An ecological approach to expertise effects in decision-making in a simulated sailing regatta

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Abstract

Objectives: Following an ecological approach, expertise effects on decision-making in sailing were studied. Dynamic tasks in sailing were provided through interactive computer simulations, used to reveal the utilisation of information, and the active exploration of ecological constraints by participants.

Methods and design: Sailors (n = 35) were divided into three skill groups, according to ranking: Expert, Skilled, and Intermediate. There was also a non-sailors group (N = 23). During six successive phases of a computer-simulated regatta, a concurrent verbal protocol analysis was used to measure utilization of four sources of available information: adversary, spatial, manoeuvres and wind. Simultaneously, participants pressed keys on a keyboard, registering two categories of actions used to explore the task: technical actions and adjustment actions. The outcome variables, final classification and total time were also recorded.

Results: Expertise level was significantly predicted by total time. Statistical analyses showed that non-sailors significantly differed from sailors in the use of adversary and wind information during the regatta. But, there were no significant differences among the sailors’ groups. Non-sailors performed significantly more actions than sailors, during almost all the regatta. However, polynomial trend analysis revealed that each group of sailors exhibited specific patterns of information utilization and performed actions.

Conclusions: Data demonstrated that the better the sailor, the better was performance on a simulated regatta. Decision-making in sailing is characterized by non-linear accumulated effects of exploring and using informational constraints in a regatta, which are dependent on the level of individual attunement to sport-specific information.

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Keywords: Dynamic tasks; Ecological constraints; Cognitive function; Computer simulation

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Introduction

Decision-making and cognitive processes have been widely studied in sport psychology with the ‘expert-novice paradigm’ (Starkes & Ericsson, 2003; Williams, Davids, & Williams, 1999). An extensive review of studies on decision-making and expertise by Starkes, Helsen, and Jack (2001) revealed a minimum of 28 sports analysed in at least 192 studies. A number of notable features from these studies can be emphasized. First, the findings mainly arise from analysis of ball games (e.g. soccer, racquet sports). Surprisingly, only about 8% of the studies reviewed by Starkes et al. (2001) addressed dynamic sports, other than ball games (e.g. combat sports, fencing). Second, the task constraints of dynamic non-ball sports are unique, and it is uncertain whether similar principles to ball sports underlie decision-making, given that ‘thrust and counter-thrust’ strategies characterise ball games due to their ‘invasive’ nature (see McGarry, Anderson, Wallace, Hughes, and Franks, 2002). For example, task constraints in sailing are characterised by the combination of weather and adversary influences on the ever-changing boat displacement and location (Saltonstall, 1983/1996; Saury & Durand, 1998; Wisdorff, 1997). All competitors share an entire area of the regatta, with no specific location for each boat to defend. Clearly, not all dynamic sports have the qualities associated with ‘game rhythm’ to channel decision-making processes, raising questions over the generality of previous models developed in the study of such a narrow range of ecological constraints.

To develop an adequate theory of how expertise in decision-making is acquired, it is necessary to understand how expertise effects constrain decision-making (Abernethy, Farrow, & Berry, 2003). Current frameworks of decision-making in sport are based on athletes’ inner models (Anderson’s ACT* theory, 1983), explaining that experts have developed a larger and more highly differentiated knowledge-base stored in memory to expedite skilled performance (see Williams et al., 1999). This approach ignores how experts use actions to explore task structure to obtain perceptual information for goal achievement. Additionally, it has been found that, when a task situation is not representative of a specific domain, expert performance can drop to the level of novices (Allard, Graham, & Paarsalu, 1980). However, the literature is unclear about what ‘representative tasks for a domain’ are (Ericsson & Lehmann, 1996, p. 277), and it is uncertain exactly in which situations one would expect to see an expertise advantage. This lack of clarity might explain why some studies have failed to observe skill-based differences in decision-making. For example, Oudejans, Michaels, and Bakker (1997) highlighted this problem by reporting expertise differences in some baseball tasks and not in others.

For these reasons, it may be necessary to consider ecological constraints as ‘an active resource whose intrinsic dynamics can play important problem-solving roles’ (Clark, 1997, p. 83). Ecological constraints are constraints specific to the domain towards which the analysed task is supposed to generalise. Indeed, according to Vicente and Wang (1998), the higher the expertise level of participants, the better is attunement to task-specific information. Therefore, development of expertise includes the gradual perceptual differentiation and selection of relevant information to achieve the desired task goal (Adolph & Eppler, 1999). An interesting question raised by these arguments concerns why active task exploration has not been explicitly considered in previous studies of expertise in decision-making.

The problem of an exclusive focus on rationality

One reason for this concern may be because, traditionally in psychology, human decision-making has been seen as a rational process and poor decision-making has been defined as ‘irrational’
Frameworks for studying expert-novice comparisons on decision-making in sport, fall into the category of ‘rational models’ (Bar-Eli, Lurie, & Breivik, 1999), where the goal of decision analysis is the achievement of rationality (von Winterfeldt & Edwards, 1986). For example, the vast majority of studies reviewed by Starkes et al. (2001) followed the assumption that decision-making and perceptual judgements were based on knowledge structures stored in memory, from where the appropriate decision could be recalled. Rationality works in a closed system, where, given certain assumptions, specific conclusions can always be derived if a rational reasoning process is followed. The rational model is based on the assumption that the athlete can normatively infer the maximal utility of the external information, which is known in advance. That is, there is an equally accessible inference for every person—athlete, coach, or experimenter. Since it is assumed that all observers share the same goals and resources, it becomes plausible to believe that some athletes decide well and others decide badly. From this normative view, variability in decision-making is not acceptable; there is only a unique decision that is correct. But does this assumption of validity of decision-making correspond to behaviour observed during expert performance?

According to Brunswik (1939), ‘in the natural environment of a living being, cues, means or pathways to a goal are usually neither absolutely reliable nor wrong. In most cases there is, objectively speaking, no perfect certainty that this or that will, or will not, lead to a certain end, but only a higher or lesser degree of probability’ (p. 175). In order to understand the implications of these ideas for empirical work on decision-making in sailing, it is important to consider in some detail the role of ecological constraints during active task exploration, i.e. the organism–environment relationship.

Ecological decision-making

The ecological approach for understanding decision-making has existed in psychology for some time (Brunswik, 1955; see Hammond and Stewart, 2001 for a complete review). In sport psychology, the ecological approach has typically been developed following a Gibsonian (Gibson, 1979) viewpoint (Beek, Jacobs, Daffertshoer, & Huys, 2003, but see Spence and Lee, 2003), although other perspectives on human behaviour exist in ecological psychology, such as those proposed by Barker (1968), Brofenbrenner (1977) or Brunswik (1955). Albeit sharing a broad viewpoint with some common fundamental assumptions, these perspectives differ in accents and priorities, and integration of the ideas of the founders of ecological psychology has been attempted by some authors (Heft, 2001; Vicente, 2003). For example, a common underlying aim of much Brunswikian and Gibsonian psychology is to understand the extent to which an organism has adapted to functionally significant environmental regularities, a core assumption of ecological psychology (Reed, 1996; Vicente, 2003).

A Brunswikian theory of decision-making

Where Neo-Gibsonianists have mainly focused on problems of perception and action (Michaels & Beek, 1995), Neo-Brunswikians have focused mainly on judgment and decision-making tasks (Hammond, 2000). Brunswik’s (1955) approach embraces uncertainty as a characteristic of both the environment and the organism, an idea that was captured by the symmetrical shape of Brunswik’s ‘lens model’ (Fig. 1).

In general, the lens model addresses the probabilistic relationships between the distal descriptors available to an organism, and the proximal information (or ‘cues’ in Brunswikian terms meaning ‘pieces of information’, cf. Adelman, Miller, Henderson, and Schoelles, 2003) actually picked up by the organism (e.g. the wind speed that the sailor picks up on the basis of such perceptual variables).
The latter of course correspond to the descriptors that are available to be picked up. On the other hand, the distal descriptors could be some type of artificial display (e.g. the display of the measured wind speed on a computer screen) or the natural environment (e.g. sounds and visual variables that indicate wind speed). In Fig. 1, these concepts are represented in the centre and the left side of the model, respectively. Brunswik (1955) argued that individuals could not perceive distal properties directly, but instead must judge events from the imperfect (i.e. probabilistic) perceptual variables provided by proximal stimuli. He created the term ‘ecological validity’ to refer to the correlation between the proximal stimuli available to the individual and the distal properties of interest in studies of human behaviour (Hammond & Stewart, 2001). Thus, ecological validities of perceptual variables refer to their potential utility for organisms in their local environment.

Whereas the left side of the model describes the structure of the environment, the right side describes the organism (Fig. 1). The extreme right shows the organism’s judgment of the state of the environment. This judgment is achieved by combining the proximal stimuli in some manner, so as to infer the status of the distal descriptors (e.g. the sailor’s decision based on information picked up). This inferential process is demanded by Brunswik’s probabilistic view. The actual weights that give the probabilities of using the proximal stimuli by each individual are termed ‘information utilization’, as shown in Fig. 1. The weighting of perceptual variables denotes the probability of use by individuals and not that all perceptual variables are used at the same time with different weightings attached (Savelsbergh & Van der Kamp, 2000). One source of ineffective decisions and judgements lies in the failure to give the relative weighting to perceptual variables (Hammond, 2000). Following a Gibsonian view, another source of ineffective judgements lies in their reliance on non-specifying perceptual variables. A non-specifying perceptual variable might be related to the to-be-perceived property, but it is not specific to this property as its value does not under all circumstances reliably predict the value of this to-be-perceived environmental property (Beek et al., 2003).

**Different mappings between the proximal and the distal descriptions of the environment**

It is important to clarify that Brunswik’s approach is based on the premise that organisms detect information from the environment in the form of multiple imperfect indicators of some unobservable state of the environment (e.g. one cannot observe what the opponent is likely to do in the beginning of

![Brunswik’s (1955) lens model.](image-url)
the regatta, or where the stronger wind is likely to be latter on downwind). These indicators, or perceptual variables, are those features of objects or events that one can use to infer those aspects of the objects or events that are not directly available. There are many of them, and they rarely are perfectly dependable in their ability to indicate those impalpable aspects that one is trying to infer (Hammond, 2000).

The relationship between Gibsonian and Brunswikian interpretations of information is clarified when it is understood that there are also ‘perfect’ perceptual variables. According to Gibson’s (1979), Kirlik (1995) theory of direct perception represents the special case where the ecological validity of a particular perceptual variable is total (i.e. $r = 1.0$) and there is a direct specification of the affordance of an object or event for an individual’s actions. According to Vicente (2003), different proximal descriptions are required to account for different psychological phenomena: ‘Direct perception requires invariants, whereas judgement and decision-making require probabilistic cues’ (p. 259). Thus, there may be various kinds of mappings between the proximal and the distal descriptions of the environment (see Neisser, 1994). Gibson (1979), himself, did not deny this view, and as Shaw (2003) argued, it is a myth to think that Neo-Gibsonians do not believe in indirect perception or in inference. As he suggested, indirect processes like virtual realities have their place in human action and it is not surprising to find that problem solving in computer simulations of complex performance domains are being studied by Neo-Gibsonians (Shaw, Effken, Fagen, Garrett, & Morris, 1997; Vicente & Rasmussen, 1990).

Ecological expertise

Brunswick’s (1955) perspective presupposes that an organism intends to be as empirically accurate as possible in its decisions about environmental objects and events. Following this, the lens model begins by analysing the ecological constraints on behaviour, and only then does it address the organism’s adaptation. If a performer is faced with a situation in which perceptual variables available have limited diagnostic value, then performance will be poor, regardless of the strategy adopted (Vicente, 2003). As a result of these arguments, the lens model provides a way of measuring the degree of adaptation between the organism’s behaviour and the structure of the environment. This is possible because the environment side of the model provides a referent for evaluating the fitness of behaviour, to the extent to which the utilization weights mirror the ecological validities. This idea is in line with data reported by Beek et al. (2003) who explained that novices may rely on probabilistic perceptual variables and become attuned to relevant information only with experience. According to Vicente (2003) this finding indicates that the distal structure of the environment can be described in terms of affordances, and there is information available to which experts have become attuned, but novices may rely instead on judgments based on probabilistic variables, because they are not yet sensitized to the relevant information sources. Moreover, according to Runeson and co-workers (Jacobs, Michaels, Zaal, & Runeson, 2001; Runeson, Juslin, & Olsson, 2000) novices often rely on non-specifying variables, as they still have to learn to attend to the more useful (i.e. specifying) perceptual variables. Specifying variables are specific to the to-be-perceived properties of the environment. Therefore, detecting a certain perceptual variable that specifies a property of interest in the environment allows the decision-maker to make reliable judgments about this property (Beek et al., 2003).

Representativeness of decision-making experimental tasks

According to Gibsonian theorising, ecological decision-making is typically based on an active process of exploration and selection of relevant information to support choices. Hammond, Stewart,
Brehmer, and Steinman (1975) even went as far as stating that ‘human judgment is a cognitive activity of last resort’ (p. 272) that must only be relied upon when individuals are not allowed, or able, to act on the task to determine the state of the environment. Therefore, according to Hammond et al. (1975), when conditions prevent people from engaging in typical exploratory behaviours ‘they must do the best they can by passive rather than active means to arrive at a conclusion regarding a state of affairs clouded by causal ambiguity’ (p. 272). Thus, passive perception and decision-making, typically encouraged by task design in psychophysics laboratories, may be misleading when studying dynamic sports.

The methodological counterpart of Brunswik’s (1955) theory of decision-making is called ‘representative design’. Brunswik’s approach led to an experimental design that specifies those conditions toward which a generalization is intended. Nowadays, advances in technology make it relatively straightforward to represent the circumstances toward which findings may be generalized. For example, if the intention is to study what people do when confronted with noisy decision tasks, Brehmer (Brehmer, 1996; Brehmer & Dorner, 1993) proposed the use of ‘microworlds’, which are computer simulations of a system with the specific conditions in terms of their representativeness of the complex judgement tasks in human ecology. These computer simulations are not designed to be high-fidelity simulations. Instead, they incorporate the main task features so that it is possible to recognize what is being simulated, without enormous detail. This is important because it means that no special knowledge is needed by experimental participants about the characteristics of various types of sailing equipment, for example, and they can perform in simulations with very little training. This does not mean that perception and action are decoupled. Instead the representativeness of the situation implies that participants can achieve their goals by ‘acting to create information to guide action’ (Kirlik, 1998, p. 15).

In the study of expert decision-making, the experimental task should be designed in such a way that, picking up a perceptual variable that specifies a property of interest in the task should allow one to make reliable judgements about this property, particularly for expert performers.

**Decision-making in dynamic, ongoing tasks: a role for computer simulations**

What do the ideas of task representativeness imply for the design of decision-making studies in sport? In their extensive review of cognitive expertise in sport, Starkes et al. (2001) pointed out that, whereas the performance of athletes in expert-novices studies can be highly variable (e.g. the hardware comparisons), observations of experts’ decisions conducted in actual practice have consistently shown a high level of performance (Starkes & Ericsson, 2003). Williams et al. (1999) convincingly argued that one reason for this discrepancy may be that experiments using the expert-novice paradigm comprise ‘one-shot’, static decision-making tasks, whereas performers’ judgment in practice involves an interactive, dynamic process with tactical decisions followed by actions, followed by revised judgments, followed by new actions: a continuous process. The study of decision-making behaviour within such a dynamical system reveals unexpected structure in the long-term, because decisions can be conditionally coupled. That is, each separate decision in activities like sailing should not be viewed as functionally independent from other decisions made by the performer during performance. Behaviour that is conditionally coupled occurs because the state of a system (i.e. boat-wind) at any one moment remains dependent on previous states of the system. For example, the preferred start location on a starting line of a regatta is clearly coupled with the area of upwind towards which the sailor intends to go. These arguments highlight the need to study decision-making behaviour of athletes performing under sport-specific constraints. Furthermore, contrary to the traditional expert-novice paradigm, analysis of
momentary anticipation or accuracy may be less important than understanding the nature of an athlete’s cumulated accuracy of decision-making behaviour emerging from the continuous interactions within the task context towards some overarching goal.

Obviously the study of dynamic decision-making in natural environments can often be limited by many practical problems (e.g. the impossibility of studying sailing-specific decision-making of novices, since they do not know how to sail) as well as by ethical and safety considerations (e.g. sailing a regatta in a very high intensity wind). One important way in which dynamic decision-making can be studied is through the use of computer simulations. This approach has been successfully applied to the study of decision-making in domains other than sport (Adelman et al., 2003; Brehmer & Dorner, 1993). Simulations allow participants to explore task constraints when looking for specific information to originate new movements in goal-directed behaviour. Therefore, the specific perception–action couplings inherent to the cognitive processes under analysis are maintained.

In sport, computer simulations have been extensively used to assess decisions of expert athletes (Alain & Sarrazin, 1990; Raab, 2002). However, these studies have not actually analysed the process of expert decision-making, but instead have attempted to simulate expert decisions (but see Todorov, Shadmehr, and Bizzi, 1997 for learning through a simulated table tennis task). Normally these decisions have been accessed through process-tracing methods (e.g. eye registration, verbal report techniques or movements like button pressing or joystick manipulation, e.g. Savelsbergh, Williams, van der Kamp, and Ward, 2002). Sanders (1991) has argued that in studies of simulated decision-making tasks verbal protocols and movements are an accurate way to measure cognitive processes. Ericsson (2003) proposed that there are many types of behaviour where participants spontaneously report concurrent thoughts. He suggested that when appropriate verbal reporting procedures are used, participants can report on the information they are attending without changing the structure of the underlying processes. He argued that researchers have now accepted that participants provide valid concurrent verbal reports on their cognitive processes matching other evidence for the associated performance and process-trace data. Interestingly, the ecological psychologist Reed (1996) argued that verbalization is a bona fide ‘means of selecting and making information available to others’ (p. 157), and that ‘it refers not to inner representations but to environmental situations and states of affairs’ (p. 156). Thus, there is clear support for the circumscribed use of verbal protocol analysis techniques by sport psychologists within different theoretical frameworks in studying perception, cognitions and actions.

To summarise, the ecological constraints in previous research on decision-making have not been broad enough to capture the various sports and physical activities that humans undertake. Previous work has laid a solid foundation but may be somewhat limited in representativeness and generality. There is a need to examine decision-making under dynamic task constraints that allow people to actively explore information to guide action. Most importantly, ecological constraints should be explicitly considered in a theory of expert decision-making. In the present study, we attempted to analyse how concurrently verbalized information and performed actions evolved during a computer simulated sailing regatta and how they correspond to performance of participants. We expected that when active exploration of the task was possible, even individuals with no knowledge of this complex task, could achieve useful goals. A strong relationship was predicted between expertise in sailing and performance on a dynamic decision-making sailing task. Also, we expected that each group would use the available information differently, creating distinct patterns of utilization and of exploration of perceptual variables, although expertise effects were expected to reveal greater attunement to the most relevant information for goal achievement.
Method

Participants

Twenty-three ‘non-sailors’, 14 male, 9 female, aged 20–29 years ($M=22.2; SD=2.1$); and 35 sailors, 26 male, 9 female, and aged 17–40 years ($M=23.1; SD=4.8$) participated in the study. In sport, contrary to other domains, the definition of expertise levels can be facilitated by the existence of objective criteria such as competition results and conventional systems of ranking (e.g. ranking ATP for Tennis). In this study, we exclusively considered sailors with international experience. Following criteria used in previous studies (Araujo & Serpa, 1999), we defined expertise level according to sailors’ ranking score. Based on ranking points ($M=2348.89; SD=1767.70; \text{min}=0; \text{max}=4752$), participants were divided into three subgroups: (i) ‘experts’ ($N=12; M=4409.75; SD=152.76$); (ii) ‘skilled’ ($N=11; M=2276.22; SD=813.70$), and (iii), ‘intermediate’ ($N=12; M=354.58; SD=236.35$). One-way ANOVA confirmed that rankings of these groups differed, $F(2,32)=210.88, p<0.001$, with post hoc tests showing that each group was different from each other ($p<0.001$). Furthermore, all the sailors in the expert group had been among the top three finishers in several World Championships, European Championships, Olympic Games, or similar high-level competitions. The skilled group contained sailors that regularly competed at international level, but lacked consistent top classifications. Sailors in the intermediate group had experienced at least one international competition (they had been selected for the national team) during the last 4 years. Non-sailors did exactly the same tasks as the sailors, but had never sailed in a natural context. All participants (sailors and non-sailors) had the same level of familiarity with computers, but were not familiar with the specific computer simulation used.

Measurement

In line with previous dynamic decision-making studies (Adelman et al., 2003; Brehmer & Dorner, 1993), verbal protocols and behavioural measurements were taken in real time, and a concurrent protocol was used to measure focus on selected information (Ericsson, 2003). An experimenter made one of two probe statements during each individual’s performance: (i) ‘continuously verbalize from which area of the screen you are using information’; (ii) ‘keep talking’ (Williams & Davids, 1997).

The verbalisations (from the verbal protocol) were categorized into four clusters: (i) adversary (verbalisations about opponents, e.g. ‘That boat will shadow my wind’); (ii) spatial (about positioning relative to the fleet or to the regatta area, e.g. ‘There’s more space on the other side’); (iii) manoeuvres (about individual actions, e.g. ‘I’m going to tack’); (iv) wind (e.g. ‘there’s more wind on starboard’). In addition the number of movements (pressing the four possible keys in the computer keyboard) were

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1 A ranking system was developed to take into consideration the best six international competitions of each sailor over the last 4 years. To obtain the score of each of the six regattas, the sailor’s classification ($C$) was multiplied by the level of difficulty of each regatta ($D$) (according to the weighting established by the International Sailing Federation) and by the weighting established according to the number of participants in the race ($W$). Equation is: $C\times D \times W = \text{regatta score}$. The ranking score was the sum of a maximum of six international regatta scores. Note that some sailors had just completed one international regatta, scoring just those points.
categorised into two clusters: (i) technical actions (tack, to change direction when going upwind so that the wind shifts from one side of the boat to the other; and jibe, to shift from one side or board to the other, when going downwind); (ii) adjustments (luff, to orient the bow of the boat towards the wind direction; and bear, to move the bow of the boat away from the wind direction).

The four verbalised variables and two movement variables described above were analysed in real time in a ‘three-race’ regatta, by dividing each race into six portions, identified by high level coaches (Wisdom, 1997) as specific phases: (i) start; (ii) 1st upwind (or 1st beat); (iii) round the 1st mark; (iv) downwind; (v) round the 2nd mark; (vi) 2nd upwind (or 2nd beat) until the finish line. Each one of the six variables was registered during each of the continuous six structural phases of the regatta. The dependent variables included the ordinal variable ‘final classification’ (ranking out of 14 other competitive boats in the simulated regatta), and ‘total time’ spent on the regatta (measured in seconds).

Apparatus

The simulation used was an adaptation of commercialised software by Posey (1996). To measure cognitive processes functional fidelity is of greatest importance, being relevant to use a partial (visual) simulation (see Vicente, 1996). The term functional signifies that the simulation should simulate the functions of the natural context instead of its structure. This characteristic provides the conditions of interest as well as recording the participants’ interaction with these conditions (see Starkes and Lindley, 1994 for discussion of functional fidelity in simulations in sports). The simulation in this study was of the

![Fig. 2. The visual display of the computer simulator. Ellipses put evident some relevant information as described in the text.](image-url)
visual display around the boat during a regatta (vertical ellipses in Fig. 2). The display is not structurally
equal to a natural regatta, but it demands the same type of interaction, i.e. the same functions. For
example, the simulation shows a change at the colours of the lake from blue to blue with white dots
(more or less intense), indicating the displacement of the wind, as it occurs in the natural situation. Some
non-visual information (e.g. wind strength and boat direction) can be quantified on a small monitor
(horizontal ellipses on Fig. 2). Participants’ verbalisations were recorded using a video camera and an
audio recorder, being transcribed verbatim later for analyses. The camera was positioned to
simultaneously record participants’ verbal reports, the keyboard and the computer simulation displayed
on the screen.

Representative design

The essential characteristic of representative design is that the experimenter carefully specifies
what generalizations are to be made from the experiment and then sets it up to support those
generalizations (Hammond & Stewart, 2001). The aim was to generalise the decision-making
demands of a simulated regatta to the decision-making demands of a natural regatta. All the regattas
were similar (e.g. same range of wind intensity, same number and skill level of adversaries).
However, each participant faced three different races in each regatta, with each race evolving in a
unique way, according to the interaction established with other boats. It is important to note that the
purpose of a sailing regatta is to attempt to master the use of the wind, in order to avoid or perturb
opponents’ actions and to arrive at the finish line in front of the other boats. This goal must be
achieved through the performance of actions inside the boat to control its direction and speed. The
direction and the speed of the boat are constrained mainly by wind direction and strength, and by
the position of opponents (Araújo & Serpa, 1999; Saury & Durand, 1998). The goal of a regatta and
the constraints exerted on the direction and speed of the boat, which the participants were required to
control, were present in the simulation. Furthermore, we asked five head coaches from the
Portuguese Sailing Federation and two head coaches from the Dutch Sailing Federation to rate the
correspondence between the competition presented on the simulator and natural competitive events,
with respect to on-line tactics and decision-making. They were also asked whether the simulation
would allow sailors to manifest their ‘typical’ decision-making and tactical behaviour in competition.
Despite the consideration that the simulation could be improved on several structural features, all the
experts agreed that it was a functionally effective method to assess decision-making and tactics in
competition. In other words, it demanded from participants the same judgement and decisional
processes as a natural regatta. At the end of the experiment, sailors were also asked to evaluate the
simulation. They manifested the same level of agreement as the expert coaches, confirming that the
simulated information allowed them to make similar judgements and decisions as in sailing.

A split-half reliability method with Spearman–Brown corrections was used (Helsen & Pauwels,
1988) to assess reliability of the method of providing evolving regatta simulations (i.e. with specific
dynamics according to the behaviour of the subject). Results indicated $r_{tt} = 0.88$ for adjustment
actions; $r_{tt} = 0.78$ for technical actions; $r_{tt} = 0.77$ for attended adversary information; $r_{tt} = 0.88$ for
attended wind information; $r_{tt} = 0.81$ for verbalized manoeuvres information; and $r_{tt} = 0.81$ for
attended spatial information. These coefficients indicated that there was no main learning effect in the
first half of the experiment compared to the second half for participants. This finding demonstrated
that performance was not biased by the improvement of any specific computer skill for this particular
 simulation.
Participants were told that the simulated regatta involved three races. In each race the individual had to control the direction taken by the boat, while the computer automatically controlled the dynamics of sail and boat balance. During the regatta individuals verbalised, the information attended to, while controlling the direction of the boat.

The familiarization phase of the experiment consisted of performing one race, prior to the three-race regatta. The first half of the race (from the start, until the middle of downwind) aimed to familiarise participants with the computer simulation. Participants could control the boat direction (using four specific computer keys) with the goal of traversing the racecourse faster than the other boats. The second half of the warm-up race was performed with concurrent verbalisation. In a previous study with the same computer simulation (Araújo & Serpa, 1999) it was established that verbalisations did not interfere with performance on the task (i.e. there was no reactivity, cf. Williams and Davids, 1997; see also Ericsson, 2003).

Results

Ecological validities

In this study, we investigated whether there was a relationship between expertise in sailing and outcomes on a simulated regatta, i.e. investigate whether there was a relationship between the proximal stimuli available to sailors (i.e. the simulation) and the distal proprieties of interest in a regatta (i.e. a correspondent level of performance). If this relationship existed, the descriptors available on the simulation would reveal themselves as diagnostic enough to allow participants to demonstrate correspondent levels of expertise (regardless of the strategy adopted by each participant). We began by examining the relationship between expertise level and outcomes on the simulated regatta (see Table 1). Importantly, all the participants (N=58) completed the task. Pearson’s product–moment correlation coefficients and Spearman’s correlations were used to estimate the relationship between expertise-level and total time and final classification, respectively. We found that expertise level was closely related to final classification ($r_{s}(58) = -0.77$, $p < 0.001$) and total time ($r(58) = -0.58$, $p < 0.001$). Simple linear regression analysis revealed that Total Time predicted approximately 33% of Expertise level ($R_{adj}^2 = 0.326$; $F = 28.54$, $p < 0.001$; $\beta = -4.706$, $\alpha = 9229.01$, $p < 0.001$).

2 This analysis could not be made with the *ordinal* variable ‘final classification’.

### Table 1

Mean and standard deviation of output variables, according to the four levels of expertise in sailing

<table>
<thead>
<tr>
<th>Variables</th>
<th>Experts</th>
<th>Skilled</th>
<th>Intermediates</th>
<th>Non-sailors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M$</td>
<td>SD</td>
<td>$M$</td>
<td>SD</td>
</tr>
<tr>
<td>Final classification</td>
<td>2.00</td>
<td>1.13</td>
<td>3.27</td>
<td>2.57</td>
</tr>
<tr>
<td>Total time</td>
<td>1493.58</td>
<td>92.12</td>
<td>1525.18</td>
<td>132.67</td>
</tr>
</tbody>
</table>

D. Araújo et al. / Psychology of Sport and Exercise 6 (2005) 671–692
Information utilisation

To examine the relationship\(^3\) between expertise (Group) and information utilisation and movements performed (to simplify we call these group of variables ‘Cluster’) at structural phases of a simulated regatta (Time) a \(4 \times 6 \times 6\) (Group×Cluster×Time) multivariate mixed model MANOVA was conducted with each of the six variables of the Cluster as a dependent measure (see Fig. 3). Wilk’s \(\Lambda\) (LRATIO) was used to statistically evaluate the relationship between expertise and the nature of the information used at different times of the regatta (Liu, 2002). Results showed that the effect of time was significant (LRATIO = 41.60, \(p < 0.001\)). The Group×Time interaction was also significant (LRATIO = 5.62, \(p < 0.001\)). Significant differences in information utilization and actions performed among the four groups were also noted: (i) Adjustments, LRATIO = 13.85, \(p < 0.001\); (ii) Technical actions, LRATIO = 21.41, \(p < 0.001\); (iii) Wind, LRATIO = 3.06, \(p < 0.04\); (iv) Adversary, LRATIO = 8.52, \(p < 0.001\); (v) Spatial, LRATIO = 3.74, \(p < 0.02\). We found no differences in the Manoeuvres variable, LRATIO = 1.90, \(p > 0.10\).

Post hoc Tukey tests on the between-subjects analysis showed that the three groups of sailors could not be differentiated (\(p > 0.23\)) by any of the process-tracing variables. However non-sailors were different from the three groups of sailors in adjustments and technical actions (both \(p < 0.001\)). The same was observed for adversary information (\(p < 0.04\)). Only experts differed from non-sailors in use of wind information (\(p < 0.02\)). Similarly, for spatial information only skilled sailors differed from non-sailors (\(p < 0.04\)). Noticeably, there were no differences among the four groups concerning manoeuvres (\(p > 0.11\)). Because the main research question was related to the trend across the successive structural phases of the regatta rather than multiple comparisons among repeated measures, we used polynomial trend analysis for a deeper investigation of the data.\(^4\) According to Liu (2002), this analysis is more powerful than the overall test of significance of repeated measures. Results showed that linear and non-linear trends existed for the time factor and specifically in the Time×Group interaction (see Table 2).

In performing the same trend analysis for the performance measure (i.e. time on each structural phase of the regatta, see Fig. 4), we observed that linear, \(F(3,54) = 17.52, p < 0.001\), and non-linear trends existed in the Time×Group interaction, namely, cubic, \(F(3,54) = 4.66, p < 0.007\); and order 4, \(F(3,54) = 8.79, p < 0.001\). Trends in the Time factor existed at all levels until order 5 (\(p < 0.001\)).

Inter-relation among variables

Since non-linear trends were found, we calculated how each group specifically used the information and performed actions. We normalised all the process-tracing variables, assuming that

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\(^3\) The selected parametric tests are specific formulations of a more general mathematical model called General Linear Model (Aron & Aron, 1994). This model identifies a linear mathematical relationship between a dependent variable and one or more independent (predictor) variables. The mathematics of the model permits, among other calculus, quantification of differences between two or more mean values representing different groups.

\(^4\) The trend analysis procedures are designed to help assess whether there is a functional relationship between the independent variable (successive phases of the regatta) and the dependent variables. The functional relationship describes the general trend or nature of the relationship between the dependent variables and the independent variables. Using this procedure, we can precisely describe the trend in the data in terms of its five component parts (since we have five degrees of freedom for the independent variable). Importantly, we can see if there are different trends among the groups if the Time×Group interaction is significant.
Fig. 3. Accumulated verbalised information and performed actions along a regatta, according to the four levels of expertise in sailing.
100% of any of the six variables corresponded to the highest frequency of variable use achieved by the participant scoring the maximum value. Assuming that the six variables were the totality of the resources that could be used to perform the regatta, we calculated each relative weight (i.e. probabilities of variable utilization by subjects) (Cooksey, 1996). The relative weights of actions

<table>
<thead>
<tr>
<th>Factors</th>
<th>Trends</th>
<th>Adjustments</th>
<th>Technical</th>
<th>Wind</th>
<th>Adversary</th>
<th>Manoeuvres</th>
<th>Spatial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Linear</td>
<td>140.90***</td>
<td>712.18***</td>
<td>247.11***</td>
<td>516.06***</td>
<td>236.77***</td>
<td>469.00***</td>
</tr>
<tr>
<td></td>
<td>Quadratic</td>
<td>0.51</td>
<td>0.17</td>
<td>18.25***</td>
<td>6.20*</td>
<td>6.16*</td>
<td>10.90**</td>
</tr>
<tr>
<td></td>
<td>Cubic</td>
<td>0.03</td>
<td>52.05***</td>
<td>10.45**</td>
<td>18.69***</td>
<td>14.96***</td>
<td>2.84</td>
</tr>
<tr>
<td></td>
<td>Order 4</td>
<td>23.41***</td>
<td>91.72***</td>
<td>11.51***</td>
<td>37.12***</td>
<td>58.06***</td>
<td>89.74***</td>
</tr>
<tr>
<td></td>
<td>Order 5</td>
<td>15.60***</td>
<td>138.36***</td>
<td>175.19***</td>
<td>135.38***</td>
<td>42.55***</td>
<td>112.98***</td>
</tr>
<tr>
<td>Time × Group</td>
<td>Linear</td>
<td>14.89***</td>
<td>26.48***</td>
<td>3.74*</td>
<td>7.57***</td>
<td>2.06</td>
<td>1.86</td>
</tr>
<tr>
<td></td>
<td>Quadratic</td>
<td>2.56</td>
<td>3.59*</td>
<td>0.59</td>
<td>0.74</td>
<td>1.93</td>
<td>3.07*</td>
</tr>
<tr>
<td></td>
<td>Cubic</td>
<td>4.68**</td>
<td>6.00**</td>
<td>1.08</td>
<td>0.22</td>
<td>0.64</td>
<td>3.49*</td>
</tr>
<tr>
<td></td>
<td>Order 4</td>
<td>11.09***</td>
<td>5.10**</td>
<td>1.14</td>
<td>2.71*</td>
<td>0.16</td>
<td>1.22</td>
</tr>
<tr>
<td></td>
<td>Order 5</td>
<td>0.53</td>
<td>4.61**</td>
<td>3.58*</td>
<td>3.21*</td>
<td>12.50***</td>
<td>2.71*</td>
</tr>
</tbody>
</table>

Note: F(3,54); *p ≤ 0.05; **p < 0.01; ***p < 0.001.

Fig. 4. Accumulated time on the successive phases of the regatta.
Table 3
Relative weights (%) of information utilization and performed actions in each phase of the regatta, according to expertise levels

<table>
<thead>
<tr>
<th>Group</th>
<th>Start</th>
<th>1st Upwind</th>
<th>1st Mark</th>
<th>2nd Mark</th>
<th>2nd Upwind</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Adj</td>
<td>Tech</td>
<td>Advr</td>
<td>Wind</td>
<td>Mano</td>
</tr>
<tr>
<td>Experts</td>
<td>22.4</td>
<td>14.4</td>
<td>12.4</td>
<td>13.5</td>
<td>10.4</td>
</tr>
<tr>
<td>Skilled</td>
<td>21.5</td>
<td>9.9</td>
<td>16.7</td>
<td>11.5</td>
<td>11.3</td>
</tr>
<tr>
<td>Interme</td>
<td>23.0</td>
<td>13.1</td>
<td>17.8</td>
<td>9.1</td>
<td>15.0</td>
</tr>
<tr>
<td>NonSail</td>
<td>29.6</td>
<td>16.5</td>
<td>12.1</td>
<td>12.3</td>
<td>10.1</td>
</tr>
</tbody>
</table>

|        | Adj  | Tech | Advr | Wind | Mano | Spati | Adj  | Tech | Advr | Wind | Mano | Spati | Adj  | Tech | Advr | Wind | Mano | Spati | Adj  | Tech | Advr | Wind | Mano | Spati |
|--------|-------------------------------|-----------------------------|-----------------------------------|----------------------------|--------------------------------|----------------------------|
|        | 8.4  | 16.3 | 14.7 | 24.7 | 16.8 | 19.1  | 12.8 | 16.3 | 21.9 | 13.1 | 13.6 | 22.3  | 3.8  | 18.3 | 16.6 | 21.3 | 14.4 | 25.6  |
| Skilled| 12.8 | 14.9 | 17.7 | 17.6 | 13.6 | 23.4  | 15.4 | 14.4 | 26.7 | 8.0  | 15.7 | 19.8  | 5.4  | 19.7 | 22.5 | 17.9 | 13.5 | 21.0  |
| Interme| 12.3 | 15.0 | 18.8 | 18.0 | 20.5 | 15.4  | 14.7 | 17.5 | 22.9 | 7.5  | 15.6 | 21.8  | 6.3  | 22.6 | 20.7 | 14.2 | 16.0 | 20.2  |
| NonSail| 22.0 | 28.2 | 11.5 | 15.6 | 7.2  | 15.5  | 19.4 | 21.9 | 19.9 | 6.8  | 14.2 | 17.8  | 14.4 | 31.2 | 11.5 | 11.9 | 9.4  | 21.6  |

Note: Adj, adjustment; Advr, adversary; Mano, manoeuvres; Spati, spatial; Interme, intermediates; NonSail, non-sailors.
performed and of information utilization in each phase of the regatta are presented in Table 3, differentiating each expertise level. At the start of the regatta it can be observed that experts had a higher probability of attending to spatial information and of adjusting actions. Skilled and Intermediate sailors gave similar weighting to available information and action, except that skilled sailors tended to attend more to adversary information. On the 1st upwind phase expert and skilled sailors accorded similar importance to the sources of information and actions available. However, intermediate sailors tended to emphasise spatial information and non-sailors showed a completely different use of the information and actions available. In the phase corresponding to rounding the first mark there was a large diversity of the relative weights for use of information and performance of actions at different expertise levels. Interestingly, in the downwind phase skilled and intermediate sailors exhibited similar probabilities of using similar information, but experts showed a different weightings distribution. The same occurred with the non-sailors. In the next phases, rounding the 2nd mark and the 2nd upwind, the three groups showed similar probabilities of actions and information use.

All the groups demonstrated distinct preferences for different sources of information. For example, it’s interesting to note that expert sailors showed a higher probability of using wind information in all regatta phases (see Fig. 3). Non-sailors demonstrated a lower probability of using adversary information, contrary to intermediates and skilled sailors. Interestingly, experts tended to rely less on adversary information than the other groups of sailors. Experts and skilled sailors exhibited a higher probability of using spatial information, particularly the latter group. On the other hand, intermediate sailors tended to use spatial information in a similar way to non-sailors. Finally, regarding manoeuvres, experts and skilled sailors tended to exhibit similar probabilities of information use, particularly in the last three phases of the regatta. In all phases of the regatta, non-sailors performed more adjustments and technical actions than the other groups.

Discussion

Brunswik’s (1955) lens model provides a way of measuring the degree of adaptation between an organism’s behaviour and the structure of the environment. This is possible because the environment side of the model provides a referent for evaluating the fitness of behaviour. On the organism side of the model, the utilization weights of experts reflect the ecological validities. This description of adaptation to the structure of a sport-specific task is useful because it can support training of decision-making skills. In line with this reasoning, we first discuss the role of ecological constraints on decision-making in sailing, and then we consider possible applications.

Ecological validities

The ecological validities of the perceptual variables available in the simulator indicated that they were reliable indicators of sailing expertise. The information on the simulator was diagnostic enough to let all

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5 This approach does not imply that these were the only information sources used by the participants, but they were the main ones.
participants complete the task at correspondent levels of performance. The data verified that expertise level in sailing had a significant relationship with performance variables such as total time and final classification on the simulated regatta. This result indicated that the more skilled sailors performed more successfully on the simulated regatta. Indeed, the outcome variable ‘total time’ on the simulated regatta predicted 33% of the expertise level of the individual. Consequently, it can be inferred that decision-making skills under competitive constraints are very important for sailing, with the best sailors functioning as better decision-makers. This finding is relevant for coaching since normally the major constraint seen in teaching sailing is its technical difficulty (tuning the sails, executing manoeuvres, etc.) (Saltonstall, 1983/1996).

Consideration of the ecological validity of the available information in the experiment might help explain why some previous expert-novice analyses failed to obtain between-group differences. For example, in the study of Oudejans et al. (1997), because specific constraints of catching in baseball were deliberately not presented in one condition of the experiment, differences were not reported between expert outfielders and non-baseball players. As the authors highlighted, information from the batter’s movements was not available (p. 594). The need for ecological validities was emphasised by the authors, when they clearly showed that their experts were better attuned to sport-specific information (i.e. they were faster in acting on ball flight information), and not to just reacting to the sudden appearance of ball flight information.

The data from the present study suggest that, when the possibility of actively exploring the task is provided, even people with limited previous knowledge, can achieve success (e.g. all the participants in our study achieved the task goal). This finding contradicts typical results of the psychophysical tradition in decision-making, which presents contrived tasks with normative solutions (Shafir & LeBoeuf, 2002). We have shown that when performing complex tasks, humans are not irrational. The way of using information, and the way of actively exploring the environment was, of course, different between participants with and without knowledge about the task. This outcome is in agreement with Brunswikian theory (Brunswick, 1955), in that, when the information available is valid it supports individual variation in achievement (see Fig. 1). This point is demonstrated in Fig. 4, where obviously the difference between non-sailors and sailors was larger than among the groups of experienced sailors. But importantly, differences in the sailors’ expertise levels were also distinguished. These are the apparently small, but robust differences in sailors’ competition behaviour that were confirmed by trend analysis. This finding would not have been obtained if task dynamics and participants’ accumulated accuracy over the duration of performance were not considered (Brehmer, 1996). Thus, the traditional irrationality attributed to humans may be due to the lack of ecological validity of the information available in the experimental tasks and the tendency to measure decision-making with discrete tasks.

**Information utilization**

The specificity of the sailing task was reinforced by the observation that sailors and non-sailors displayed differences in the way that they attended to meaningful task information, like wind and adversary information. The between-group differences noted seem to be related to differences in information use and active exploration of the environment. We observed different trends in information use and in performed actions in each group. Interestingly, these trends were mostly non-linear, signifying that group-specific use of different information and different exploration actions were made at each structural phase of the regatta. Confirming the integration between the insights of Brunswik and
Gibson made by Vicente (2003), non-sailors seemed to rely mainly on probabilistic perceptual variables in order to make their judgements. Because they could only rely on probabilistic sources of information, subsequent searches for information were initiated. As expertise level increased, sailors were showing a greater attunement to the most relevant information sources to help them achieve their goals. For example, non-sailors relied equally on manoeuvres and wind information, whereas experts tended to rely far more on wind information. Attunement to this variable seems to be really developed with expertise. Interestingly, the adversary variable tended to be overemphasised by non-expert sailors (skilled and intermediate), which may be due to the traditional, excessive emphasis on adversaries by sailing coaches (Saltonstall, 1983/1996). Evidence of the non-linearity of the development of expertise can be observed in the use of spatial information, where the intermediates demonstrated utilization tendencies similar to non-sailors. The tendency for non-sailors to use an inferential mode of decision-making and for experts to use a perceptual mode was also demonstrated in differences in the number of actions performed. Data showed that non-sailors were constantly exploring the immediate context in order to improve their judgments, and that experts were acting much more prospectively due to their reliance on meaningful information in the wider performance context.

This idea is in line with observations by Rosenbaum, Carlson, and Gilmore (2001) who argued that cognitive skills ‘consist of actions that relate not just to the here and now but also to events that may be remote in time or space’ (p. 465). Our findings suggested that actions must be related to the situated context. Put simply, this means that sailors tend to act prospectively (Reed, 1996) without losing their actual functional relation with the environment, i.e. their cognition is situated (see Costall and Leudar, 1996). When individuals are not attuned to relevant information sources, they tend to engage in exploratory behaviour of the local environment to seek information that allows them to make better judgments and decisions. If actions are not meeting the goal, more actions will occur, exploring the context in order to find the relevant information to rely upon (i.e. to be attuned).

*Inter-relation among variables*

The probabilities of cue utilization to achieve the regatta goals differed according to expertise level. The relative weightings of cue utilization and actions performed in each phase of the regatta indicated the probability of using each of the different resources available to solve the ongoing task problem. As Savelsbergh and Van der Kamp (2000) argued, depending on the specific task constraints, multiple perceptual variables may be available to control performance. That is to say, different types of information at different times may be used to perform the task successfully. This idea was supported in the current study, where data showed slight differences in the probability of use of certain perceptual variables and the performance of certain actions in each regatta phase. These differences accumulated from phase to phase, lead to robust differences among groups. These expertise level distinctions in the interrelation among perceptual variables become more effective as they began to mirror the ecological interrelations among ecological descriptors, as the lens model predicted (Hammond, 2000). We observed that the utilization of information evolved in a non-linear way with expertise. Initially, information was used according to the immediate goals of the performer, and as skill level increased, sailors tended to act more prospectively. This development led to abrupt changes in use of one type of information to another that better fitted the sailor’s goals. For example, non-sailors tended to give similar weightings to wind, and manoeuvres and lower weighting to adversary information, a combination, which was clearly distinct from any other groups. As expertise increased, sailors tended to give higher
weighting to the wind, although, there were phases of the regatta where other variables were prioritised (e.g. spatial information at the start). In particular, expert sailors were more attuned to wind information than the other groups of sailors who, in contrast, prioritised more local sources of information, such as adversary. The implication is that the use of local sources of information for decision-making by experts was constrained by use of perceptual variables that specifies the wider context of the regatta.

**The development of sailing expertise**

These findings may explain the higher number of actions carried out by the non-sailors, actively exploring the environment to distinguish information that is relevant and that which is not. Active exploration of a task environment is a fundamental aspect of problem solving (Kirlik, 1998). In the development of sailing expertise, the action system progresses when the learner tries to coordinate the degrees of freedom of the body-boat system (e.g. by freezing some body-boat movements). Although graceless, the resulting movements precipitate and reveal the dynamic characteristics of the action system, allowing exploration and discovery of its inherent potentials for qualitatively distinct task-specific modes of coordination and control (see Davids, Araújo, Shuttleworth, and Button, 2003). The perceptual counterpart to the novice’s deliberate control of singular motor (i.e. body-boat) components, and the freezing out of the rest, would be the inferential use of perceptual variables that capture only limited features of the available task-relevant information. By proceeding in such a way, the novice can get on with the task and experience a suggestive pattern of success and failure while exploring different perceptual variables. These fluctuations sooner or later lead to the discovery of a stable, qualitatively different, and more efficient mode of control. This conclusion has implications for coaching, recommending that the inherent complexity of sports does not have to be necessarily reduced (or decomposed) during learning (see Davids et al., 2003). Instead, reliable perceptual variables should be provided to the learner to allow him/her to converge upon relevant information (Beek et al., 2003; Kirlik, 1998; Runeson et al., 2000).

Our findings emphasized that an adequate theory of how expertise effects in decision-making are generated, is dependent on an accurate account of exactly what those effects are because the latter can put strong constraints on the former (see Vicente and Wang, 1998). The same principle can be used for training applications. If our understanding of decision-making in motor learning is not clear (see Sherwood and Lee, 2003, pp. 178–179), then we need to understand the process before we can design practice for acquiring decision-making skills.

**Applications**

From an applied point of view, given that dynamic decision-making is one of the most distinguishing variables in assessing sailing performance, the use of computer simulations with the kind of information presented here may be relevant. Computer simulated regattas, with a representative design, may be used for talent identification and development purposes. For example, those non-sailors who started sooner relying on the relevant information sources demonstrated more talent than other participants.

The decision-making simulator can be used as a tool for training decision-making in safe and desired environments (see Vicente, 1996) and subsequently developing sailing expertise. For example, by manipulating the information on which the learner is relying, coaches can direct the learner’s search toward the sources that could facilitate higher achievement (see Williams and Ward, 2003).
Thus, coaches could help sailors to overcome the need for use of probabilistic perceptual variables to make judgments, and to help them become attuned to relevant information that enhances their prospective action.

Also, computer simulations can be used for designing training situations by the coach, where specific tactical skills may be practiced. Coaches can create a variety of new—‘what if’—situations of interest and display them to the sailors. Most of all, it is important to consider variability in decision-making in sport. Perhaps errors identified by coaches in athletes may be seen as misperceptions of which ecological constraints are most influential over the athlete-situation system. To offer the athlete the possibility of exploring solutions under specific constraints may be a more effective way to improve decision-making, rather than to prescriptively instruct sailors.

In conclusion, our results indicated a positive association between sailing expertise and decision-making skills. Decision-making in sailing was characterized by non-linear accumulated effects of exploring and using information in a regatta, which were dependent on the level of attunement to task-specific information. Decision-making skills could be developed through progressive reliance on better information, related to specific phases of a regatta. Further research is needed to compare decision-making behaviour in boats on the water with the performance on simulated regattas.

References


