study is focused on the role of
13 sport equipment in coordination between teammates when this equipment is shared in real time,
14 as is the case in sailing. The role of this kind of equipment is still little known in team sports in
15 which performance is highly equipment-dependent (e.g., rowing, sailing, canoeing). This study,
16 carried out from an enactive approach of human cognition (Maturana & Varela, 1987; Varela
17 et al., 1991), is based on the general hypothesis that in these sports the shared sport equipment
18 generates specific conditions of coordination between teammates (e.g., Millar et al., 2013,
19 R’Kiouak et al., 2016; Terrien et al., 2020). In this study, we refer to *shared sport equipment*
20 as sport equipment which is the instrument of a mechanical coupling between the athletes so
21 that: (a) both athletes’ bodies are simultaneously in contact with the same piece of equipment;
22 (b) each athlete can modify the dynamics of the movements of this sport equipment through
23 their actions; and (c) the movements of this sport equipment play a determining role in the
24 team’s performance. For example, a rowing boat, a sailing boat or a tandem bicycle are shared

1 sport equipment. In contrast, a basketball court is not: the athletes' bodies are simultaneously
2 in contact with the court, but the latter remains static. Moreover, the movements of a soccer ball
3 play a determining role in the team's performance, but the athletes' bodies are not
4 simultaneously in contact with the ball, and therefore we do not consider a soccer ball as shared
5 sport equipment.

6 Studying the potentially singular role played by the shared sport equipment in the
7 coordination between teammates leads us to examine more broadly how previous research
8 considered the influence of the material environment on team coordination. Indeed,
9 interpersonal coordination within teams has been widely studied in sport psychology, referring
10 to diverse theoretical and methodological frameworks (according to various ontological and
11 epistemological assumptions) and considering in various ways the interactions between
12 teammates and their shared environment (e.g., Araújo & Bourbousson, 2016; McNeese et al.,
13 2016; Passos et al., 2016; Ward & Eccles, 2006). For example, the social-cognitive approach is
14 grounded in the mainstream human information processing perspective and addresses team
15 coordination in terms of shared knowledge (e.g. Blaser & Seiler, 2019; Eccles & Tenenbaum,
16 2004; Eccles, 2016; Lausic et al., 2009). According to this approach the material environment
17 of the athletes is considered as a source of perceptual cues for building knowledge, as mental
18 representations, that could be processed, shared and distributed among players. Other
19 approaches such as ecological dynamics or enactive approaches are non-representational
20 approaches of cognition and address team coordination in terms of dynamical coupling between
21 the athletes and their environment (e.g., Bourbousson et al., 2010; Feigean et al., 2018; Gesbert
22 et al., 2017, Passos et al., 2008; Silva et al., 2013; Vilar et al., 2012). Research on team
23 coordination within the ecological dynamics approach seeks to identify collective variables that
24 capture the team organization as a dynamic complex system, and its changes over time (Vilar
25 et al., 2012). In this approach the scale of analysis is the performer-environment relationship

1 (Davids & Araújo, 2010). The shared environment (e.g., teammates, opponents, ball, goal, court
2 lines) is considered as a source of constraints influencing the on-going self-organized activity
3 of the athletes (e.g., Passos et al., 2008; Silva et al., 2013, Vilar et al., 2012). Within the enactive
4 approach, research on team coordination considers the step by step articulation of the athletes'
5 individual sense-making activity with their performing environment (including their teammates
6 and opponent) (e.g., Bourbousson et al., 2010; Feigean et al., 2018; Gesbert et al., 2017). In this
7 approach the environment is considered through the perspective of the athletes as a world of
8 meaning that is constructed through the athletes' activity.

9 These different approaches clearly consider the shared material environment in the
10 explanation of team coordination. However, regardless of the approach considered, the specific
11 role of shared sport equipment in coordination within teams or crews seems to have been
12 relatively neglected in the literature. One reason for this may be that most of the studies on team
13 coordination in sport have mainly focused on court and field sports (e.g., Blaser & Seiler, 2019,
14 Bourbousson et al., 2010, Eccles & Tenenbaum, 2004, Eccles, 2016, Esteves et al., 2012;
15 Feigean et al., 2018; Gesbert et al., 2017, Lausic et al., 2009, Passos et al., 2008; Vilar et al.,
16 2012). Another reason is that the idea of an interdependence between the joint actions of
17 teammates and the characteristics of their shared sport equipment has only recently been
18 introduced by a small number of studies. As such, research in sports psychology has not yet
19 produced a significant amount of empirical knowledge on this issue. Indeed, few studies have
20 highlighted the role of shared sport equipment on the collective coordination of teammates (e.g.
21 Cuijpers et al., 2017, 2019; Millar et al., 2013; R'Kiouak et al., 2016; Terrien et al., 2020).

22 Grounded in the theoretical framework of coordination dynamics (Kelso, 1995; Tognoli
23 et al., 2020), Cuijpers et al. (2019) studied the coordination of pairs of rowers on rowing
24 ergometers. Given the cyclical nature of the rowing stroke, the authors considered "a crew of
25 rowers as a system of coupled oscillators" (Cuijpers et al., 2019, p. 39). From this perspective,

1 they tested the effect of mechanical coupling on the stability of interpersonal coordination,
2 using a crew rowing task. In this laboratory experimental setup, pairs rowed on two ergometers
3 placed behind each other. The ergometers were either mechanically connected to each other
4 through slides or disconnected from each other. The results showed that the strength of the
5 coupling of the interpersonal coordination was improved when the ergometers were connected
6 through slides compared to non-mechanically-coupled ergometers. These results support the
7 hypothesis that when individuals coordinate their movements through a material shared
8 equipment, interpersonal coordination does not only result from perceptual forms of interaction,
9 but also involve interactions of mechanical nature.

10 Grounded respectively in an ecological dynamics approach and in an enactive approach,
11 Millar et al. (2013) and R'Kiouak et al. (2016) highlighted the constitutive interweaving of
12 social and material aspects of the environment (Van Dijk & Rietveld, 2017) in collective
13 activity by attributing a mediating role to the shared sport equipment. R'Kiouak et al. (2016)
14 showed that during a race, rowers can be synchronized in their rowing movements without
15 having an extensive salient experience of their joint action. In this case, the authors assumed
16 that each rower regulates their activity through the boat's information, as highlighted by Millar
17 et al. (2013). R'Kiouak et al. (2016) referred to the notion of stigmergy to describe the
18 contribution of the boat as the sensitive part of the environment capable of transmitting
19 information from one rower's activity to their teammate. The stigmergic theory of collective
20 behavior was initially introduced by Grassé (1959) to explain social insect behavior. This theory
21 describes how individuals can affect the behavior of others through artefacts (Susi & Ziemke,
22 2001). In this case, the artefact plays a mediating role by "recording" the individual traces of
23 activities and in turn organizing collective behavior: "the basic principle in stigmergy states that
24 traces left and modifications made by individuals in their environment may give feedback on
25 them and others" (Susi & Ziemke, 2001, p. 277).

1 More recently, Terrien et al. (2020) described typical forms of interactions between the
2 crew members and the boat in hydrofoil sailing, by considering both the crew members'
3 experience and the stability of the flight, within an enactive approach. The authors discussed
4 the role of a foiling catamaran as an “interacting agent”. For these authors, this notion supports
5 a functional distinction between two kinds of material structures: on the one hand, a mediating
6 material structure responding primarily to the crew members' actions, as in rowing; and on the
7 other hand, a material structure having a greater degree of autonomy of movements in relation
8 to the crew members' actions, due to its interactions with its natural environment. From this
9 point of view, the flying boat is not only transferring information about the activity of one sailor
10 to the other; it is also producing its own information about its relation to the natural
11 environment. While this could also be the case with a rowing boat, it does not appear to be
12 determinant for the rowers' coordination (e.g., R'Kiouak et al., 2016). The authors claimed that
13 the main distinction between a rowing boat and a flying sailboat is that the relation between a
14 flying sailing boat and its natural environment is functional, whereas in rowing the natural
15 environment has a less functional role (Terrien et al., 2020). Indeed, in the case of rowing, the
16 water is a supportive base for the boat, but it does not move the boat forward; the wind can push
17 the boat to some extent, but it is not the main means of propulsion of the boat. Conversely, in
18 the case of a flying sailing boat, the boat's motion relies strongly on both the forces created by
19 the interaction between the sails and the wind, and lift created by the interaction between the
20 foils and the water. From this analysis, the authors hypothesized that the boat plays a different
21 role in these two cases: a “mediating structure” in rowing versus an “interacting agent” on
22 foiling boats (Terrien et al., 2020, p. 305).

23 Together, the results of these studies show that shared sport equipment and their specific
24 characteristics are relevant when a better understanding is being sought of team coordination
25 in team sports in which performance is highly equipment-dependent. In particular, they

1 highlight how a mechanical coupling between team members contributes to their coordination
2 and how the behavior of this shared equipment can influence and be influenced by the respective
3 actions of these team members. However, empirical knowledge on these phenomena needs to
4 be deepened.

5 In line with the previous studies in rowing (R'Kiouak et al., 2016) and flying boats
6 sailing (Terrien et al., 2020), the present study was conducted within an enactive approach,
7 using the theoretical and methodological framework of the Course of Action (Theureau, 2003,
8 2006; Poizat & San Martin, 2020). The Course of Action framework and its methodological
9 tools have been used in sports psychology to study both individual and collective activity in a
10 wide variety of sports, like soccer, basket-ball, orienteering, table tennis, rowing, ice climbing,
11 and sailing (e.g., Boyer et al., 2020; Bourbousson et al., 2010; Gesbert et al., 2017; Mottet &
12 Saury, 2013; Poizat et al., 2012; R'kiouak et al., 2016; Seifert et al., 2017; Sève et al., 2013;
13 Terrien et al., 2020). The enactive approach (Maturana & Varela, 1987; Varela, 1979; Varela
14 et al., 1991) considers that the living organism's world is not pre-given, but is enacted through
15 the continuous interactions between this living organism and its environment. This approach is
16 based on ontological assumptions according to which the cognition is embodied in that it is
17 rooted on perceptual, sensorimotor and emotional processes: it expresses the history of the
18 dynamic relations of an individual with his or her own world. These relations are conceived as
19 a structural coupling, so that the cognition is fundamentally situated (i.e., inseparable from a
20 situation). The structural coupling is said to be asymmetric because it is fundamentally oriented
21 by the living organism's own perspective: cognition emerges through interaction between the
22 organism via its sensorimotor capacities and the environmental features to which it is sensitive
23 (Corris, 2020). Therefore, the notion of asymmetric coupling considers the organism's capacity
24 to be, to assert his existence, and to continuously shape an ever-changing but meaningful and
25 pertinent own world, or *umwelt* (Bourgine & Varela, 1992).

1 The main epistemological implication for the study of human practices *as enaction* is to
2 emphasize the primacy of the actor’s lived experience in the analysis of human activity, i.e., his
3 or her own perspective on his or her situation. The Course of Action framework operationalizes
4 the enaction assumptions by providing methodological tools to collect and analyze data on
5 human experience. The meanings that constitutes at any moment the experience of the actor
6 during the course of his or her activity are supposed to emerge from the actor/environment
7 coupling. This continuous sense-making process is lived by the actor as a flow of practical
8 actions, communications, focus of attention, interpretations, preoccupations, and emotions, that
9 are meaningful at each moment for him or her. This experience is conceived as the “pre-
10 reflective self-consciousness”, that is considered as a “constant structural feature of conscious
11 experience” (Legrand, 2007, p. 583). This pre-reflective self-consciousness is the part of their
12 activity that is meaningful for the actor, i.e., the part of this activity that is showable, tellable
13 and commentable at any instant by the actor in favorable methodological conditions, such as
14 self-confrontation interviews (Theureau, 2003).

15 Within the Course of Action framework, collective activity in sports is conceived as the
16 articulation of the individual experiences of the team members. This process of articulation
17 includes the elements of the material and social environment that are meaningful for each team
18 member. From this perspective, when sport equipment is shared by team members in real time,
19 the interaction with this sport equipment, as well as the interaction with their teammate, may or
20 may not be meaningful for each team member. Thereby, analysis of the teammates’ experiences
21 reveals, moment to moment, how each team member interacts with the shared equipment and
22 with their teammate in order to reach common goals, and how each element of this system can
23 influence and be influenced by the others.

24 Given the relevance of the study of the role of shared equipment in teammates’
25 coordination in team sports in which performance is highly equipment-dependent, the aim of

1 this study was to deepen the analysis of crew members' mutual modes of regulation of flight
2 on foiling catamarans, i.e., in the case of a kind of shared sport equipment that maintains a
3 functional relationship with its natural environment (Terrien et al., 2020). According to the
4 assumptions of an enactive approach, the design of this study consisted in identifying typical
5 modes of regulation of flight from the perspective of each crew member.

6

7 **Methods**

8 **Participants and situations**

9 Six sailors (two women and four men) participated in this study. They belonged to four
10 double-handed foiling catamaran crews (Nacra 17 and Flying Phantom crews). All participants
11 were expert at catamaran sailing, and had been training intensively on flying catamarans for six
12 months. The crew members of the Nacra 17 (Olympic mixed multihull) were part of the French
13 national sailing team¹. The remaining four sailors were taking part in an elite training program
14 dedicated to training young adult sailors for high-level international sailing competitions. They
15 formed two Flying Phantom crews. In the rest of the text, the participants are respectively
16 identified as follows: HNA (helmsman of the Nacra 17), CNA (crew of the Nacra 17), HFP1
17 (helmsman of one of the Flying Phantoms), CFP1 (crew of the aforementioned Flying
18 Phantom), HFP2 (helmsman of the other Flying Phantom) and CFP2 (crew of the other Flying
19 Phantom). The protocol of the present study was approved by the Ethical Committee for Non-
20 Interventional Research of the University of Nantes, France, and all participants provided
21 written informed consent.

¹ It should be noted that the crew members of the Nacra 17 were the same in the present study and in the study of Terrien et al., 2020. However, data were collected during different training sessions for each study.

1 Nacra 17 and Flying Phantoms are double-handed sports catamarans² which are
2 respectively 17 feet (5.2 meters) in length and 18 feet (5.5 meters) in length. On this type of
3 boat, the respective roles of the helmsman and the crew go beyond the simplistic view of the
4 helmsman steering the boat by acting on the rudders while the crew trims the sail for power and
5 balance. Indeed, the light weight of these boats combined with the set-up of hydrofoils make
6 them extremely sensitive to both the crew members' actions and environmental conditions.
7 Once flying, the stability of the flight requires a balance of the forces produced by the sails, the
8 forces produced by the foils, and weight distribution on the boat. From a mechanical viewpoint,
9 the regulation activity of the crew members consists primarily in finding and maintaining a
10 balance between these forces. To do so, both crew members simultaneously regulate the sails
11 through the sheets³, and use their bodyweight to counterbalance the forces produced by the sails
12 and the foils. On these types of boat, any lack of coordination in the ongoing regulation by the
13 crew members can lead to sudden losses of speed and crashes.

14 The crew members' activity was studied during three training sessions (one for each
15 crew). In total, 6 hr of on-water training sessions were studied. During HFP1's and CFP1's
16 session the windspeed ranged from six to ten knots and the sea conditions were calm. During
17 HFP2's and CFP2's session, the windspeed ranged from 18 to 22 knots and the sea conditions
18 were calm despite strong wind. During HNA's and CNA's session the windspeed ranged from
19 ten to twelve knots and the sea conditions were calm.

20 **Data collection**

21 Data was collected in two steps: (a) *in situ* data was collected during the sailing sessions, and
22 (b) self-confrontation interviews were conducted after the sailing sessions.

² See <https://nacra17.org/> for technical information about this type of boat.

³ In nautical usage, the term "sheet" refers to the rope attached to the lower corners of the sails.

1 The *in-situ* data was collected by filming the foiling boat from a motorboat.
2 Furthermore, the onboard conversations of the crew members were recorded by connecting
3 their wireless communication system to the camera filming the boat.

4 Individual self-confrontation interviews (Theureau, 2003) were conducted after the
5 sailing sessions. Self-confrontation interviews consisted of confronting each sailor individually
6 with the recorded videos of the training session while the researcher guided them to describe
7 the course of their lived experience of that session. The purpose of these interviews was to
8 collect the expression of the pre-reflective self-consciousness (Legrand, 2007; Theureau, 2003,
9 2006) of the sailor associated with the lived situation described. The questions and follow-ups
10 used by the researcher in this type of interview are inspired by Vermersch's (1994) explicitation
11 interview method. The time lapse between the training session and the self-confrontation
12 interviews varied from 2 hr to 12 hr, depending on the availability of the crew members to
13 participate in the interviews. The interview length ranged from 40 min to 1 hr 30 min. The
14 sailors were asked to watch selected video sequences of the training sessions. The video
15 sequences were selected by the researcher in agreement with the crew members. This selection
16 included the take-off and flying legs of navigation, and excluded non-flying legs (e.g., upwind
17 legs in low wind), breaks, and series of tacks or jibes. A total of 1 hr 4 min of recorded training
18 sessions were used for self-confrontation interviews. Both crew members of a same boat were
19 interviewed individually about the same video sequences. During the interviews the crew
20 members were asked to immerse themselves in the past training session, using the video-
21 recorded data as a means of contextual recall. Each crew member was invited to relive each
22 specified moment of the training session, and to comment on it aloud to the interviewer. At the
23 end of each interview, the researcher offered the sailor the possibility to review a sequence, or
24 to select another sequence of their choice in case they had failed to describe salient experiences.
25 All the sailors declined to review a sequence or select another sequence and expressed their

1 satisfaction with the completeness of their description. All interviews were recorded using a
2 video camera.

3 **Data analysis**

4 Data analysis involved three steps: (a) transcription and synchronization of the data; (b)
5 identification of episodes of flight control; (c) categorization of typical modes of flight control.

6 First, all recorded on-board verbalization of the crew members as well as the
7 verbalizations obtained from the self-confrontation interviews were transcribed verbatim. In
8 addition, the boat's salient movements (e.g., heeling, counter-heeling, breaching, flying,
9 skimming) and the crew members' salient actions (e.g., trapezing, modifying the rake, salient
10 movements of easing or sheeting the sails) were precisely described in the technical language
11 of sailing. The transcriptions and descriptions were then synchronized to retrieve the
12 chronology of the crew members' experience in relation to their actions and the boat's
13 movements.

14 The second step of the analysis consisted in identifying the episodes of flight control.
15 This comprehensive analysis was derived from the self-confrontation interview verbalization
16 data (i.e., the expression of the pre-reflective consciousness of the actor) and also relied on the
17 descriptions of crew members' actions and boat movements as cues to understand the context
18 of the action and in order to avoid misinterpretation of the verbalization data.

19 Each episode of flight control was identified and delimited on the basis of an evolution
20 of the concerns of each crew member relating to flight control. The concerns of each crew
21 member were identified in relation to the answers to the following questions: What are the crew
22 member's meaningful interests in the situation? What is their intention? What are they trying
23 to do? (Mottet & Saury, 2013). An episode was delimited whenever an evolution of the
24 concerns was identified for a crew member. A total of 107 episodes were identified, including

1 53 episodes for the helmsmen and 54 episodes for the crews: 27 episodes for HFP1 and 27 for
2 CFP1; 20 episodes for HFP2 and 19 for CFP2; 7 episodes for HNA and 8 for CNA (see details
3 in Appendix A). Each episode lasted an average of approximately 30 seconds. For each episode,
4 we also identified the meaningful perceptions and actions of each crew member. Meaningful
5 perceptions were identified by answering the following questions: What element is the
6 meaningful element supporting the crew member's activity? What element is the crew member
7 considering? (Feigean et al., 2018). Actions were identified by answering the following
8 questions: What is the meaningful action in relation to the control of the flight in the crew
9 member's experience during this episode?

10 The third step of the analysis consisted of a categorization of the crew members' typical
11 modes of regulation of the flight during the episodes. We started the analysis by grouping the
12 episodes in which the concerns of the crew members presented similarities in terms of
13 intentionally aiming to regulate flight stability. For example, all episodes in which the crew
14 members' concerns were to modify the rake angle to facilitate the control of the boat were
15 grouped in the same category: "To modify the set-up to facilitate the control of the boat". Eight
16 categories of typical modes of regulation of the flight were distinguished (Appendix A).

17 Finally, the eight categories of typical modes of regulation of the flight were classified
18 into main types of modes of regulation according to: (a) the nature of the perceptual elements
19 considered by the crew member to act on flight stability ("are the perceptions of the crew
20 member mainly related to the boat's movements or to their teammate's action?"); and (b) the
21 purpose of addressing this crew member's action ("are the actions of the crew member mainly
22 directed towards the control of the teammate's action or towards control of the boat's
23 movements?").

24 The analysis was conducted by the first author with the other co-authors acting as a
25 "critical friend" (Marshall & Rossman, 2006). This involved reading transcripts and watching

1 videos, discussing and asking provocative questions about the labeling of the episodes, and
2 contributing to the development of the categories. The three co-authors are experienced in
3 conducting qualitative research within the Course of Action framework. The first and the third
4 authors have extensive knowledge of sailing from personal practice. All three authors are
5 familiar with sailing terminology and have been involved in previous research on qualitative
6 research on sailing and hydrofoil sailing.

7

8 **Results**

9 The analysis revealed three main modes of regulation of flight, in terms of both
10 perceptual object and purpose of the action: (a) actions directed to the boat's movements
11 coupled with perceptions of the boat's movements, (b) actions directed to the teammate's
12 behavior coupled with perceptions of the boat's movements, and (c) actions directed to the
13 boat's movements coupled with the perception of the teammate's actions.

14 **Actions directed to the boat's movements coupled with perceptions of the boat's** 15 **movements**

16 This main mode of regulation of the flight stability of the boat corresponded to episodes
17 in which the perceptions of the crew members were strongly related to the boat's movements,
18 and their actions were related to the regulation of the boat's movements through the available
19 controls. In this way, the actions of the crew members were guided by the perception of the
20 boat's movements, without the actions of their teammate being meaningful in their experience.
21 Indeed, while their actions were triggered by the perceptions of the boat's movements, they
22 triggered boat movements through their respective actions. During these episodes, the
23 possibilities for action of the crew members were directly linked with the ongoing movements
24 of the boat.

1 This main mode of regulation includes four categories of typical modes of regulation of
2 flight: “to modify the set-up to facilitate the control of the boat” (category 1); “to limit one’s
3 own actions to limit the movements of the boat” (category 2); “to regulate the movements of
4 the boat by actively focusing on the boat’s movements” (category 3); “to react to unexpected
5 catastrophic movements of the boat” (category 4). It includes a total of 53 episodes: 26 episodes
6 for helmsmen and 27 episodes for crews.

7 For an example illustrating category 2, in a situation of stable flight (i.e., without rocking
8 or heeling movements), when the boat was flying on a broad reach at steady speed, we observed
9 reduced amplitude of the movements of the crew members compared to episodes with unstable
10 flight on the same leg. Referring to this situation, HNC17 said in the self-confrontation
11 interview:

12 As soon as I managed to stabilize the tiller and the mainsheet and it lasts 100 meters without
13 having anything to touch [then] it was a good phase and in fact to get to that you have to
14 constantly tell yourself to try to smoothen the actions and the smoother you are, the more
15 precise [in driving the boat] you are, in fact. (HNC17, episode 4, category 2)

16 This example highlights a crew member’s consideration of the interdependency between
17 their own actions (i.e., regulating with the tiller and the sheet) and the boat’s movements (i.e.,
18 stable flight). In this situation, the crew’s activity was not salient in the helmsman’s experience.
19 Interestingly, the helmsman’s possibilities for action (i.e., not to touch anything for 100 meters)
20 were also related to the boat’s possibilities of movement: smoothening the actions contributed
21 to stabilizing the flight, but it was also because during this episode the wind strength was steady
22 and the water was calm, that the boat, once stabilized, could remain stable for a certain duration.
23 At this point, any hydrodynamic or aerodynamic variation would have changed the possibilities
24 of movement of the boat (e.g., acceleration, decelerating, rolling or rocking) and therefore the
25 helmsman’s possibilities for action.

1 **Actions directed to the teammate's behavior coupled with perceptions of the boat's**
2 **movements**

3 This main mode of regulation of the boat's flight stability corresponded to episodes in
4 which one of the crew members explicitly influenced their teammate's action in order to regain
5 or improve their (the crew member's) own control of the boat. In this case, the crew member's
6 perceptions were strongly linked to the boat's movements, and their actions were directed at
7 controlling the teammate's action. Although the teammate's action was also perceived, it was
8 the perception of the boat's movements that drove the action.

9 This main mode of regulation includes three categories of typical modes of regulation
10 of flight: "to encourage the teammate to take concrete actions on the control of the boat"
11 (category 5); "to influence the teammate's concerns to anticipate boat movements" (category
12 6); "to limit the teammate's action to facilitate the control of the boat" (category 7). It includes
13 a total of 35 episodes: 19 episodes for the helmsmen and 16 episodes for the crews.

14 For an example illustrating category 5, in a situation where the boat was flying at high
15 speed, the bows pointing up and the foils about to breach the surface of the water, the helmsman
16 told the crew: "Move forward!" Referring to this situation, HFP1 said in the self-confrontation
17 interview:

18 I told him [the crew] to move forward because I felt that it [the boat] was going up (...) I
19 tell myself it [the foils] must not ventilate so the crew must move forward, not too suddenly
20 so that we keep the flight and the speed, but he must move forward. (HFP1, episode 25,
21 category 5).

22 This example highlights one crew member's consideration of the interdependence
23 between their teammate's action and the movements of the boat. In this case, the teammate was
24 used by the crew member as a means of control of the boat, to regulate the boat's movements.

1 The possibilities for the crew to move forward (or not) extended the helmsman's possibilities
2 for action to act on boat movements. However, in this situation, it was not the perception of the
3 crew's action by the helmsman that was meaningful. Instead, it was the perception by the
4 helmsman of the boat going up that led her to "choose" the crew to control the boat by asking
5 him to move forward.

6 **Actions directed to the boat movements coupled with perceptions of the teammate's action**

7 In contrast with the first two main modes of regulation, the third represents a mode of
8 regulation in which one of the crew members had a salient experience of their control of the
9 boat while feeling constrained by their teammate's action. In this case, the crew member's
10 perception was closely linked to the effects of their teammate's action on the boat, and their
11 actions were directed at controlling the boat's movements.

12 This main mode of regulation includes one category of typical mode of flight regulation:
13 "to act on the boat while feeling constrained by the teammate's action" (category 8). It includes
14 a total of 19 episodes: nine episodes for helmsmen and ten episodes for crews.

15 For an example illustrating category 8, during a situation where the boat was flying at
16 high speed and the helmsman bearing away from a reaching point of sail to a broad reach, the
17 crew fully released the mainsail, which started to flap. Referring to this situation, CFP2 said in
18 the self-confrontation interview:

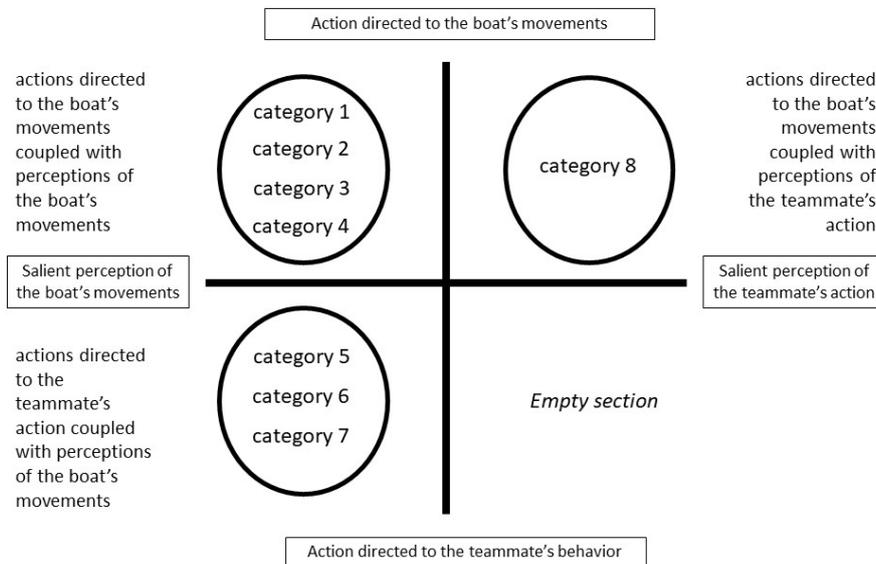
19 I was expecting us to take off upwind and I see him [the helmsman] bearing away quickly
20 and there I say to myself that's tricky, because the mainsail starts to flap because I can't do
21 anything else I'm totally overpowered, [even] having released all the energy of the
22 mainsail. (CFP2, episode 16, category 8)

23 During this episode, the crew perceived the action of the helmsman on the rudders,
24 making the boat bear away and causing the subsequent acceleration of the boat, which made

1 him release the mainsheet to try to keep control of the boat. As in the previous main mode of
2 regulation, this situation highlights a crew member's consideration of the interdependency
3 between his teammate's action and the boat's movements. However, in this case, it was the
4 perception of the teammate's action that was considered as determinant in the situation, and led
5 to acting on the boat to keep it in control, even if in this specific case the control was lost. In
6 sum, this example illustrates that for one of the crew members, the actions of his teammate
7 limited his own possibilities for action on the control of the boat (here, by "forcing" the crew
8 member to release the mainsheet so much that it "flapped", as a last resort to reduce the power
9 in the boat, due to the change in point of sail carried out by the helmsman). While in this main
10 mode of regulation we could have expected situations in which a crew member perceived his
11 teammate's action as facilitating his own actions on the boat, no such situation was identified
12 in the present study.

13 The three main modes of regulation previously described and the categories that
14 compose them are presented in Figure 1. Interestingly, a gap is observed in the diagram (Figure
15 1). Indeed, no main mode of regulation was identified in the present research that could fit the
16 fourth space, that would correspond to "action directed at the teammate's behavior coupled with
17 perceptions of the teammate's action".

1 // INSERT FIGURE 1 HERE //



2

3 *Figure 1. Synthetic diagram of the three main modes of regulation and the categories that compose them*

4

5 **Discussion**

6 The aim of this study was to deepen the analysis of crew members' mutual modes of
7 regulation of flight on foiling catamarans. The results describe three main modes of flight
8 regulation, that were identified from the crew member's perspective. The characteristics of
9 these three modes of regulation and of the categories they include highlight original modes of
10 relationship between each crew member and the boat, if we consider both (a) the nature of the
11 perceptual elements that leads the crew member to act in a certain way on flight stability, and
12 (b) the addressing of crew member's purposeful action. These three modes of regulation reflect
13 three forms of interdependence between the respective activities of each crew member and the
14 movements of the boat, with those activities and movements generating the opening or the
15 limiting of each crew member's possibilities for action, and the possibilities of movement of
16 the boat.

1 These findings are discussed in the following subsections in relation to three issues
2 concerning respectively, (a) the consideration of the boat as a “third partner” of the coordination
3 between crew members; (b) the two levels of analysis (local/global) of the partnership between
4 the crew members and the boat; and (c) the introduction of new distinctions regarding the role
5 of the material environment in team coordination in sports.

6 **The boat as the third partner of the coordination?**

7 The results show that each teammate interacts constantly and intensively in relation to
8 the movements of the boat, in order to control its flight stability. Indeed, out of eight categories
9 of modes of regulation of the flight, seven categories reflect a sensitivity of each teammate to
10 the movements of the boat, which determines their respective actions directed towards the boat
11 (four categories: 1 to 4), and towards their teammate (three categories: 5 to 7). Conversely,
12 there is only one category (category 8) in which actions directed to the boat’s movement are
13 associated with perception of the teammate’s action, and there is no category in which action
14 directed to the teammate’s behavior is associated with the perception of the teammate’s action.
15 The distinction between modes of regulation based on the perception of the boat’s movements
16 coupled with action directed to the boat’s movements, and modes of regulation based on
17 perceptions of the teammate’s action or with action directed to the teammate’s behavior is in
18 line with previous studies on collective coordination in rowing (e.g., Millar et al., 2013;
19 R’Kiouak et al., 2016) and sailing (Terrien et al., 2020). Indeed, these studies highlighted the
20 distinction between interpersonal modes of regulation of the coordination (i.e., when athletes
21 with a salient experience of their joint action coordinate their action), and extrapersonal modes
22 of regulation of the coordination (i.e., when athletes coordinate without having salient
23 experience of their joint action). In our results, categories 1 to 4 can be interpreted as reflecting
24 extrapersonal modes of regulation, and categories 5 to 8 as reflecting interpersonal modes of
25 coordination.

1 However, these results allow us to go beyond the previous analyses. They highlight
2 more precisely how the actions of each teammate and the movements of the boat open or close
3 interdependently teammates' possibilities for action and boat's possibilities of movement. That
4 is, these actions and movements open or close for each teammate, on the one hand, their own
5 possibilities for action on the boat and those of their teammate, and on the other hand, the
6 possibilities of movement of the boat at each moment. Indeed, each crew member of the foiling
7 catamaran regulates the flight, considering both the teammate's actions as opening or closing
8 their own possibilities for action on the boat, and their perceptions of the possibilities for action
9 of the teammate on the boat. Previous research refers to the capacity of each team member to
10 accurately perceive what actions are possible for another team member and what actions
11 another team member renders possible. That is, the mutual perception of shared affordances
12 “for the teammate” and “of the teammate” has been considered as the main process underlying
13 team coordination (Fajen et al., 2008; Silva et al., 2013). However, in the case of coordination
14 between crew members on a flying catamaran, the perception of both the boat's movements
15 and the boat's possibilities of movement open or close (define) the extent of possibilities for
16 action to control flight stability, in the ongoing activity of each crew member. Thereby, from
17 the experience of each crew member, the boat is perceived, just as the teammate's is, as having
18 possibilities of movements defined by one's actions and at the same time defining possibilities
19 for one's actions. From this perspective, the boat appears as a “material partner” of crew
20 coordination, from the lived experience of each crew member.

21 The idea that the boat could be considered as an “interacting agent” rather than as a
22 “mediating structure” of the coordination (e.g., Millar et al., 2013; R'Kiouak et al., 2016) has
23 already been advocated by Terrien et al. (2020), in a study focused on expert sailors'
24 coordination in flying catamarans (Nacra 17). The authors suggested that on a flying boat,
25 ongoing modifications of the boat's movements are not only generated by the activities of each

1 teammate, but depend on environmental constraints such as wind and waves in a way that is
2 not fully predictable by the crew members. The results of the present study reinforce the idea
3 that in the crew members' experience, the boat "comes to life", in that the behavior of the boat
4 is partly independent of the actions of the teammates (Terrien et al., 2020), but still makes it
5 possible for the crew members to regulate its possibilities of movement to some extent. Thus,
6 the boat is experienced by the crew members as a "third partner" endowed with a quasi-agency,
7 that plays a fundamental role in the teammates' coordination. Indeed, from a phenomenological
8 point of view, for each crew member this coordination is based on both possibilities for action
9 of/for the teammate, and on possibilities of movement of/for the boat.

10 It is important to note that we do not consider the boat (and particularly the flying
11 catamaran) as an autonomous system, nor as a living system, *per se*. Flying catamarans, like all
12 sail boats, are material equipment whose mechanical functioning is fundamentally determined
13 and explained by physical laws (e.g., fluid hydrodynamics and aerodynamics) (Fossati, 2009).
14 However, the fact that the boat is phenomenologically experienced by the crew members as
15 material equipment that "comes to life" in its interactions with the crew and with its fluctuating
16 and uncertain natural environment (i.e., wind flow, waves), behaving like a "third partner", is
17 of interest for understanding team coordination in such team sport situations that include shared
18 material equipment.

19 **The boat as a singular partner and as a global hybrid system**

20 The distinction between the three main modes of flight regulation described in the
21 present study provides details on local and global modes of regulation of team coordination.
22 Indeed, the hypothesis of the existence of interdependent levels of regulation has been
23 advocated by authors of previous studies in sport (e.g., Bourbousson et al., 2019; Bourbousson
24 & Fortes Bourbousson, 2016; Feigean et al., 2018; Gesbert et al., 2017). Feigean et al., (2018)
25 highlighted that football players do not rely only on local information to achieve team

1 coordination, but also have a sense of the dynamics of global behavior. In the present study, the
2 two main modes of regulation respectively titled “Actions directed to the teammate’s behavior
3 coupled with perceptions of the boat’s movements” (categories 5 to 7), and “Actions directed
4 to the boat’s movements coupled with the perception of the teammate’s action” (category 8),
5 can be seen as modes of regulation at a local level, as they reflect interactions between each
6 crew member and the boat, mediated or constrained by the teammate. Conversely, the main
7 mode of regulation titled “Actions directed to the boat’s movements coupled with perceptions
8 of the boat’s movements” (categories 1 to 4), can be seen as a mode of regulation at a global
9 level, as it reflects interactions between each crew member and the boat considered as a whole
10 (system including the catamaran and the teammate).

11 Therefore, from a phenomenological perspective (i.e., from the crew members’ lived
12 experience), the boat could be considered both as a singular partner of the crew members, and
13 as a global hybrid system, with these two levels being important to understand the coordination
14 between the sailors. In sum, onboard coordination to reach or maintain stable flight is a “game
15 of three”, in which the boat is a third partner, both at a local and at a global level. At a local
16 level, the boat constitutes a source of constraints opening or limiting each crew member’s
17 possibilities for action, depending on the specific controls each one handles as helmsman or as
18 crew. At a global level, it can be seen as a hybrid system, inseparably including both the foiling
19 catamaran and the teammate, and manifesting its own behavior in the interaction with its
20 environment. Thereby, sailing on a double-handed foiling catamaran provides an interesting
21 example of an upward/downward causation (Thompson & Varela, 2001): on the one hand, the
22 interactions between local modes of regulation of each crew member coupled with the foiling
23 catamaran’s movements cause a global behavior of the whole system (i.e., flight stability); on
24 the other hand, this global behavior of the boat in turn causes adjustments of regulation modes
25 in each crew member, at a local level. Interestingly, Bourbousson & Fortes Bourbousson (2016)

1 emphasized that the distinction between local and global scales of collective behavior may not
2 be clearly distinguished in studies with participants adjusting to a single co-agent. In the case
3 of the double-handed foiling catamaran, although there are only two humans onboard, the
4 results of the present study reveal the distinction between local and global levels of regulation.
5 In fact, we suggest that the use of shared sport equipment may contribute to revealing a
6 phenomenon of holoptism (Bourbousson & Fortes Bourbousson 2016; Feigean et al., 2018), as
7 the capacity of teammates to grasp the global picture they collectively contribute to enacting
8 (Bourbousson & Fortes Bourbousson, 2016). But unlike previous studies that have described
9 this phenomenon, in the present study the global level does not emerge from social interactions
10 between humans, but rather emerges from interactions between the components of a hybrid
11 system. This is likely to broaden the notion of holoptism, by extending it to material components
12 of collective situations.

13 **Towards new distinctions regarding the role of the material environment in team** 14 **coordination in sports**

15 The results of the present study, following previous studies (Millar et al., 2013;
16 R'Kiouak et al., 2016; Terrien et al., 2020), contribute to highlighting the role of the material
17 environment, including shared sport equipment, in team coordination. We propose to
18 distinguish three main categories of situations in which the material environment plays different
19 roles in team coordination, from a phenomenological perspective: (a) the material environment
20 as an inert “surrounding landscape” providing teammates with informational resources to
21 coordinate; (b) the material environment as a mediating structure for team coordination; and (c)
22 the material environment as a partner of team coordination.

23 First, the material environment can be considered as a spatial frame for the athlete's
24 activity. For example, in basketball the distance between the players and the basket is a
25 parameter influencing an attacker-defender's dyad coordination (Esteves et al., 2012). Vilar et

1 al. (2012) highlight the influence of the positioning of an attacker in relation to the goal and a
2 defender on interpersonal interaction in futsal. Passos et al. (2008) show that the proximity
3 between an attacker and defender to the try line in rugby union influences the organization of
4 attacker-defender dynamics. In all these situations, the shared environment is a spatial frame
5 for the players' activity and the evolution on the affordance landscape for the players only
6 depends on the players' activity. Typical examples of sport situations within this category may
7 be found in most ball sports played on courts and fields (e.g., football, futsal, basketball, rugby).

8 Second, the material environment can be considered as a mediating structure for team
9 coordination, when this environment is mainly formed of shared sport equipment whose
10 behavior is essentially subordinate to the actions of the crew. This kind of situation has been
11 described by Millar et al. (2013) and R'Kiouak et al. (2016) on rowing boats. In these situations,
12 the material environment takes an active role in crew coordination by transferring information
13 about the activity of one rower to the other. R'Kiouak et al. (2016) refer to a stigmergic process
14 that explains the mediating role of a mechanical structure. Applying this theory to shared sport
15 equipment presupposes that: (a) the equipment is sensitive to individual activities (this is the
16 case for a boat, not for a basketball court) in order to record traces of individual activities, and
17 (b) the traces left by a person's activity on the equipment are available for that person and others
18 to organize the collective activity. Thus, it seems acceptable to consider that a rowing boat can
19 respond to these characteristics, as a mediating, mechanical structure, as can a sailboat to some
20 extent also (e.g., the sailboat "records" the crew members' settings). A typical example of a
21 sports situation within this category may be found in sports involving shared sport equipment,
22 when the athletes' primary activity is to produce the movements of that equipment (e.g., rowing
23 in crew, sprint kayaking and sprint canoeing in crew, tandem cycling).

24 Third, the material environment can be considered as a partner of team coordination,
25 when this environment is mainly formed by shared sport equipment whose behavior is partly

1 independent of the crew members' activity. This kind of situation is typically represented by
2 sailing on double-handed foiling catamarans. The present study reinforces the idea of enabling
3 a distinction between the shared sport equipment as a mediator and the shared sport equipment
4 as a "quasi agent" from the athletes' perspective. Indeed, while in both situations athletes are
5 mechanically coupled through the shared sport equipment, we argue that the boat is experienced
6 by the sailors as actively participating in the regulation of their possibilities for action through
7 its possibilities of movements. These possibilities of movements depend on the sailors' actions
8 and on the environmental conditions. Furthermore, while this is beyond the scope of this study,
9 we postulate that in some way, the boat is co-responding to environmental changes thanks to
10 its mechanical characteristics⁴ at the same time as it co-responds to the sailors' actions.

11 The aim of our study was to pursue the exploration of collective coordination in highly
12 equipment-dependent sports. While the role of shared sport equipment has been highlighted
13 recently by studies in rowing, the main contribution of this paper is to mark the distinction
14 between sport equipment as mediating mechanical structure and sport equipment as a quasi-
15 agent. Therefore, this study brings: (a) complementary insight compared to previous studies on
16 collective coordination in rowing (e.g., Millar et al., 2013; R'kiouak et al., 2016) and sailing
17 (e.g., Terrien et al., 2020), and (b) a global contribution to the understanding of collective
18 coordination in sports by emphasizing the distinction between classes of situations in which the
19 process underlying collective coordination may differ, regarding the role of the material
20 environment in this coordination.

21 However, our study also has its limitations. First, the small number of participants
22 included in the study, the limited time duration of the analyzed dataset and the singularity of
23 the chosen sport (i.e., double-handed foiling catamaran) may be seen as a limit to the

⁴ Without entering into advanced technical considerations, we can illustrate this phenomenon by the following example: when entering a gust of wind, the increased aerodynamic forces on the sails may contribute to an increase in the boat's speed that in return modifies the direction and strength of the wind in the sails.

1 generalization of the findings. It is worth noting that part of the epistemology of the Course of
2 Action research program relies on the notion of “privileged situation for the resolution of a
3 scientific problem” (Theureau, 2020, p. 16). In the present study, it is the specificity of the
4 double-handed foiling catamaran, as a boat that is fast, unstable and very sensitive to the crew
5 members’ actions and to the variations in environmental conditions, that makes it a “privileged
6 situation” to study collective coordination confronted to such types of constraints. In relation to
7 other team sports, the situations experienced by the crew members sailing on these boats can
8 be considered as “extreme cases” (Flyvbjerg, 2006). In sum, the present study contributes to
9 qualitatively describing phenomena revealed by the use of shared sport equipment that is
10 sensitive to the teammates’ actions while maintaining a functional relationship with its natural
11 environment. We hypothesize that while these phenomena may not represent the main process
12 of team coordination in most sports, there may be an underlying process that has hitherto been
13 neglected.

14 A second limitation of our study is the qualitative characterization of the crew members’
15 behavior and the boat’s movements. Indeed, other studies in rowing (e.g., R’Kiouak et al., 2016;
16 Seifert et al., 2017; Sève et al., 2013) combine phenomenological and mechanical data to study
17 collective coordination. In those cases, mechanical measurements were made using onboard
18 instruments in order to quantify key aspects of the crew members’ behavior or the boat’s
19 movements. In sailing, Terrien et al. (2020) used onboard instruments to quantify the boat’s
20 angle of heel. In the present study, using a standardized method of measurement of the crew
21 members’ behavior and boat movements has not been possible. Further study should focus on
22 the validation of tools and methods of analysis of boat movements in relation to sea conditions
23 and crew members’ behavior on single or double-handed sailing boats.

24 Despite these limitations, the empirical phenomena highlighted in this study seem to us
25 to be of sufficient interest to invite researchers to deepen and complete these preliminary results

1 in future studies. The present study highlights the fruitfulness of using qualitative methods of
2 analysis based on phenomenological data to explore team coordination in ecological settings.
3 Indeed, the study of collective coordination in highly equipment-dependent sports offers a
4 particularly favorable ground for the development of mixed methods, associating
5 phenomenological and mechanical approaches (e.g., R'Kiouak et al., 2016; Seifert et al., 2017;
6 Sève et al., 2013). These can provide better understanding of the collective performance of
7 complex systems integrating human agents and shared material equipment. This includes
8 paying particular attention to the specificity of their interactions in different sporting situations.
9 Such an understanding can in turn have interesting consequences for the optimization of team
10 performances.

11 Funding: This research did not receive any specific grant from funding agencies in the public,
12 commercial, or not-for-profit sectors.

13

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1 **APPENDIX A**

	Main category 1: Actions directed to the boat's movements coupled with perceptions of the boat's movements				Main category 2: Actions directed to the teammate's behavior coupled with perceptions of the boat's movements			Main category 3: Actions directed to the boat's movements coupled with perceptions of the teammate's action		
	Category 1: To modify the set-up to facilitate control of the boat	Category 2: To limit one's own actions to limit the movements of the boat	Category 3: To regulate the movements of the boat actively by focusing on the boat's movements	Category 4: To react to unexpected catastrophic movements of the boat	Category 5: To encourage the teammate to take concrete actions on the control of the boat	Category 6: To influence the teammate's concerns to anticipate boat movements	Category 7: To limit the teammate's action to facilitate the control of the boat	Category 8: To act on the boat while feeling constrained by the teammate's action	Total	
Crew members										
HFP1	0	1	5	0	9	5	0	5	25	
CFP1	1	1	6	0	2	6	3	8	27	
HFP2	5	0	5	5	1	3	0	3	22	
CFP2	3	0	6	5	0	2	0	2	18	
HNA	0	2	0	3	0	0	1	1	7	
CNA	0	2	0	3	0	2	1	0	8	
Total Categories	9	6	22	16	12	18	5	19	107	
Total Helmsmen			26			19		9	54	
Total Crews			27			16		10	53	
Total Main Categories		53				35		19	107	

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