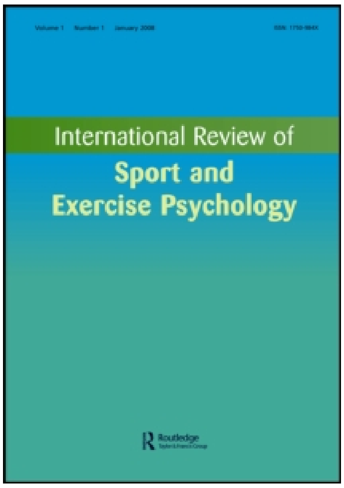

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Pay attention! A review of visual attentional expertise in sport

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Pay attention! A review of visual attentional expertise in sport

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The objective of this paper is to review current literature on visual attentional processes in the area of sport expertise. Based on recent findings in neuroscience, attention can be divided into four distinct sub-processes, all of which differ across individuals to varying extents: orienting attention, selective attention, divided attention, and sustained attention. These four sub-processes serve as a heuristic tool to categorize the presented studies. Then, a critical assessment of the merits and limitations of the discussed studies is provided. Following that, conceptual and methodological issues in the field of attention and sport will be discussed. Finally, new potential directions for further research in the field of attention processes and expertise will be presented with a link to other research topics (e.g., motivation, creativity) and disciplines (e.g., developmental psychology). The overall aim is to show that human movement science can use important insights from other branches of the discipline (e.g., social psychology) in order to test and optimize sports training programs. At the same time, though, it is hoped that the use of ecological and complex settings will, in future, enable further development of theoretical models from other disciplines, like general, or developmental psychology.

Keywords: orienting attention; selective attention; divided attention; sustained attention; inattentional blindness; breadth of attention; motivation; creativity; ERP

When watching World Championships or the Olympic Games, one can only admire the incredible visual attentional performance displayed by athletes, coaches or referees during the competition. The world-famous referee Pierluigi Collina from Italy appeared to have extraordinary attentional orientation, because he could follow the movements of 22 football players (without the benefit of slow motion replay) and extracted relevant features from the complex surroundings in such a way that he was able to recognize irregularities and made a decision instantaneously. Legendary coaches in track-and-field sports such as Gerd Osenberg or Leszek Klima have great selective attention skills because they can recognize from a distance of more than 10 metres the key feature of a complex technique (e.g., Fosbery flop) that needs to be changed for the athlete to be able to jump higher on the next attempt. The creative French soccer player Franck Ribery seems to be able to divide his attention perfectly because he takes in all relevant stimuli of a complex situation and subsequently uses this information to fool his opponents by looking in the direction of the most obviously free team-mate, but then passing the ball to another player instead without

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even looking at him ('no-look-passes'). Snooker players like the world-class Scottish snooker player Stephen Hendry have the ability to maintain their attention between a white and a colored ball as well as the snooker pocket for several seconds in order to be able to hit the white ball with a snooker queue so precisely that the other ball is sunk into the pocket.

Research has recognized the significance of attention in sports some time ago (Abernethy, 1988; Nougier & Rossi, 1999; Moran, 2003; Williams, Davids & Williams, 1999) and the scientific literature provides numerous findings reporting the predominant attentional capacities of experts in comparison with relative novices (Abernethy & Russell, 1987; Castiello & Umiltà, 1992; Memmert, 2006; Pesce-Anzeneder & Bösel, 1998; Rossi, Zani, Taddei & Pesce, 1992; Williams & Grant, 1999).

Although one can assume that visual attention and visual perception are closely linked, they are not identical from a scientific viewpoint. Perception is the basis of human recognition, experience and action (Marr, 1982). The individual experiences made are based on information absorbed via our knowledge systems, processed and saved in subcortical and cortical knowledge structures of the different perception systems (Bruce, Green & Georgeson, 1997). This means that perceptual processes contain all activities that serve the acquisition of information, including cognitive activities such as attention, memory, executive functions as well as motor and affective processes.

Therefore, it is wrong to equate attention processes with perception; instead, they must be interpreted as a sub-function of human perception, whose task it is to select relevant aspects from a large number of sensations in order to be able to efficiently guide actions and thought processes (Allport, 1987; Duncan, 1984; Posner, 1980). For example, the spatial resolution of attention is different from that of vision (Intriligator & Cavanagh, 2001). Hence, visual attention, but not basic visual processes, must be assigned to the category of higher cognitive performances. This issue becomes apparent considering that various aspects of attention are affected by workload, working memory, memory load, top-down sensitivity control, or competitive selection (Knudsen, 2007; Schweizer, Zimmermann & Koch, 2000). For example, more demanding attention tasks seem to yield higher correlations between measures of attention and intelligence because 'higher' mental processes are involved (Bates & Stough, 1997).

A great amount of research in the past 20 years dealing with athletes' fundamental visual perception has examined basic visual perceptual abilities (e.g., visual acuity, color vision, and depth perception) between sports experts and novices (for an overview, see Williams & Ford, 2008; Williams & Grant, 1999; Williams & Ward, 2003). In summary, one can agree with the statement by Eccles (2006, p. 1103) regarding the state of research on basic perception capabilities: 'The findings from over a decade of research on expertise within and beyond sports have provided limited support for the existence of differences between expert and less skilled performers in terms of basic visual and neural systems'.

Interestingly, in a recent study Memmert, Simons and Grimme (2008) have found similar results for basic attention abilities. The conscious perception of unexpected objects (inattentional blindness task; Simons & Chabris, 1999), performance in the detection of peripheral stimuli (functional field of view task; Green & Bavelier, 2003), and performance in attention distribution tasks (multiple-object tracking task; Alvarez & Franconeri, 2005) did not differ between experts and novices.

Because there are important differences between experts and novices in pattern recognition, determination of situational probabilities, and picking up perceptual cues (see for a recent meta-analysis, Mann, Williams, Ward & Janelle, 2007), specific perceptual skills were investigated and training programs for specific types of sports were developed which try to improve specific demands of perception (for overviews, see Abernethy, Wann, & Parks, 1998; Starkes, Helsen & Jack, 2001; Vickers, 2007; Williams & Grant, 1999; Williams & Ward, 2003; Williams, Ward, & Smeeton, 2004). Similarly a stronger focus has been placed on more specific attentional strategies and processes contributing to sports performance in recent years.

Therefore, the main objective of this review article is to provide an overview of current research in the area of specific attention processes and extraordinary performance in sport. Using a framework borrowed from neuroscience as a heuristic tool, current studies focusing on attention and expertise are discussed and categorized at first. In a second step, a critical assessment of the merits and limitations of these studies is provided. More specifically, it will address conceptual and methodological issues in the field of attention and sport. Finally, potentially fruitful new directions for further research in the field of attention and expertise will be presented with a link to other research topics (e.g., creativity) and branches of psychology (e.g., social psychology).

On the current state of research: attentional expertise in sport

In the research literature attention is primarily described as the selection of relevant stimuli and the selective structuring of the field of perception (e.g., Knudsen, 2007; Smith & Kosslyn, 2007). Recent developments in the field of this construct suggested the existence of four sub-processes of attention (e.g., Mirsky, Anthony, Duncan, Ahearn & Kellam, 1991).

This classification of sub-processes is based on the insights from electrophysiology, functional neuroimaging, neuropsychology, and psychopharmacology (Coull, 1998; Van Zomeren & Brouwer, 1994). Emerging here is a classification of different attentional sub-processes, which include attentional orientation, selective attention, divided attention, and sustained attention. Therefore, we draw on the four mentioned attentional processes as classification framework in order to categorize the present studies in sports. Naturally, the individual sections vary in length depending on the body of research available. In addition, due to limitations in the length of the present review, only the key articles of some areas can be mentioned.

Attentional orienting

The sub-process of attentional orientation is assumed to refer to the orientation towards salient stimuli or salient details of a stimulus (cf. Coull, 1998). According to Posner (1980), orienting of attention in the visual field facilitates the processing of the information present in the attended location and inhibits the processing of information present in the unattended location. The cuing paradigm by Posner (1980) is usually used to examine the costs and benefits of orienting attention in the visual field. In general, this paradigm shows that performance in signal detection tasks is enhanced by pre-cueing the location where the target stimulus is likely to appear.

A number of researchers used the cueing paradigm to study the orienting of attention in sport (for a review of earlier studies, see Nougier & Rossi, 1999). Overall, the following results were found:

1. Almost every study, with the exception of Nougier, Azémar, Stein and Ripoll (1992) could show that experts participating in open skill sports such as boxing (Nougier, Ripoll & Stein, 1989), hockey (Enns & Richards, 1997), pentathlon (Nougier, Ripoll & Stein, 1989), soccer (Lum, Enns & Pratt, 2002), or volleyball (Castiello & Umiltà, 1992) exhibited a higher attentional flexibility than novices for orienting their attention in the visual space. Expert athletes may prefer to pay proportionally less attention to highly likely events and more attention to less likely events. This is probably not the case for athletes practising closed skills sports (Nougier, Rossi, Alain & Taddei, 1996).
2. Expert athletes who participated in disciplines requiring a high attentional workload outperformed novices in orienting of attention (Nougier, Ripoll & Stein, 1989; Nougier, Stein & Bonnel, 1991; Pesce-Anzeneder & Bösel, 1998).
3. Further findings demonstrated that experts can modulate their attentional resources according to more specific task demands (e. g. Nougier, Ripoll & Stein, 1989, Castiello & Umiltà, 1992). More specifically, experienced volleyball players (Pesce-Anzeneder & Bösel, 1998) and professional ski-racers (Turatto, Benso & Umiltà, 1999) showed a better adaptation of the efficient size of the attentional focus. This means that, depending on the task, experts are better than novices at modulating the size of the attentional focus.
4. Sub-maximal physical exercise or load leads to a reduction of reaction time among experts, and especially for invalid cues, the attentional costs of reaction time decreased (Pesce, Capranica, Tessitore & Figura, 2003; Pesce, Casella & Capranica, 2004).
5. Attentional orienting can also have an influence on controlling a motor skill during its execution (Lépine, Glencross & Requin, 1989; Rosenbaum, 1980) or performing a sport-specific decision-making task (Cañal-Bruland, in press, a). Cued movements or information rich areas have a high likelihood of being selected and the uncued movement or 'information poor' areas a low likelihood to be executed.

Selective attention

The sub-process of selective attention is supposed to direct attention to a particular target in favor of another at a specific point in time or within a limited time window (cf. Coull, 1998; Posner & Boies, 1971). Selective attention is closely linked to attentional orienting, because both sub-processes are involved in directing attention (steering) to certain areas. Nevertheless, Posner and Peterson (1990) showed that different areas of the brain are activated during the two attentional performances. This can be explained by the fact that with selective attention, certain stimuli are preferred over others whereas attentional orienting only relates to a single stimulus.

Selective attention is, along with attentional orienting, probably one of the most researched and discussed subject in sports sciences. This is not only brought about by this attention process being probably the most significant in sport specific situations but also because there are several different possibilities to research selective attention methodologically. On the one hand, interest has been focused on the question of where experts look during a competition (*visual search strategies*) in order to be able to react as quickly and appropriately as possible. Magill (1998) speaks of 'information-rich areas', in which there are hidden visual characteristics that can be used to anticipate movement. In badminton, for example, not just regions remote from the body, such as the racket or the shuttlecock flight, but also the arm and upper body area serve as important sources of information for anticipating an opponent's stroke (Abernethy & Russell, 1987). On the other hand, there are attempts to systematically vary selective attention manipulations in training studies. This is possible by directing attention to important 'information-rich areas' through visual (*attentional cues*) or verbal (*instructions*) hints. In the following paragraph, contemporary research on selective attention is divided into three areas accordingly: Visual search strategies, attention cues, and instructions.

Visual search strategies

Abernethy and Russell (1987) demonstrated that experts show extremely high scores in an applied selective attention task (i.e., determination of the landing position of a stroke in badminton) and are further capable of extracting important information more quickly in order to perceive more relevant features (temporal occlusion paradigm; cf. Abernethy, Wann & Parks, 1998). The ability to select information from one location rather than another is one of the key components of extraordinary performances in sport (Abernethy, 1988). A large number of important empirical findings showed that skilled performers have more efficient and appropriate visual search behaviors compared to their less-skilled counterparts (e.g., Abernethy, 1990; Vaeyens, Lenoir, Williams, Mazyn & Philippaerts, 2007; Vickers, 1992). According to a recent meta-analysis by Mann and colleagues (2007), highly skilled athletes seem to perform fewer fixations of longer duration with prolonged quiet eye periods. This means that experts pay more attention to few important rich areas and exhibit less search rates than novices. It seems that for skilled athletes, it is not the *amount* of attention (i.e., more fixations) that is important at an early processing stage to answer quickly and accurately, but the *location* of attentional focus (Williams *et al.*, 1999). More specifically, there is still controversy over whether fixation is identical with the focus of attention and therefore gathering information (e.g., peripheral vision, Posner, 1980) and whether the distribution of attention is linked to the size of the attentional focus (e.g., zoom lens analogy, Eriksen & Yeh, 1985). Superior visual search behaviors could be based on integrative viewing within a single fixation and hidden attention shifts.

Attentional cues

Selective attentional cues which direct awareness to the information rich area can be researched using the priming paradigm by Posner (1980). The idea is that participants' reaction times to a given stimulus (target stimulus) are influenced by an earlier, in part not consciously perceived, stimulus (prime). It was shown that perceived movement sequences could prime human motor reactions (Bernieri &

Rosenthal, 1991; Schmidt, Bienvenu, Fitzpatrick, & Amazeen, 1998). Of course, such priming effects only occur if internal representations of the perceived movement sequences exist (Tulving & Schacter, 1990).

Kibele (2006) showed that the processing of non-consciously perceived visual stimuli may be distorted when participants are asked to perform complex motor reactions with higher demands on motor program planning rather than simple motor reactions. Farrow and Abernethy (2002) provide some evidence for the ability of individuals to acquire non-conscious perceptual movement representations by implicit learning processes in order to utilize this form of implicit knowledge. Hagemann, Strauss and Cañal-Bruland (2006) have used red transparent patches to highlight the most informative cues which in turn lead to better perceptual performance.

Memmert, Hagemann, Althoetmar, Geppert and Seiler (2009) used the same attention cues for studying different kinds of training conditions for badminton players ('easy-to-hard' principle, context interference conditions, and feedback effects). Similarly, Cañal-Bruland (in press, b) showed that visual guiding of attention by flicker cues in video-based decision-making training leads to faster decisions in 3-on-2 situations in soccer than verbal instructions.

Instructions

The use of instructions enables coaches the opportunity to steer attention towards information rich areas which contain the most important motion features or learning cues in the environment (for a recent overview, see Jackson & Farrow, 2005). Normally, sport specific information rich areas have been taught via film-based simulation and training sessions on court with a live model (badminton: Tayler, Burwitz, & Davids, 1994; squash: Abernethy, Wood & Parks, 1999; field hockey: Williams, Ward & Chapman, 2003). Specific laboratory tests afterwards usually indicate that this integrated attention-guided coaching program lead to significant improvements in anticipatory performance. Hagemann and Memmert (2006) showed that verbal instructions for coaching anticipatory cues in badminton within a real field-based training program improved anticipatory skills as much as a laboratory video-based training program with attention cues. One particularly important issue is how to give attention guided information to the learners. Studies have evaluated various approaches such as explicit, implicit, and guided discovery learning (e.g., Farrow & Abernethy, 2002; Smeeton, Williams, Hodges & North, 2004; Williams *et al.*, 2003; Williams, Ward, Knowles & Smeeton, 2002).

Recently, some studies showed that sometimes simple instructions lead to a reduced selective attention focus, and essential characteristics of a situation (e.g., free team-mate) are not taken into account in decision making (Memmert & Furley, 2007). In addition, a six-month longitudinal study in the area of sport by Memmert (2007) replicated this finding in a real-world training scenario. Children who were given too many instructions on important information rich areas in team ball games did not achieve any learning improvements in the generation of surprising, original and flexible tactical response patterns.

In the area of motor learning, instructions were used to guide attentional focus for the learning of motor skills as well as the motor control of complex movements (for an overview, see Wulf, 2007). Based on the work by Wulf and Prinz (2001), the experiments distinguish between an internal and external attention focus in the execution of motor skills. Internal focus means that the learner was instructed to direct his attentional focus on the movement itself (e.g., for a golf-put: swing of the arm). In the case of the external focus, however, the attentional focus is concentrated on the movement effects, i.e., on the aim (e.g., for a golf-putt: swing of the club). The results of a number of studies suggest that, across many different movement skills, skill levels and target groups, an external attentional focus is superior to an internal, movement-related focus (Wulf, Shea & Park, 2001, Wulf, 2007). An external focus of attention is believed to lead to better performances in acquisition and learning, not only for novices but also for experts (Wulf, McConnel, Gärtner & Schwarz, 2002).

Divided attention

The sub-process of divided attention is assumed to enable the individual to focus on two or more sources of information (cf. Coull, 1998). Generally, the methodological design of dual-task conditions is used to: (1) measure the effects of distraction on performance of another task; or (2) to measure basic attention performance of a secondary task while performing a primary task. So far, these conditions have been used to analyze divided attention in sports in two paradigms. One class of studies typically explores motor expertise in dual-task conditions within the skill-focused versus environmental focus of attention paradigm. Another class of studies examines decision-making expertise in dual-task conditions within the inattentional blindness paradigm.

Skill-focused versus environmental focus of attention

There are numerous studies that have used a dual-task paradigm to examine the effects of secondary loading on primary motor task performance between experts and novices (e.g., Beilock, Bertenthal, McCoy & Carr, 2004; Rowe & McKenna, 2001; for a review, Castaneda & Gray, 2007). For example, Beilock and colleagues showed that a skill-focused attention tends to inhibit experts in the execution of their highly automated motor movements (Beilock, Carr, MacMahon & Starkes, 2002). Castaneda and Gray (2007) showed that a better attentional focus for expert batters is one that does not interrupt proceduralized skill knowledge, whereas a better attentional focus for novice batters is one that allows attention to the step-by-step execution of the motor skill.

Inattentional blindness

This paradigm suggests that if attention is diverted to another object, observers sometimes fail to notice an unexpected object, even if it is right in front of them (Mack & Rock, 1998; Most, Scholl, Clifford & Simons, 2005). Most impressive was the presentation of the inattentional blindness paradigm by Simons and Chabris (1999). They showed a 23-second video to their participants, in which six people were passing two basketballs among each other. Subjects were faced with the task of counting the number of passes made between three basketball players. What was surprising about this experiment was that some did not even notice that a gorilla was moving through the group as the game was played. Memmert (2006) showed that in this dynamic basketball task by Simons and Chabris (1999), there were significant differences between basketball experts and basketball novices with a similar average age in the inattentional blindness paradigm. Subjects with a basketball-specific awareness of the situation were not able to better complete the primary counting task, but they were more likely to see the unexpected object than those without specific previous experience. This result suggests that sport experts seem to have special attentional skills which enable them to direct their attention toward other stimuli that initially appear to be irrelevant.

Extrapolating from this paradigm, unexpected objects, such as free team-mates, occur very frequently in team sports. And precisely perceiving these unexpected players and passing the ball to them is, in many cases, the best solution in complex game situations. Memmert and Furley (2007) showed that it exists among skilled adolescents in handball who failed to detect a free team-mate when attention was diverted to the direct opponent. In addition, these results were replicated in more realistic, therefore challenging, decision-making situations with a more complex primary attention-demanding task. Experienced adult basketball players also failed to perceive an obviously unmarked player as their optimal solution in this situation (Furley, Memmert & Heller, under review).

Sustained attention

The sub-process of sustained attention is assumed to maintain the attention on a particular stimulus or location for quite a prolonged period of time (cf. Coull, 1998). It is often used synonymously with the term 'vigilance'. But vigilance refers to longer-term attention processes in the range of minutes and hours, rather than seconds to minutes as in the case of sustained attention. Some recent literature gives an idea of how athletes could improve their concentration skills in team sport (e.g., Moran, 2003). Current studies emphasize that while vigilance is a temporal process, selective attention is much more of a spatial process and both operate independently of each other (Fernandez-Duque & Posner, 1997).

Given the importance of understanding whether sustained attention differences can contribute to expertise in sports, it is surprising that we could not find a single study which explored differences in sustained attention as a function of sports expertise. Clearly, this is a topic worthy of further research attention in future.

Assessment of merits and limitations of previous research on attention in sport

So far, various studies on attention in sports have been categorized and summarized in terms of four distinct attention sub-processes from neuroscience (orienting, selective, divided, and sustained attention). The following section deals with the merits and limitations of the outlined research on attention in sports.

Merits of research on attention in sports

One of the key strengths of the research conducted so far is its diversity and versatility: These include:

a. studies within the attentional orienting paradigm which have explored attentional flexibility, workload, and attentional focus;
b. studies within the selective attention paradigm have investigated information rich areas with visual search strategies, attention cues, and instructions; and
c. further research on divided attention has investigated skill-focused versus environmental focus of attention and inattentional blindness.

What is remarkable is that the research methods borrowed from psychology (e.g., cueing, priming, eye-tracking methods) have been used in more complex and realistic settings. Thus numerous findings gained in more internally valid settings have been replicated under more ecological conditions. For example, the inattentional blindness effect which appeared in simple static experiments (Most *et al.*, 2005) were found in much more complex sport-specific settings with dynamic stimuli (Memmert & Furley, 2007).

The addition of the expertise approach further allows elaboration on the effects of attention performance within a long-standing and high-quality wealth of experience in a certain domain. The setting up of interventions or treatment studies enables further the evaluation and validation of training programs for athletes. It has thus been possible to derive immediate practical implications for coaching and teaching in sports. For example, specific instructions could be given to athletes where they should focus their attention (e.g., arm and upper body area for anticipating an opponent's overhead badminton shot, see Abernethy & Russell, 1987).

Limitations of research on attention in sport

First of all, surprisingly, we were not able to find research in the area of sustained attention (not concentration or vigilance) focusing on athletes or team ball players. As already mentioned, the ability to maintain attention on a particular stimulus or location for quite a prolonged period of time is important for sport. Not only for ball sports, like soccer, but also for individual sports like running, jumping, or gymnastics, it is of great significance to maintain attention over long periods of time. Given the importance of understanding the influence of sustained attention on extraordinary performance in sport, this should be addressed in future research.

Further potential of the results gained so far will be illustrated under the following headings: 'integration of contents', 'theoretical relevance' and 'methodological problems'.

Integration of contents

After a multitude of research on attentional processes in sports related situations, it is now time to integrate and compare different findings resulting from different paradigms or sub-processes of attention (e.g., selective and divided attention). On the whole, such paradigm integrations will not only result in a gain in insight but will also generate new ideas for future areas of research. This is demonstrated by two examples.

1. Almost all of the studies described here suggest that selective and divided attentional processes can be used to explore extraordinary performance in

sports. Viewed in a different light, however, such processes reveal one of two different conclusions: On the one hand, at first seemingly irrelevant characteristics that would affect athletes' decisions cannot be perceived when attention is steered too strongly (inattentional blindness). This leads to disadvantages in decision making skills in sports (cf. Memmert & Furley, 2007). On the other hand, tactical performances, especially anticipation skills, can be improved by directing athletes′ attention to relevant key stimuli (attention cues; Hagemann *et al.*, 2006). In order to resolve this contradiction, it will not suffice to point out the difference between technique anticipation in racket games and tactical decision-making performances in team ball sports. Nor will it be enough to distinguish between different attentional foci, such as a narrow focus of attention in independent sports like archery and a wide focus of attention in interactive sports (Nougier, Stein & Bonnel, 1991; Nougier & Rossi, 1999). Instead it is important to embed these findings in general attentional theories in order to be able to derive further testable hypotheses. Moreover, few of the studies to date on selective or divided attention processes can give any indication of the underlying attentional mechanisms. Hence, it is difficult to derive general training principles not specific to the type of sport.

2. Interestingly, studies on selective and divided attention in the areas of motor learning and decision-making come to similar conclusions. Both approaches (internal/external focus of attention versus inattentional blindness) suggest that instructions can lead to negative consequences for the motor or tactical task at hand when experts direct their attention to a certain area of the motor or tactical task (Wulf, 2007; Furley, Memmert & Heller, under review). The motor learning approach accounts for this by postulating that conscious attention on the node of an already automated motor movement leads to interferences (disturbing effects) in the already proceduralized technique. The inattentional blindness approach explains this by an overload of the available attentional resources and a lack of pre-tuning of the attention system due to the lack of bottom-up generated motivational stimuli. In future, broader attentional theories must be formulated offering a convergence of these approaches.

Theoretical relevance

After illustrating the results of studies focusing on attentional processes, these are then discussed in the context of possible theories. For instance, within the paradigm internal versus external attentional focus, numerous studies were published that showed interesting effects with regard to the orientation of the appropriate attention focus in the control and learning of motor skills in a wide variety of sports. However, the description of explicit approaches in the form of theoretical attention models is only in the starting phases (Castaneda & Gray, 2007; Ehrlenspiegel, 2001, Wulf, Shea & Park, 2001). Following this, however, a stronger emphasis needs to be placed on building theoretical frameworks from which testable theory driven hypotheses can be derived (and not by results from previous studies). Only then will it be possible for sports science to effectively contribute to attentional models discussed in psychology. The following is a further example illustrating this point.

Various results from the inattentional blindness paradigm suggest (cf. Most *et al.*, 2005, Memmert, 2006) that the observed findings can be attributed to the filter theory of early attention selection by Broadbent (1958). In brief, it states that the selection of presented input stimuli occurs on the basis of physical stimuli features. Thus the filter works to limit capacity according to a strict serial processing system. A good sports-related overview of limited information-processing resources according to controlled and automatic aspects of skill learning and expert performance is provided by Abernethy *et al.* (2007) and Moran (2003). The attention to one of the stimuli according to the principle of 'all-or-nothing' was replaced by a more flexible 'attenuator' which allows for some unattended but possibly emotionally important stimuli to 're-enter', the attentional mechanism for further processing. This can then explain why, within experiments in the area of inattentional blindness, emotional or significant unexpected objects are more easily consciously perceived than others (cf. Mack & Rock, 1998). For instance, important words like the first names of the participants were consciously perceived significantly more often than the two most frequently used nouns in America, 'house' or 'time'.

However, this stands in opposition to functional explanatory approaches that suggest that more attention is paid to the unexpected object when it has a function with regard to the task at hand. For example, enactive theories make stronger use of preconscious self-organizing processes, which precede every state of awareness in the cortex and attempt to optimize the resulting state of awareness for the purpose of the organism (for a review, Ellis, 2001). According to Ellis (2001), self-organized processes act as an early 'gating' mechanism that influences the direction of attention through potentially useful or emotionally interesting information before conscious knowledge of the observed object is available. This could also explain the effects found by Mack and Rock (1998), as described above.

On the whole, this comparison (limited attention resources versus functional relevance for the task) should have shown that the usual unexpected stimuli used in psychology with no functional relevance for the task (e.g., perceiving the gorilla) do not provide conclusive evidence for one or the other theory. In sports, however, it seems much more feasible to look for suitable functionally important unexpected objects (e.g., free team-mate in a decision making situation, cf. Memmert & Furley, 2007) that allow for theoretical verification. This would also bear significance for the further development of general theories of psychology.

A good overview of existing models of attention from psychology is given by Abernethy *et al.* (2007) as well as Moran (2003), discussing at the same time what role these could play in extraordinary attentional performance in sports. However Abernethy *et al.* (2007, p. 257) also reach the conclusion: 'The development of suitable, robust models and theories of attention still remains controversial'. Broader attention theories must also contain ideas about additional cognitive components, such as working memory (Schweizer, Zimmermann & Koch, 2000). A number of studies have examined the role of working memory in skill learning (e.g., Maxwell, Masters & Eves, 2003).

Methodological problems

Many studies have been conducted on differences between experts and novices in different sub-processes of attention. On the one hand, this appears important in order to gain more detailed information on what differentiates experts from novices with regard to attentional performance or what the information rich areas in different types of sports are. On the other hand, all these findings do not seem to be able to describe concrete mechanisms which are responsible for superior attentional performance. Not surprisingly, a training program to improve specific attentional domains has not been universally agreed yet.

Abernethy (1988) points out problems using eye-trackers in visual search processes since attentional shifts can occur without any movement of the eyes (peripheral vision). For example, covert attention can enhance processing of visual stimuli outside the focus of gaze. In addition, eye-tracking paradigms cannot supply any information on the type of attentional processing (bottom-up versus top-down) which has a big impact on attentional performance. While top-down mechanisms include knowledge from previous experience and thereby influence information processing, bottom-up mechanisms represents mere sensory processing, which passes the sensory input, through perceptual analysis, towards motor output. Hence, the problem that the stimuli themselves can draw attention or a person's knowledge or expertise of the subject can interfere cannot be solved by eye-tracking methods. If these two aspects which interact continuously are separated, the mechanisms of attention can be understood and training of attentional skills can be developed. One possibility to meet this requirement is to use brain imaging studies. Analyzing neural correlates with event-related potentials (ERP), the underlying effects of expert attentional performance could be assessed. In addition, these studies could examine attentional processes without having interdependencies from anticipation.

Beyond this, a further solution would be to employ different methods simultaneously (e.g., eye-tracking and cueing, or priming and ERP) in order to be able to make up for the weaknesses of individual methods.

New directions for further research on attention in sport

Visual attention plays an important role, not only in team sports in which players have to simultaneously monitor the activities and positions of multiple players, but in sports in general (Abernethy *et al.*, 2007; Williams *et al.*, 1999). The aim of this section is to show that human movement science can use important insights from other branches of the discipline (e.g., developmental, cognitive, or social psychology) in order to test and optimize training programs in sports. On the one hand, the focus is placed on developmental research, on motivation, and on creativity. On the other hand, the possibilities and advantages of neurophysiological methods to study attentional performance in sports are demonstrated using the example of event related potentials (ERP). This attempts to illustrate the potential that can open up for future research programs with an emphasis on attentional expertise in sports when considering these theoretical and methodological avenues.

Development of attention

The paths of motor and perceptual development in children and young people have been studied intensively (for a review, see Busseri, Rose-Krasnor, Willoughby & Chalmers, 2006; also Rebok *et al.*, 1997; Rose-Krasnor, Busseri, Willoughby & Chalmers, 2006; Ruff & Lawson, 1990). According to these studies, performance in different motor and perception tasks exhibits a relatively uniform developmental progress in 6 to 12 year olds. Comparable studies investigating attention skills have only been carried out for general sub-processes of attention. For example, Betts, Mckay, Maruff and Anderson (2006) investigated sustained attention in children between 5 and 12 years of age. They diagnosed a rapid development from 5–6 years to 8–9 years and a developmental plateau from 8–9 years to 11–12 years. Further developmental research indicates that performance in different attention tasks (e.g., focus of attention) improves in children in the 8 to 13 year-old age group and then remains at the same constant level into adulthood (e.g. Rebok *et al.*, 1997; Ruff & Lawson, 1990). So far no studies in the area of sport have been conducted.

Attention and motivation

Different kinds of motivationally-oriented theoretical models from social psychology (see Higgins, 1997 or Kuhl, 2000) indicate that different cognitive performances can be influenced through emotional states. For example, Higgins (1997) suggests that goal pursuit can be achieved by keeping different kinds of modes of self-regulation in order to regulate pleasure and suffering. More specifically, a focus on accomplishments and aspirations is labeled as a 'promotion focus', and a focus on safety and responsibilities is called a 'prevention focus'. In addition, there is no *a priori* advantage of either motivational orientation in terms of performance. According to this approach, the performance on a given task may depend on the fit between people's regulatory focus (promotion or prevention) and people's chronic regulatory orientation (promotion or prevention; Higgins, 2000). This idea of better performance and a more positive effect via regulatory fit has already received some empirical support in the domain of cognitive tasks (for a recent review, see Keller & Bless, 2006). Not long ago, the first piece of evidence was given that the regulatory focus theory improves our understanding and enhancement of sport performance (Plessner, Unkelbach, Memmert, Baltes & Kolb, 2009).

A number of studies revealed the influence of motivation (e.g., regulatory focus) on attentional performance (for a review, see Förster, Friedman, Özelsel & Denzler, 2006). Kuhl and Kazén (1999) and Memmert and Cañal-Bruland (accepted) showed that approach-related states bolster the flexibility of attentional selection. Findings by Friedman and Förster (2005) indicated that unconscious motivational states influence attentional flexibility without mediation by conscious feelings. Förster *et al.* (2006) provided evidence that enactment of approach behavior broadens the focus of perceptual attention. In contrast, a prevention mode, or avoidance behavior, narrowed the attentional focus. The participants in the study by Memmert, Unkelbach and Ganns (under review) were influenced with regard to their motivational orientation before solving the inattentional blindness task by Simons und Chabris (1999). This regulatory focus condition was produced by giving the participants the pencil-and-paper maze by Friedman and Förster (2001). In addition, the participants' chronic regulatory orientation was assessed again. The participants in the 'Fit' condition (e.g., chronic promotion focus and regulatory promotion focus) outperformed the participants in the 'Non-Fit' condition (e.g., chronic prevention focus and regulatory promotion focus) in noticing the unexpected object.

To further examine the robustness of the regulatory focus manipulations on selective attention tasks, it seems fruitful to study promotion and prevention manipulations more carefully in more complex attention demanding tasks in sport. In addition, because a series of experiments indicate that a promotion focus can positively influence creative performances (for an overview, see Friedman & Förster, 2001), more focus could in future be placed on a cognitive performance that surprisingly has been neglected in the past: creativity in sports.

Attention and creativity

The analysis of creative thinking is currently a frequently discussed scientific topic among investigators (Csikszentmihalyi, 1999; Damasio, 2001; Dietrich, 2004). Sternberg and Lubart (1999, p. 3) define creativity as 'the ability to produce work that is both novel (i.e., original, unexpected) and appropriate (i.e., useful)'. A number of recent studies have shown that *attention* is positively related to creative performance (for a review, see Martindale, 1999). Several of them indicate a positive yet moderate association between creative behavior and the breadth of attention (for a review Kasof, 1997). Breadth of attention is used here to refer to the number and range of stimuli that a subject attends to at a specific point of time. These correlation studies are almost completely based on data not specifically related to sports. Up to now, only a few studies exist confirming this relationship for experts in sport.

In the domain of sport games, dissociating from the so-called best solutions (convergent tactical thinking), creativity (divergent tactical thinking) is understood to be the surprising, original and flexible production of tactical response patterns (Memmert & Roth, 2007). What is significant for generating decision possibilities and for seeking original solutions is that one player is able to perceive all important information from his or her environment (positions of team mates and opponents, players emerging unexpectedly, etc.) and to take it into account in his or her action plan. Through the development of versatile and at times extraordinary solutions (divergent tactical thinking), a significant and domain-relevant ability in sport games has emerged.

Preliminary findings suggested that attentional processes and expertise effects play a considerable role in the development of non-sport-related and sport-related divergent thinking. A study with gifted children (IQ $>$130) showed the importance of attention performance and inattentional blindness for the development of creativity (Memmert, 2006). A wide breadth of attention makes it possible to associate different stimuli that may initially appear to be irrelevant. In addition, Memmert (2009, in press) establishes a direct link between inattentional blindness, expertise and creativity. The results show that the trained 13-year-old children with the ability to notice the free player (less inattentional blindness) could also describe more original solutions in sport-related situations than adolescents who were 'blind' to the free team mate (more inattentional blindness).

Attention and ERP

A great deal of research has been conducted on neurophysiological methods such as event-related potentials (ERP; for a review, see Hatfield, Haufler, Hung, & Spalding, 2004; Hill & Raab, 2005). Many studies have used this method in order to find effects of expertise in many different kinds of sports (e.g., fencing: Rossi *et al.*, 1992; karate: Collins, Powell & Davies, 1990; golf putting: Crews & Landers, 1993; darts: Radlo, Steinberg, Singer, Barba & Melnikov, 2002; volleyball: Fontani, Maffei, Cameli & Polidori, 1999; table tennis: Hung, Spalding, Santa Maria & Hatfield, 2004; baseball: Radlo, Janelle, Barba & Frehlich, 2001). While most of these studies analyze spectral power and interelectrode coherence in order to show differences in the neural networking of high level athletes, only a few of them use event-related potentials to disclose differences in their attentional mechanisms. Given the prevalence of inattention and failed attention, particularly in attention-demanding team sports, it is surprising that few studies have recorded and analyzed ERPs in connection with attention performance.

However, Hung *et al.* (2004) revealed that expert table-tennis players have a higher focus of attention ('N1-amplitudes') than control subjects if the stimuli do not occur in the precued area of Posner's 'oddball-paradigm' (stimulus discrimination task). Zani and Rossi (1991) showed that clay-pigeon shooters in different competitions ('skeet' and 'trap') have different attentional strategies because of disparities in their attentional orienting (N2-latency) and selective attention performance (P300-latency). Radlo *et al.* (2001) found different P3-amplitudes and latencies between expert and intermediate baseball players who had to classify approaching baseball pitches which were presented with video sequences. Recent findings by Hack, Memmert and Rupp (2009, in press) indicated task-specific effects for advanced basketball referees in attentional focus (N1) and selective attention (P300). Experts also profit from their superior top-down strategy and thus are able to evaluate the stimuli more rapidly. The great advantage of this EEG-design is that it is possible to examine attention processes in complex, sport-specific decision making tasks without having interdependencies from anticipation.

In conclusion, this review provides an overview of different kinds of attentional performance in the area of sports. The field of sports seems a fruitful area in which to study complex behavior in a complex context. At the same time, though, this it is hoped that the use of ecological and complex settings will, in future, enable further development of theoretical models from other disciplines beside sport science, like general psychology. Only through this approach will we understand completely the extraordinary attentional performance from sports figures such as Franck Ribery, and Stephen Hendry.

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