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► To cite this version:

D. Adé, G. Poizat, Nathalie Gal-Petitfaux, Huub Toussaint, L. Seifert. Analysis of elite swimmers' activity during an instrumented protocol. *Journal of Sports Sciences*, 2009, 27, pp.1043-1050. 10.1080/02640410902988669 . hal-00570395

HAL Id: hal-00570395

<https://u-bourgogne.hal.science/hal-00570395>

Submitted on 6 May 2011

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Analysis of elite swimmers' activity during an instrumented protocol

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Abstract

The aim of this study was to examine swimmers' activity–technical device coupling during an experimental protocol (MADsystem). The study was conducted within a course-of-action theoretical and methodological framework. Two types of data were collected: (a) video recordings and (b) verbalizations during post-protocol interviews. The data were processed in two steps: (a) reconstruction of each swimmer's course of action and (b) comparison of the courses of action. Analysis from the actors' point of view allowed a description of swimmer–technical device coupling. The results showed that the technical device modified the athletes' range of perceptions and repertoire of actions. They also indicated that changes in coupling between the swimmers and the MAD-system were linked to utilization constraints: the swimmers' experiences were transformed in the same speed intervals, suggesting that this was an essential situational constraint to swimmer–technical device coupling. This study highlights how a technical device and the conditions of its use changed athletes' activity and suggests that it is important to develop activity-centred design in sport.

Keywords: Activity-oriented approach, technical device, course of action, swimming

Introduction

Biomechanical analyses in swimming usually require equipment, tools, and technical devices to assess kinematic and kinetic measures that influence performance. However, few studies have examined how interactions between swimmers and these technical devices affect swimming behaviour. This led us to focus on swimmers' activity in these heavily instrumented environments. Human locomotion in water poses the challenge of optimizing movement coordination to exploit aquatic resistance and so maximize propulsion while minimizing active drag. It would therefore be informative to examine how technical devices used to quantify propulsion and active drag affect the motor habits of swimmers. Indeed, most biomechanical studies use measurement devices that are wired to swimmers and manipulated by the investigators. Since much of the energy expenditure in swimming is used to overcome drag, di Prampero and colleagues (di Prampero, Pendergast, Wilson, & Rennie, 1974) quantified active drag from the variation in oxygen consumption that resulted from additional forces used to overcome the drag. Hollander et al. (1986) used a new system for the Measurement of Active Drag (MAD-system), which directly measured the forces of the hand as it pushed off from a series of pads fixed on a rod. A third method, the speed-perturbation method, calculates the active drag by comparing two conditions of swimming at

maximal speed: swimming in a free condition and swimming with an attached hydrodynamic body that imposes additional resistance (Kolmogorov & Duplischeva, 1992; Toussaint, Roos, & Kolmogorov, 2004). In summary, the different technical devices used to assess propulsive forces and active drag modify swimming technique to varying degrees over that used in the "free" condition, suggesting that even if they provide valid and reliable measures, they could affect swimmers' activity. A better understanding of the coupling between the swimmer and the technical device is thus required, and the concept of activity provides a way of conceptualizing this coupling (Beguin, 2003; Leplat, 2001). The present study was conducted using an activity-oriented approach (Daniellou & Rabardel, 2005). We opted for the course-of-action theoretical and methodological framework (Theureau, 2002, 2003), which has previously been used to analyse the components of elite athletes' activity during competition and training (e.g. d'Arripe-Longueville, Saury, Fournier, & Durand, 2001; Hauw, Berthelot, & Durand, 2003; Hauw & Durand, 2007; Se`ve, Poizat, Saury, & Durand, 2006). Course-of-action provides a means to study simultaneously characteristics of a technical device and swimmers' activity. The theory and method of course of action were developed in French ergonomics research (Daniellou, 2005) for the analysis of occupational tasks and ergonomic conceptions of occupational settings. The course-of-action theory has been enriched by the work in "situated action/cognition" (Hutchins, 1995; Kirshner & Whitson, 1997; Lave, 1988; Suchman, 1987), which postulates that: (a) all activity is situated, meaning that it cannot be dissociated from the context in which it takes shape, and must therefore be studied in situ; and (b) a structural coupling defines the relationship between the actor and his or her environment. This coupling, which is continuously transformed over the course of activity, emerges from actors' efforts to adapt to a context whose meaningful elements are resources that they will use to act. According to course-of-action theory, couplings between actors and environments are asymmetric in that they concern only those elements from the environment that the actors select moment by moment as most relevant to their internal organization. Thus, to understand this coupling between actors and their material environment, the course-of-action framework provides tools to study the meaning that actors construct during these couplings from their verbalizations. The course of action is the part of activity that is meaningful for the actor. It can be defined as follows: "the activity of a given actor engaged in a given physical and social environment, belonging to a given culture, where the activity is meaningful for that actor; that is, he [sic] can show it, tell it and comment upon it to an observer-listener at any instant during its unfolding" (Theureau & Jeffroy, 1994, p. 19). The semiological framework of the course of action is rooted in the hypothesis that actors think (and act) through signs (Peirce, 1931–1935). The course of action is made up of a chain of signs that are meaningful units of activity emerging from the coupling between an actor and the context. By identifying these signs, the actor's course of action is reconstructed, and this reconstruction provides insight into the process by which meaning is built during action. The aim of this study was to analyse the coupling between swimmers and a technical device (the MAD-system) during an experimental protocol. This was accomplished by first

describing the swimmers' activity as they used the device, particularly the dynamics of change in two dimensions: the swimming mechanics (i.e. speed and force) and the meaning that the swimmers themselves attributed to the activity (i.e. the swimmers' report of their experience of swimming with the MAD-system). The starting point of this work was to question the prevailing assumption that these devices are "content-free" (Dyson & Grineski, 2001): that is, independent of swimmers' activity. Our research assumption was that, since the environment continuously structures activity, it is important to examine *in situ* the dimensions of swimming activity that emerge from the coupling of swimmers and a technical device. These dimensions, notably dynamic and meaningful, are often overlooked in evaluation protocols and yet they could be helpful in improving technical design. We anticipated that: (a) the MAD system would change the usual activity of swimmers to a degree that exceeded the expectations of its designers, and (b) the coupling between the swimmers and the MAD-system would be diverse.

Methods

Participants

Three international-standard male swimmers participated in this study (Table I). The protocol was explained in full to them and they provided written consent to participate in the study, which was approved by the university ethics committee. Although the swimmers did not ask to remain anonymous, they were given pseudonyms to maintain confidentiality: Max, Eric, and Luc.

Procedure

The protocol we chose for our study of swimmer–technical device coupling is often used in high standard swimming to assess the relationships between speed and active drag and so evaluates swimmers' body shape. The experimental protocol was undertaken in a 25-m swimming pool.

Table I. Main characteristics of the swimmers.

Swimmer	Age (years)	Experience (years)	Weekly training volume (h)	Time for 100-m freestyle in 50-m pool (s)
Max	20	9	10	50.3
Eric	22	13	10	50.1
Luc	22	10	10	52.3

The swimmers were all swimming for the first time on the MAD-system. They had to swim ten 25-m laps with each lap at a different but constant speed. A rest period of 3 min was

taken between laps. The participants were given no specific instructions about times for each lap: they were only given feedback on their performance time for each lap and were asked to swim the next lap a little bit faster than in the previous lap. For the last two laps (9 and 10), the instructions were to swim as fast as possible. To ensure that the laps were swum at maximal speed, the experimental protocol usually gives the swimmer two trials (Toussaint van der Meer, de Niet, & Truijens, 2006). Table II gives the speed and force for each lap. Using the MAD-system (Hollander et al., 1986), the swimmers pushed off from a fixed pad with each stroke, with a total of 16 pads. The swimmers used their arms only and their legs were supported by a small pull-buoy. The pads were attached to a 22-m rod, which was mounted 0.8 m below the water surface. The distance between the push-off pads was 1.35 m. The rod was connected to a force transducer for direct measurement of the push-off force for each stroke.

Data collection

Two types of data were gathered: (a) continuous video recordings of the swimmers' behaviours during the experimental protocol and (b) their verbalizations during post-protocol interviews. The behaviours of the three swimmers during the experiment were recorded with three digital cameras (Figure 1). The first camera recorded an aerial, frontal, and wide-angle view of the swimmers. The second camera was placed in a waterproof box and was positioned underwater, 20 m from the edge of the pool. A diver experienced in underwater filming recorded the contacts between the swimmers' hands and the MAD-system pads as accurately as possible.

Table II. Swimmers' speed and force for each lap when using the MAD-system.

Lap	Speed ($\text{m} \cdot \text{s}^{-1}$) / Force (N)		
	Max	Eric	Luc
1	1.02/28	1.27/37	1.16/34
2	1.20/40	1.42/44	1.19/37
3	1.27/44	1.54/52	1.35/47
4	1.35/51	1.62/58	1.47/53
5	1.46/58	1.71/66	1.58/62
6	1.54/66	1.72/70	1.68/74
7	1.62/72	1.80/81	1.77/84
8	1.72/85	1.84/89	1.86/96
9	1.83/96	1.90/92	1.94/103
10	1.91/107	1.88/97	1.95/111

The third camera was positioned close to the edge of the pool and recorded complementary ethnographic data. The verbalization data were gathered from individual self-confrontation interviews with the swimmers. This interview consists of confronting a person with his or her activity in a particular situation (Theureau, 2003). The present interviews were conducted immediately after the experimental protocol and lasted about 30 min. During each

interview, the swimmer viewed the videotape of the laps together with one of the present authors. The swimmer was asked to describe and comment on his activity during each lap. He was invited to reconstruct and share his personal experience during the action viewed on the videotape, and not to justify or explain it. During the interviews, the researchers sought to keep the swimmer's attention on the study topic with specific questioning (Theureau, 2006). The researcher's prompts concerned sensations (e.g. what sensations are you experiencing here?), perceptions (e.g. what are you perceiving here?), focus (e.g. what are you paying attention to here?), concerns (e.g. what are you trying to do here?), thoughts and interpretations (e.g. what are you thinking here?), and emotions (e.g. what emotions are you experiencing here?). All the interviews were conducted by a researcher who had already conducted self-confrontation interviews of this type in previous research.

Data processing

The verbal exchanges between the swimmer and the researcher during the interview were recorded and fully transcribed. The data were processed in two steps: (a) reconstruction of each swimmer's course of action and (b) comparison of these courses of action. Reconstructing each swimmer's course of action This step consisted of identifying and documenting the six components of the hexadic signs that constitute the course of action.

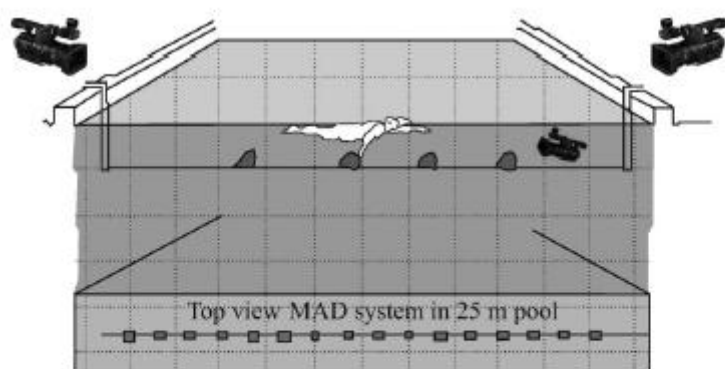


Figure 1. Positions of the three cameras.

When asked to describe their activity, actors spontaneously break down a continuous stream of activity into discrete units that have personal meaning. It is assumed that these discrete units are the expression of a sign, termed "hexadic", as it consists of six components: the unit of course of action (U), the representamen (R), the involvement in the situation (E), the anticipatory structure (A), the referential (S), and the interpretant (I) (Theureau, 2003, 2006). For each course of action, the components of the hexadic signs were documented step-by-step on the basis of (a) the video recording, (b) the verbalization transcript, and (c) specific questioning. The unit of course-of-action (U) is the fraction of pre-reflexive activity that can be shown, told, and commented on by the actor. The unit could be a symbolic construct, physical action, interpretation or emotion. It was identified by asking the following questions

about the collected and transcribed data: What is the swimmer doing? What is he thinking? What is he feeling? The representamen (R) corresponds to the elements that are taken into account by the actor at a given moment. The representamen can be perceived or mnemonic. It was identified by asking the following questions about the collected and transcribed data: What is the significant element for the swimmer in this situation? What element of the situation is he considering? What element is being remembered, perceived or interpreted by the swimmer? The involvement in the situation (E) corresponds to the actor's concerns at a given moment. These concerns arise from past courses of action. The involvement in the situation was identified by asking the following question about the collected and transcribed data: What are the swimmer's notable concerns about the element being taken into account in the situation? The anticipatory structure (A) corresponds to the elements expected by the actor in his or her dynamic situation at a given moment, taking into account the involvement. It was identified by asking the following question about the collected and transcribed data: What are the swimmer's expectations at this instant with regard to his concerns and the elements he finds meaningful in this situation? The referential (S) corresponds to the actor's knowledge, inherited from past experiences that he or she can mobilize at a given moment, taking into account the involvement and the potential actuality. It was identified by asking the following question about the collected and transcribed data: What knowledge is being mobilized by the swimmer at this instant in the situation? The interpretant (I) corresponds to the validation and extension of past knowledge and the construction of new knowledge at a given instant. It was identified by the following question about the collected and transcribed data: What element of knowledge is the swimmer validating, invalidating or constructing at this moment? As our focus was on the swimmer-device coupling, we were particularly interested in the unit of course of action (physical actions, interpretations), the representamen, and the involvement. Comparison of the swimmers' courses of action To describe and understand how the three swimmers interacted with the technical device, we compared their courses of action for each lap. The simultaneous analyses of the unit of course of action, representamen, and involvement of each swimmer allowed us to specify the convergent or divergent character of their experiences. This analysis revealed both unique occurrences and recurrences in the swimmers' activity while interacting with the MAD-system. The recurrences were the expression of typical couplings between the swimmers and the technical device. Trustworthiness of the data and analysis Several measures were taken to enhance the credibility of the data (Lincoln & Guba, 1985). First, the interviews were conducted in an atmosphere of trust between the swimmers and researcher. Second, the transcripts were presented to the participants so that they could ensure the authenticity of their commentary and make any necessary changes to the text. Minor editorial comments were made to confrontational responses. Third, the data were coded independently by two trained investigators. These two researchers had already coded protocols of this type in previous studies and were accustomed to course-of-action theory.

Results

Analysis of changes in the swimmers' experiences showed (a) convergence of their experiences during the first three laps and the last three laps and (b) the divergence of their experiences during laps 4–7. As their experience was transformed in the same speed intervals, this seems to have been an essential situational constraint to the swimmer–technical device coupling. For this reason, we chose to organize the results around this feature of the context. The results are presented in three stages: (a) swimmer–MAD system coupling in the context of slow speeds, (b) swimmer–MAD system coupling in the context of medium speeds, and (c) swimmer–MAD system coupling in the context of maximum speeds. For each stage, we identified the concerns and the modifications in the usual activity of the swimmers.

Swimmer–MAD system coupling in the context of slow speeds

During the first three laps, we identified two major concerns of the swimmers. The first was to put their hands on each pad and not to miss any: “Here I’m thinking about trying to see where the other pad will be because otherwise I might miss it, be too short or too long” (Luc). The second concern was to place their hands correctly and, more specifically, to set them down flat on the pads: “Here I’m trying to find the right position for my hand. I try to have my whole hand on the pad” (Max). The aim was to be neither too far forward nor too far backward of the pad to avoid grabbing it by the fingertips: “In fact, during my first lap I was too far behind the pad and so I was forced to grasp it and pull it. Whereas during my second lap I am more forward and I can wedge my arm behind it better so that I can push on the pad better” (Luc). To place their hands flat on each pad, the swimmers changed their usual swimming activity. First, they raised their heads to look at the pads: “In fact, the marker, the pad, we look at it first of all because they are lined up one by one” (Eric); “I’m not holding my head in the same position as when I swim naturally . . . As soon as I finish my push-off, I put my head up a little to see where the next pad is” (Luc). They also changed the positioning of their body segments: “When you swim, the elbow is like this [makes a 90° angle with the arm and forearm] and here in fact it’s like this [makes a 45° angle] because the pads are aligned and therefore the catch is not as deep” (Eric). This modification accompanied a change in the trajectory of their arms in and out of the water: “My shoulder is also less engaged compared to my usual stroke . . . I don’t have this forward and downward phase where my shoulder is working when I catch the water” (Max).

Swimmer–MAD system coupling in the context of medium speeds

During laps 4–7, each swimmer developed his own modality of using the technical device to deal with the speed constraints imposed by the protocol: (a) press quickly on the first pads with rhythm (Max), (b) press hard on the first pads (Luc), and (c) press hard on the pads in the middle of the pool (Eric).

Max: “Press quickly on the first pads with rhythm”. After the fourth lap, Max wanted to press faster on the first four pads and then maintain the acquired momentum. His concern was to save time by not keeping his hand too long on the pads. To ensure the brevity of the hand push-off, he tried to lay his hands very quickly on the top of the pads and to accelerate at the

end of each push: “I’m not going to accelerate in a linear fashion. In the beginning, I will do four pads. You see, I start faster and then I keep going . . . I try to take them faster . . . I look only at the top [of the pads]. I don’t need to take two seconds to reach the pad and lay my hand on it. It’s a waste of time”.

Luc: “Press hard on the first pads”. After the fifth lap, Luc first tried to press hard on the first three pads: “I would say that I press hard on the first three pads”. To do so, he pressed on the first pad with his stronger arm, the right one: “I start with the right arm because it’s my stronger arm; since I need maximum power in the beginning, I always start with the right arm”. Starting with the right arm allowed him to push twice with his more powerful arm on the first three pads.

Eric: “Press hard on the pads in the middle of the pool”. To move fast, Eric tried to press hard on the pads in the middle of the pool: “Especially in the middle, you tend to press hard”. Unlike the other swimmers, Eric pushed against the wall with his feet to start fast: “In fact, in the beginning, you don’t really press on the pads as you push against the wall”. With this push, he gained speed, which he maintained up to the middle of the pool: “Well, I don’t press too much, I push against the wall. We seriously start the movements after the fifth pad, in fact”. Then he regained speed by pressing hard on the pads in the middle of the pool, and then as he approached the end of the pool he ended his efforts: “It’s only on the last one I don’t push because it’s near the wall”.

Swimmer–MAD-system coupling in the context of maximum speeds

During the last three laps, the swimmers sought to increase arm-stroke rate to reach maximum speeds. However, the regular spacing of the pads made it difficult for the swimmers to increase their stroke rate: “It’s different with fast strokes. Generally speaking, you have a high amplitude when you swim slowly, so here the problem is the regular intervals. We’re not able to adapt” (Eric). Each swimmer attempted to use the same modality of interacting with the technical device as during the medium speed laps, as they continued trying to lay their hands regularly on each pad at high speed. Their activity was structured from one pad to the next: “Because it goes so quickly, at the moment my hand is about to touch one pad I’m already thinking about the next pad” (Max). The increasing speed made laying the hands on the pads more random: “What is different is also the way we will lay the palm of our hands, not always right on top of the pad . . .” (Eric). To be able to lay their hands on each pad while swimming fast, the swimmers sought a compromise between a behaviour that guaranteed control of the placement of their hands on the pads and a behaviour that favoured a good chronometric performance. Luc and Eric lifted their heads slightly to see the pads, but took care not to alter the streamlining of their body: “We have to avoid excessive focus on the pads, otherwise we’re like this [he straightens his head upward]. I try to keep my head down as much as possible and not look up to see every pad . . .” (Luc). As for Max, he shortened the beginning of each arm movement: “I zap the first part of the catch phase. Usually I stay longer with my hand ahead to make sure of a good catch. I shorten it a

bit to be able to catch the pad at once because on the MAD-system you can swim even if you skip a pad”.

Discussion

This study of swimmers’ activity during instrumented protocols revealed that substantially more occurs during these protocols than what is actually sought or assessed. Although our results must be generalized with caution because of the small number of participants, they showed that (a) the swimmer–technical device coupling is a dynamic process of adaptation and (b) this process leads both to idiosyncratic and typical forms of coupling with the device. The swimmer–technical device coupling as a dynamic process of adaptation. Our results indicate modifications in the forms of coupling with the MAD-system over the course of the ten 25-m laps. These modifications were related to the constraint characteristics of the device (e.g. the alignment of pads) and the changes in the protocol conditions (e.g. the increasing speed). They reflected the situated character of the swimmers’ activity.

Thus, certain forms of the observed couplings were not anticipated by the researchers. Although the increasing lap speeds suggested that we would see a linear change in the forces exerted on the pads, we instead noted propulsive strategies designed to take advantage of the protocol (Suchman, 1987). Our position about the design of technical devices is generally at odds with that conveyed in experimental protocols. The general assumption is that these devices have objective properties that: (a) promote the achievement of the tasks specified by the designer and (b) support the effects expected by the experimenter (Norman, 1988, 1993). Several studies in occupational settings have shown that the modalities of interaction and the characteristics of a technical device reveal themselves during use in a dynamic fashion (e.g. Rabardel & Beguin, 2005). Specifically, these studies have shown that activity cannot be reduced to the conditions prescribed by the protocol designer and that the actor–technical device interactions are indexed to other components of the environment and to the dynamics of the actor’s ongoing activity. Modifications observed in athlete–technical device couplings have indicated the mediating role of objects in the interaction of actors with their environment (Stewart, Khatchaturov, & Lenay, 2004). In the present swimmer–environment coupling, the MAD-system contributed to defining both the activity and the situation: (a) the technical device modified the swimmers’ range of possible perceptions and repertory of possible actions and (b) it contributed to defining the swimmers’ “world” by modifying relevant elements of the environment with which they were interacting. Yet, despite the dynamic and opportunistic nature of the forms of coupling, this does not imply that the modalities of using a protocol cannot be stabilized. In fact, complementary study is needed to analyse device-dependent protocols over longer periods to determine the learning processes by which the device is appropriated by swimmers and incorporated into their activity. Some forms of idiosyncratic and typical couplings. Our results revealed the complexity of athletes’ activity during experimental protocols. This complexity was manifested in the swimmer–technical device coupling by idiosyncratic elements that expressed an asymmetric

coupling of the actors with their environment (e.g. Conein & Jacopin, 1993) and recurring elements that indicated common modalities of adapting to the technical device. Our results show a personalization of the use of the technical device (Dodier, 1993), especially during laps 4–7. Each swimmer had a strategy to mobilize propelling surfaces or to distribute forces. They used the MAD-system differently: (a) press quickly on the first pads with rhythm, (b) press hard on the first pads, or (c) press hard on the pads in the middle of the pool. During the interaction between an actor and a technical device, an “instrumental genesis” occurs (Rabardel, 2001). This genesis refers to the user’s process of adapting to the device, which materializes as a change in the actor’s movements (Norman, 1988, 1993). The personal adaptations of our swimmers confirmed the notion that actors construct their worlds in great part through their interactions with their environment (Von Uexküll, 1956–1965). In addition to their idiosyncratic adaptations, our results also showed recurrences in the swimmer–technical device coupling. For example, the swimmers’ investigations at the beginning of the protocol their attempts to adapt their high speed stroke during the last three laps indicated activity characterized by careful focusing on the spatial arrangement of the pads (Salembier, Theureau, Zouina, & Vermeesch, 2001). Moreover, all the swimmers changed their usual head position: they raised it a little to check where the next pad would be. In certain conditions (e.g. in the context of slow or maximum speeds), these high-standard swimmers had similar coupling with the MAD-system and modified their activity for the same elements. These observations suggest that swimmers’ behaviour while using technical devices can only be understood by simultaneously taking into account the objective constraints, such as the imposed speeds of a protocol, and the processes of instrumental genesis: that is, the swimmers’ subjective interpretations about the constraints and the swimming actions required to adapt. In other words, when the environmental constraints are experienced as insurmountable disturbances from the swimmers’ point of view, for example while using the MAD-system at slow and maximum speeds, they contribute to the emergence of new forms of swimming activity, which are almost identical for all swimmers. When the constraints are experienced as surmountable disturbances, for example while using the device at a medium swim speed, swimmers are more at ease (Relieu, 1993): the device becomes inconspicuous, as for example in this study where the interval between pads was not as disturbing at medium speed as it was at slow and maximum speeds. The swimmers could thus adapt to the environment while still maintaining traces of their habitual swim technique.

Concluding remarks

This study has highlighted typical processes of adaptation that should be useful for the design of new technical devices. During the design of a technical device, disproportionate attention is paid to the technical specifications, with little thought given to the future user. However, a purely technological approach to design could create problems for the user. It is therefore important (a) to ensure that the user’s activity becomes a source for the designer’s activity and (b) to take into account the situations in which the technical devices are used. It is thus

important to develop activity-centred design in sport (Gay & Hembrooke, 2004; Norman, 2006; Theureau, 2003). Our activity-oriented approach highlights some rarely considered dimensions of technical devices that could lead to improvements in their design and the situations in which they are used. As an illustration, one recommendation might be to use the MAD-system at swimmers' "medium" speed during evaluation protocols so that each swimmer can improve the appropriation of the device and experience it as easy to use. Another recommendation concerns design: perhaps inter-paddle distances should be modulated in the future in accordance with the speed imposed by the protocol.

Although experimental protocols impose numerous constraints, two criteria for the design of technical devices are essential: usability and appropriation. To be as effective as possible without imposing an additional constraint on the user, the technical device has to: (a) correspond to the essential characteristics of the activity to which it is dedicated and (b) facilitate the idiosyncratic and typical adaptations of the athletes in situation.

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