SUMMARY AND CONCLUSIONS

To date, the majority of research with respect to the topic of perceptual-cognitive expertise has tended to focus more on closed skills (e.g., Cañal-Bruland, Mooren, & Savelsbergh, 2011; Huys et al., 2009; Savelsbergh, van der Kamp, Williams, & Ward, 2005), rather than open skills including unpredictable environments such as sailing (for an exception, see Araújo et al., 2015). Therefore, this dissertation examined perceptual-cognitive skills and expert performance in sailing. Research with respect to what degree perceptual-cognitive skills underpin decision-making in skilled sailors is scarce, while coaches consider this a very important aspect for the skill development of their athletes.
In search of such key-performance indicators, the first study (Chapter 3) examined visual search, movement behaviour, and boat control while rounding the windward mark rounding. The windward mark rounding is a crucial event in sailing, especially the first windward mark rounding after the start. The second study (Chapter 4) had two aims: to validate the use of action sport cameras for quantifying visual focus of attention in sailing and to apply this method to investigate whether an external focus of attention is associated with superior performance in upwind sailing. Finally, the third empirical study (Chapter 5) scrutinised whether expertise effects are present in cutaneous wind perception. In a wind simulator, wind stimuli were presented to sailors and non-sailors consisting of different wind directions and speeds. Participants judged the wind stimuli without having access to visual or auditory information. Capturing, understanding and predicting expert performance in the first two studies in particular was difficult, due to the unpredictable environments in which sailors typically perform. Therefore, before executing the three studies, first a novel approach (Chapter 2) was developed to translate methodological issues into technological advancements when running in-situ experiments in sports. These issues are particularly relevant when aiming to optimise the scientific guidance of athletes, coaches and staff to the desired performance at world championships and Olympics. Keeping this aim in mind, the close collaboration with elite coaches and sailors of the Dutch Sailing Team and the national sailing lab in The Hague (InnoSportNL) undoubtedly sparked the methodological development to capture and understand skilled performance in sailing. In the remainder of this Epilogue, firstly, the key findings and conclusions are summarised and, secondly, the practical implications and suggestions for future research are discussed.

TRANSLATING KEY ISSUES INTO TECHNOLOGICAL ADVANCEMENTS IN SAILING

In sailing there is a high level of inter-individual dynamics adding to the perceptual-motor complexity; sailors have to deal with wind shifts, waves, tides and fellow competitors. Moreover, sailors’ ability to ‘trim’ the boat is crucial, but difficult. Chapter 2 identified and discussed key methodological issues that are particularly relevant when aiming to translate sport scientific knowledge into practical guidelines for coaches and athletes in sailing. These issues are: the representative performance environment (including fidelity of stimuli and type of response), generalisability, and experimental control. The presented approach is a novel method to investigate skilled performance within changing environments (such as in sailing), both from a methodological and practical perspective. That is, we measured sailors’ performances on the water (see also Chapter 3 and 4). Moving to the water was necessary because a lab setting may be unsuccessful to capture the environmental characteristics adequately. Notably, sailors did
not have to wait for perceptual stimuli before actions were commenced, full information from the onset of the trial until the end of the trial could be used to start an action. Furthermore, movement behaviour was captured during every trial on the water and remained the same as in a competitive performance environment (e.g., Pinder, Davids, Renshaw, & Araújo, 2011; van der Kamp, Rivas, van Doorn, & Savalesbergh, 2008). In sum, sailors were neither limited in their motor nor perceptual degrees of freedom (Savalesbergh & van der Kamp, 2000), giving us the opportunity to gain better understanding of complex perceptual-motor expertise in sailing. To improve experimental control, we embraced technological advancements (e.g., head mounted eye tracker, waterproof cameras, GPS trackers, and boat sensors) for the assessment of skilled performance in the representative performance environment. Although capturing sailing expertise often appeared to be a challenging task, Chapter 2 shows that when methodological designs are based on theory (e.g., Brunswik, 1956; Gibson, 1979; Millner & Goodale, 1995), as well as on the collaboration between coaches, scientists, and athletes, the understanding of expertise in complex sports can be advanced in a manner that offers benefits for both science and sports practice (see also, Renshaw & Gorman, 2015). Chapter 3, studying the windward mark rounding, and Chapter 4, studying the upwind legs, followed the principles of the approach presented in Chapter 2.

KEY-PERFORMANCE INDICATORS DURING THE WINWARD MARK ROUNCING

Chapter 3 presented an attempt to examine whether, and if so, how visual search, movement behaviour, boat control, and environmental conditions contributed to a complex skill in sailing – the windward mark rounding. Measurements were conducted in a laser, a one-person Olympic boat. This study was executed on the water to couple perception and action processes in a representative performance environment (following our approach reported in Chapter 2). To this end, participants sailed more than 100 windward mark roundings on the water (sailed in two experimental conditions; without and with opponents). Results revealed that all four factors were linked with performance using generalised estimating equation (GEE) regression analyses, yet to varying degrees. The outcomes related to the visual search measures in Chapter 3 add to our understanding of expert performance during a complex perceptual-cognitive skill. Most notably, while rounding the mark (i.e., phase 2), better sailing performances were related to gazing more to the tangent point of the mark. In car driving, the tangent point is defined as the “non-stationary point of a bend where the driver's line of sight is tangential to the inner edge of the road” (Land & Tatler, 2001, p. 1215-1216). Our finding is hence in line with studies in car driving and speed skating (e.g., Kandil et al., 2010; Land & Lee, 1994; Land & Tatler, 2001;
If sailors do not succeed to gaze at the tangent point during the right phase of the windward mark rounding (i.e., phase 2), they are likely to start their initial steering actions either too late or too early which in turn may deteriorate performance.

Moreover, during the actual rounding, better performances were related to gazing more outside the boat and showing more changes between gaze locations, but solely in the experimental condition without opponents. These results suggest that sailors search for relevant information outside the boat (e.g., wind shifts) while sailing alone. However, perhaps unexpectedly, the opposite result was found for the experimental condition with opponents; that is, during the actual rounding, skilled performance was related to gazing less outside the boat and showing fewer changes between gaze locations. A potential explanation might be that, for the condition with opponents, sailors gazed almost a quarter of the time at other boats; yet, for the condition without opponents, by definition, sailors could not gaze to other boats. Alternatively, other gaze locations were available when sailing alone, such as the tangent point. This might also explain why sailors’ gaze to the tangent point was associated with superior performances. Furthermore, in the condition with opponents, other boats in front might have occluded vision towards relevant gaze locations outside the boat. It appears that the visual search of skilled sailors during the windward mark rounding is functional and adopts to the changing environment – without or with fellow competitors (e.g., Fajen, Riley, & Turvey, 2009; Passos, Araújo, Davids, & Shuttleworth, 2008).

Furthermore, during the approach (i.e., phase 1), superior performances were related to gazing less outside the boat and less to the tangent point. This finding is in contrast with earlier findings in car driving and speed skating. We surmise that the different speeds reached in sailing, compared to car driving and speed skating, offer a potential explanation. That is, speed skaters and car drivers may need to gaze relatively early at the tangent point due to the relatively higher speeds reached; in contrast, the less demanding temporal constraints and lower speeds during the approach may give sailors the opportunity to gaze inside the boat (e.g., focus on trimming lines), and only gaze to locations outside the boat when getting relatively close to the mark (i.e., when the actual rounding begins). Nevertheless, we cannot rule out the possibility that sailors may have directed their visual gaze to other pertinent information prior to the start of our measurements (i.e., before phase 1). Throughout the exit of the mark (i.e., phase 3), and similar to the approach of the mark, better performances were related to gazing less outside the boat, when sailing alone. Most likely, skilled sailors gaze more inside the boat to trim the sail optimally to maintain a higher boat speed to continue their course downwind to the next mark.

With respect to movement behaviour, superior performances were associated with the release of trimming lines close to rounding the mark. If a sailor releases his trimming line “off time” shortly before the actual rounding, this is related to a slower performance. Superior sailing
performances are related to a specific movement behaviour pattern during the approach and actual rounding, which is in line with previous findings in sailing (e.g., Araújo, Davids, & Serpa, 2005). Furthermore, better performances were related to approaching the mark with little heel, yet heeling the boat more to the windward side when actually rounding the mark. Clearly, skilled sailors possess excellent motor skills to heel the boat to windward side during the actual rounding, and to use the rudder to a lesser degree, resulting in a higher boat speed. Before approaching the windward mark, sailors typically sail an upwind leg including continuous movements such as tacking, hiking, and trimming (see “Glossary of sailing terms,” 2007). In Chapter 4, our focus of interest shifted from the windward mark rounding to upwind sailing. The aim was to quantify the external focus of attention when sailing upwind as fast as possible by means of action sport cameras.

**QUANTIFYING EXTERNAL FOCUS OF ATTENTION USING ACTION SPORT CAMERAS**

*Chapter 4* validated the practical use of action sport cameras for quantifying focus of visual attention in sailing and applied this method to investigate whether an external focus of attention was associated with better performance in upwind sailing. The agreement between gaze location measures (i.e., using a head mounted eye tracker) and head orientation measures (i.e., using an action sport camera) was high and the 95% limits of agreement were acceptable, indicating that action sport cameras are a valid tool to examine visual focus of attention in upwind sailing.

Fifteen sailors were asked to sail upwind as fast as possible. Results revealed that in sailing – within a constantly changing environment – focus of attention is not a significant predictor for better upwind sailing performances. This implicated that neither external nor internal foci of attention were per se correlated with better performances. Although our findings may not harmonize with previous research on attentional focus in closed skills (e.g., Wulf, 2007), they complement and extend these by focusing on skills within unpredictable performance environments. Furthermore, we surmise that the large individual differences of viewing percentages to external areas of interest might be explained as adaptive behaviour during exploration of the performance context (e.g., Davids, Button, & Bennett, 2008). Different foci under the same circumstances were associated with similar performances, but also similar foci were related to different performances. The role of degeneracy might help to explain the differences in anticipatory behaviour (Edelman & Gally, 2001); that is, different foci may yield equivalent outcomes. Sailors may also rely on perceptual information picked-up via other senses, such as touch (see also *Chapter 5*) (for an overview, see Gray, 2008). In order words, information from one sensory modality (e.g., tactile information from legs and feet during hiking) may
overlap information obtained by others (e.g., visual information about the sail trim), resulting in
different foci of attention. So far, it remains to be determined to what degree haptic perception,
and more specifically, cutaneous perception (i.e., by means of the touch receptors in the skin)
plays a role during perceptual-cognitive skills in sailing. Therefore, Chapter 5 examined whether
expertise effects were present in cutaneous wind perception.

EXPERTISE EFFECTS IN CUTANEOUS WIND PERCEPTION

With the aim to investigate cutaneous wind perception, Chapter 5 tested three groups of
participants (i.e., expert sailors, intermediate sailors and nonsailors) by presenting wind stimuli
reflecting 16 different wind directions and three different speeds generated by a wind simulator.
Access to any visual or auditory information was withheld. The wind simulator was integrated
within a novel sail simulator developed by the Faculty of Industrial Design Engineering (Delft
University of Technology) (e.g., Mulder, Verlinden, & Dukalski, 2012; Verlinden et al., 2013).
Results indicated that expert sailors outperformed nonsailors in perceiving wind direction
(i.e., smaller mean signed errors) when presented with low wind speeds. This suggests that
expert sailors are more sensitive in picking up differences in wind direction, particularly when
confronted with low wind speeds that demand higher sensitivity. Similar effects have been found
for other haptic tasks (for an overview, see Reuter, Voelcker-Rehage, Vieluf, & Godde, 2012).
A possible explanation for this result may be that with developing expertise (and the gathering
of experience), the accuracy of wind perception may be enhanced. However, results revealed
no difference between groups on wind speed estimates. Though this may seem to contradict
our findings on wind direction estimates, we argue that it did not. Sailing expertise is first and
foremost, characterised by perceiving the right wind direction, regardless of the wind intensity
(e.g., Davidson, 2009). Wind speed perception may develop as a subserving ability, and may
be of lower priority. Furthermore, results indicated that wind speed differences in the low
range were perceptually magnified, compared to differences in the higher ranges. Especially in
regattas with low wind speeds, this may be beneficial for sailors; that is, a correct wind speed
estimate is crucial to trim the sail, and, hence, might result in a higher boat speed. Finally,
participants (sailors and nonsailors) rated wind directions presented from the front more
accurately than those presented from the back. Likewise, participants perceived wind stimuli
presented from the front as more intense than those presented from the back, confirming that
the wind simulator is a valid and reliable setup to examine wind direction and speed estimates.
This study contributed to our understanding of perceptual expertise in sailing, and, to the best of our knowledge, is the first study to have unravelled expertise effects in the cutaneous perception of wind (see also Lewandowsky, 2015).

**FUTURE RESEARCH AND PRACTICAL IMPLICATIONS**

The efforts and initial evidence described in this dissertation focused on developing a novel approach to capture, understand and predict perceptual-cognitive skills in sailing (Chapter 2) with the aim to provide detailed descriptions of the key differences between skilled and less skilled sailors. More specifically, multiple key-performance indicators were identified that contributed to skilled performance while rounding the windward mark rounding (Chapter 3). During upwind sailing, neither external nor internal foci of attention were per se correlated with better performance, as quantified by means of an action sport camera (Chapter 4). Finally, expert sailors were more sensitive in picking up differences in wind direction, particularly when confronted with low wind speeds that demanded higher sensitivity (Chapter 5).

With respect to future research, the reported approach in Chapter 2 could also be used to explore open skills in other sports, such as surfing, kiteboarding, BMX racing, mountain biking or snowboard cross. So far, these sports have received relatively little attention from a perception-action perspective. Furthermore, this approach may also shed further light on comparing findings from lab studies (e.g., Manzanares, Menayo, Segado, Salmerón, & Cano, 2014) and in-situ studies with the aim to identify both individual and group differences in, for example, sailors’ visual search strategies. Finally, the approach could contribute to talent identification and development programmes (i.e., using representative task designs) and evidenced-based perceptual training methods in sailing (for examples in basketball and soccer, see Oudejans, 2012; Savelsbergh, van Gastel, & van Kampen, 2010).

From an applied perspective, we closely collaborated with The Dutch Sailing Team with the aim to optimise the scientific guidance of sailors, coaches and staff in an early stage in their preparations for world championships and Olympics by translating evidence-based, sports scientific knowledge into practice (for more information about our collaboration in the Dutch media, see e.g., van Driel, 2012; van Nieuwstadt, 2011, 2012, 2014). For example, eye-tracking data (e.g., visual search patterns, fixation duration and locations) assisted sailors and coaches on an individual level during debriefings after training sessions. To enhance learning, coaches are advised to design representative activities or tasks in their training sessions that couple perception and action processes. Throughout the Olympics 2012 in Weymouth, The Dutch Sailing team won three medals, including a silver medal in the laser class (women). The goal of
the Dutch Sailing Team is to win four medals during the Olympics 2016 in Rio de Janeiro. Yet, to further spark the collaboration between sport science and practice, sports scientists should report functional and concise feedback to athletes, coaches and other staff, after research has been executed (e.g., Farrow, Baker, & McMahon, 2013).

Returning to Chapter 3, our findings provide initial evidence to investigate targeted interventions in sailing for the approach and actual rounding of the windward mark. Previous research indicated that visual search behaviour may be trained in order to improve performance (e.g., Oudejans, 2012). Therefore, we are currently pursuing our research project with a training study, with the aim to examine performance by directing attention externally during the windward mark rounding (e.g., to the tangent point during the actual rounding).

It is also possible to formulate practical implications based on Chapter 3 for coaches and athletes. First, coaches and athletes are advised to train windward mark rounding with opponents, since each expert sailor solves the ever-changing opportunities for action differently as they interact with fellow opponents and the changing environment. Second, during the approach of the windward mark rounding, sailors are advised to release the trimming lines (i.e., Cunningham, kicking strap, andouthaul) close to the actual rounding. Additionally, with respect to boat control, sailors should sail the boat as flat as possible during the approach of the mark. Third, as regards the actual rounding, sailors are recommended to direct their gaze to the tangent point. Besides, sailors should try to heel the boat with a considerable angle to the windward side at the same time, to maintain a higher boat speed.

As regards our study reported in Chapter 4, future research is needed to establish whether a particular focus of attention is especially effective in enhancing performance in other open skills in sailing. Future studies could examine the impact of various wind intensities and expertise levels to further improve our understanding of the relationship between sailors’ foci of attention and their performances.

Chapter 4 suggested two practical implications. First, coaches and athletes are advised to train upwind speed legs under as many as possible different circumstances (e.g. many different locations) to enforce athletes to actively explore the manifold situational constraints, such as wind direction, currents and opponents’ actions. This implication is similar to our main advice based on our findings in Chapter 3. Second, our study suggested that action sport cameras are a valid tool to use to quantify visual focus of attention in upwind sailing, and possibly, also in other sport settings. Compared to head mounted eye trackers, action sport cameras are relatively inexpensive and hence offer an excellent opportunity to capture performance of multiple sailors simultaneously and in longitudinal designs within unpredictable environments. Based on the initial empirical evidence of Chapter 3 and 4, sports scientists may also wish to reduce the analysis
workload by manually scoring video data (e.g., Vansteenkiste, Cardon, Philippaerts, & Lenoir, 2015). For example, for the windward mark rounding, we were able to develop a more efficient measurement strategy while maintaining accuracy and reliability by scoring eye tracking video data each 5 frames instead of frame-by-frame.

Finally, as concerns Chapter 5, admittedly, the wind intensities we were able to produce were rather low as compared to wind speeds of 5-25 knots, commonly experienced during sailing regattas. Possibly, we detected the wind speed threshold by chance allowing us to differentiate between expert sailors and nonsailors in relation to their ability to accurately perceive wind directions. Therefore, future research could systematically examine a broader range of wind intensities including a larger sample size in order to enrich our initial findings. Accordingly, future research may also further explore to what degree the pickup of information via the individual senses add to sailing performance, and whether expert sailors may differ from their less skilled counterparts in integrating multisensory information to guide their actions (Gray, 2008). By all means, a training study would enrich our insights into these processes, for example, examining cutaneous wind perception while performing representative actions in the sailing simulator.

With respect to Chapter 5, the applied work with athletes inspired our research by generating new questions. When we measured gaze behaviours, and sailors wore the respective head mounted eye trackers, some indicated that they were hampered to feel the wind around their eyes because of the transparent lenses. Subsequently, removing the lower part of the lenses of the eye tracking glasses immediately improved the cutaneous perception of wind. More importantly, considering the availability of perceptual information from multiple senses, this led to the idea of testing expert sailors, intermediate sailors and nonsailors in a wind simulator while estimating wind direction and wind speed.

In conclusion, this thesis focused on developing a novel approach to capture, understand and predict perceptual-cognitive skills in sailing and provided initial evidence of key differences between skilled and less skilled sailors. Translating these evidence-based, sports scientific findings into practice supported our goal to optimise the scientific guidance of sailors, coaches and staff (see also Chapter 2). For instance, we regularly provided individual feedback to coaches and athletes with reference to visual search behaviour, movement behaviour, and boat control during various sailing events (e.g., start, upwind legs, mark roundings). Based on the findings of Chapter 3 and 4, coaches and athletes are advised to train upwind legs and windward mark roundings with opponents, under as many circumstances as possible, to enforce sailors to actively explore the performance environment and its situational constraints. More specifically, during the approach of the windward mark, sailors are recommended to release trimming lines close to the actual rounding, and sail the boat as flat as possible. For the actual rounding, sailors
are advised to gaze to the tangent point and steer the boat with a significant heel angle to the windward side. Finally, waterproof action sport cameras may be used to quantify visual focus of attention in upwind sailing with the aim to compare multiple sailors during the same training session to enhance experimental control.