# Spatial contextual cueing in handball players and action video game players

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## Abstract

Team sport athletes and action video players have shown superior performance in visuospatial attentional processing in several tasks (Mann, Williams, Ward, & Janelle, 2007; Green & Bavelier, 2003). Masters (1992) suggest that implicit learning processes may allow expert performers fast and effortless performance, leading to more efficient decision-making and motor performance. However, investigation with athletes often focus on sport-specific situations (Abernethy, 1991) making it difficult to infer general underlying processes. A recent study, however, found improved context learning skills in athletes in a neutral, non-sport specific task with substantial visuospatial demands (Faubert, 2013).

The three experiments presented in this thesis were designed to test if high-level team sport athletes or action video game players have superior context learning skills. We investigated incidental context learning in visual search in order to examine the contribution of spatial context learning and search efficiency to the superior visuospatial performance of handball players and action video game players. To this end, we used a sport-specific pseudo 3-D contextual cueing task (search of the ball-carrying player in a playing field) and the original contextual cueing paradigm (search of a “T” among “L”-shapes; Chun & Jiang, 1998).

We found comparable spatial contextual cueing of visual search in repeated displays in high-level amateur handball players, dedicated action video game players and normal controls. In contrast, both handball players and action video game players needed less time to analyze the contents of a search display than controls, measured as search time per display item, independent of display repetition, revealing superior attentive processing. Intercept data yield no evidence that non-search factors contribute to the contextual cueing effect for all groups.

To conclude, our data do not indicate superior context learning skills in handball players or action video game players. Rather, both groups showed more efficient visual search in abstract displays that were not related to sport-specific situations.

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# 1 General Introduction

## 1.1 *Motivation and structure of this thesis*

Several studies reveal that explicit learning skills failed under stressful and time-restricted conditions (Beilock & Carr, 2001; Gray, 2004; Masters, 1992), whereas implicit learning processes may allow more efficient decision-making and motor performance (Masters, 1992). In team sport like handball, players repeatedly face situations where a particular spatial constellation of players asks for a specific action in a fraction of a second. In these quickly changing situations, incidental learning of spatial contexts may occur that can optimize behavior in similar contexts.

In spite of the relevance of implicit learning, limited research has been conducted on this topic within the expert research domain. The limited research examining implicit learning processes in the sports domain entail several methodological issues, such as the usage of verbal reports of the participants about how performance was controlled in order to determine the presence or absence of implicit learning (e.g. Masters, 1992). It has been claimed that verbal reports are not sufficiently sensitive to detect implicit or explicit processes (Shanks & St. John, 1994). Implicit learning paradigms may be more suitable to assess the contribution of implicit and explicit processes in the sports domain (Farrow & Abernethy, 2002). Thus, the contextual cueing paradigm reported above may be an adequate attentional training approach to create an actually implicit learning condition (Kristjánsson, 2006; 2013).

There is no empirical evidence for enhanced memory-guided attentional selection in team sport athletes; this is nevertheless an interesting question. It may well be that these athletes have superior capabilities to learn scenes and use scene memory for attentional guidance when the same or similar scenes are repeatedly encountered. Handball players, for example, need to move in a particular direction or pass the ball to a specific team member in a fraction of a second to be successful players. Furthermore, specific situations are repeatedly encountered during a game and may facilitate selection of the appropriate action. Thus, it could be that elite team sport athletes have extraordinary skills in learning spatial contexts and using context-knowledge for efficient attentional guidance in scenes that have been encountered before. If these skills transfer to non-sport-specific situations, they would lead to benefits outside of sport and should be observed even in abstract (semantically meaningless) search tasks. This is what we investigated here in a group of high-level amateur handball players (see Schmidt, Geringswald, Sharifian, & Pollmann, 2018).

Contextual cueing in handball players was compared to two other groups, namely action video game players and control participants without sport or video game proficiency. Action video game players were selected because enhanced attentional skills have been reported in this group, including improved visual control, greater attentional capacity, and better spatial allocation of attention (Green & Bavelier, 2003), enhanced target detection (Feng, Spence, & Pratt, 2007; Green & Bavelier, 2006), and faster response selection (Castel, Pratt, & Drummond, 2005; Clark, Lanphear, & Riddick, 1987). Consequently, action video game experience may provide a further adequate domain in order to examine perceptual and attentional mechanisms underlying expert experience. Like action video game playing, playing of a team sport, particularly at an elite level, leads to complex sensory stimulation and equally complex, quickly changing task affordances. Therefore, we reasoned that expert handball players may, like expert video game players, demonstrate increased proficiency to learn repeating spatial contexts and use them for memory-guided visual search.

The three experiments presented in this thesis aim to investigate if team sport athletes (handball players) and action video game players show improved implicit learning of repeated spatial configurations for efficient search guidance in repeated environments. Team sport athletes, action video game players, and controls were compared in different contextual cueing tasks in order to shed some light on incidental context learning in experts and the attentional mechanisms underlying contextual cueing. In the first experiment, a search task designed to be advantageous for the handball players (search of the ball-carrying player in a playing field) was used. In the second experiment, a typical symbolic contextual cueing paradigm (search of a “T” among “L”-shapes) was applied in order to investigate the generality of a potential contextual cueing advantage for handball players and action video game players. Experiment 3 was carried out to examine the processes leading to contextual cueing by varying the number of distracter items (8 vs. 12 items) in a typical symbolic contextual cueing task. The target detection reaction time slopes as a function of varied set size provide an adequate measure of search efficiency, whereas intercepts were taken as a measure of non-search factors (e.g. initial perceptual processing, response selection).

The first chapter contains theories and methodological suggestions on visual search and attentional mechanisms and depicts attentional processes and strategies (conscious and non-conscious) underpinning expert performance. Chapter 2 presents the general methods of the experimental work. The first two chapters provide the background for the experiments described in Chapters 3 to 5. In conclusion, results of the present study are summarized and discussed in Chapter 6.

## 1.2 *Visual search and selective attention*

### 1.2.1 Attentional Research

Attentional processes encompass perception, cognition, and action. However, the term “attention” is poorly defined and comprises various different processes in the nervous system, which are partly quite roughly associated (Nougier, Stein, & Bonnel, 1991). Indeed, attention is not a uniform construct but rather an abstract concept which include various and contextually delicate processes (Parasuraman & Davies, 1984). Any aspect of human skill is somehow influenced by attentional processes. In the field of psychology, attention may be a crucial aspect to the improvement of skill learning and expert performance (Rogers, Rousseau, & Fisk, 1999).

According to Posner and Boies (1971), attention plays following roles in skill learning and expert performance: one major function of attention is the selection of relevant perceptual information to control behavior. During this process of selective attention, a relevant subset of information reach the nervous system’s processing resources while irrelevant stimuli will be sorted out. A further role of attention comprises the alertness and the ability to evolve and sustain appropriate sensibility and willingness to react to relevant stimuli. Sustained information is the efficient processing of received information over a prolonged time period, which is affected by aspects such as fatigue, anxiety, and motivation. Moreover, attention is involved in the deployment of restricted information-processing resources. Here, individual- and expertise-related differences in dividing and switching attention or the automation of abilities need to take into account to comprehend this role of attention (Abernethy, Maxwell, Masters, van der Kamp, & Jackson 2007).

At any given moment, a multitude of auditory, visual, and tactile stimuli reach our sensory organs. For efficient processing, it is necessary that we select the relevant aspects out of the total amount of incoming information (Alfermann & Stoll, 2005; Lavie & Cox, 1997; Müller & Krummenacher, 2012; Treisman & Gelade, 1980). These selective attentional processes are essential for daily activities, but also for high-level performance in sport or other expert domains. Therefore, first of all paradigms and theories of selective attention will be reviewed in the following section.

### 1.2.2 Paradigms and theories of selective attention

The research of selective attention developed on the basis of three paradigms: the dichotic listening paradigm (Cherry, 1953), Broadbent's (1954) Split-Span-Paradigm and the paradigm for the investigation of the psychological refractory period (Welford, 1952).

In the dichotic listening paradigm, participants were presented simultaneously separate messages to both ears. Subjects have to attend to one message by repeating the message loudly. The study pointed out that subjects were rarely able to report the unregarded message, indicating selective processing of relevant information to the task. Certain physical aspects of the unnoticed message, such as changing voices, were often noticed by the subjects, demonstrating privileged processing of this type of information.

In the split-span-paradigm of Broadbent (1954), participants were presented a sequence of pairs of numbers simultaneously – one number to the left ear and the other number to the right ear (i.e. 2-7, 6-9, 1-5). Participants were asked to repeat the numbers. Results indicate that the repetition of the pairs of numbers resulted preferential by ear (2-6-1, 7-9-5), and not by pairs presented (2-7, 6-9, 1-5) (Müller & Krummenacher, 2012).

These two paradigms, as well as the postulated psychological refractory period of Welford (1952), led to a number of attentional models which suppose bottlenecks in the information system (Figure 1).

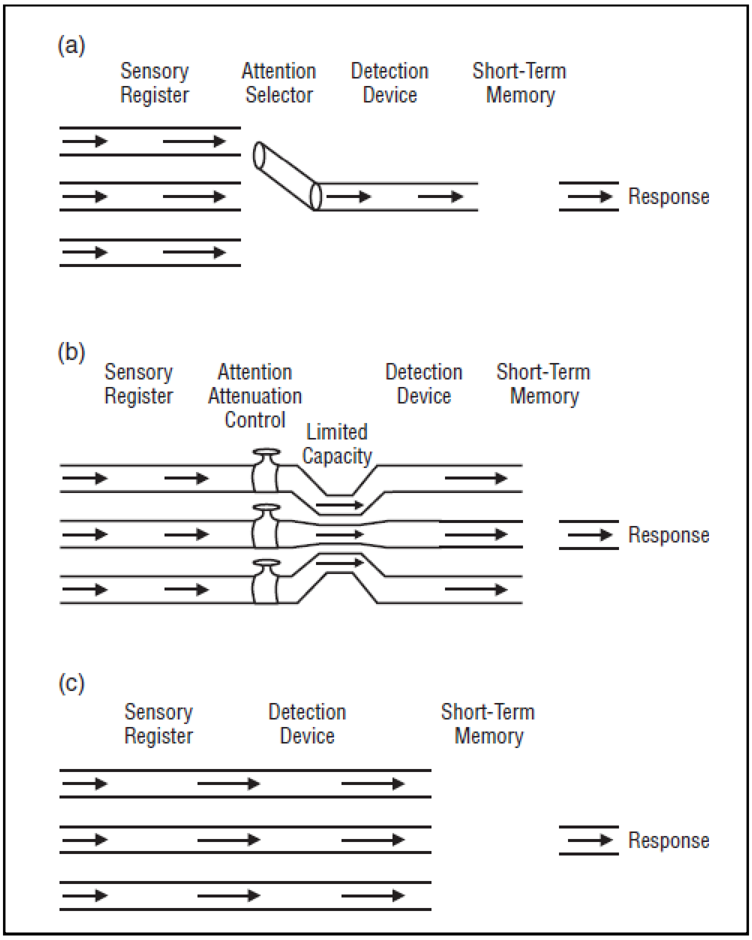

**Figure 1 | Comparative structure of (a) early filter models, (b) attenuation models, and (c) late selection models of selective attention** (Shiffrin, Craig, & Cohen, 1973; as cited in Abernethy et al., 2007)

Broadbent (1958) argued for an attentional filter model. According to the filter theory, only one stimulus can be processed (semantic). This stimulus is selected on an early processing stage by a selective filter (based on the physical features).

In contrast, Deutsch and Deutsch (1963) proposed a theory of “late selection”, where all stimuli are processed equally (semantic) and the processing bottleneck is located on a late processing stage.

Treisman (1964) suggested an attenuation model that proposes a hierarchy of processing stages: physical stimulus pattern → collective stimulus pattern (i.e. syllables) → semantics (i.e. words) and allows a progressive attenuated processing of unattended information at each processing stage. In this model the location of selection is flexible on an early perceptual processing stage and the selection is not just based on simple physical characteristics of the incoming stimuli (Müller & Krummenacher, 2012).

The inconsistent experimental results on the location of selection (early vs. late) arouse a theoretical controversy. New approaches assume that the location of attention selection is flexible, depending on the perceptual load or specific task requirements (see Kahnemann, 1973; Lavie, 1995; Müller & Krummenacher, 2012). In the 1960’s and 70’s a debate about the nature of visual attention allocation arose, discussing if people assign their attention to objects or locations. Nowadays, two influential approaches of cued visual attention are determinant: location- and object-based visual attention (Müller & Krummenacher, 2012). According to location-based theories of attention, attention works as a spotlight. The spotlight illuminates a particular location, leading to improved information processing at this location. Depending on the focus of attention, resolution of attention can be high or low. Information near to the center of the spotlight has a high resolution; accordingly, items far from the center of the spotlight have a decreased resolution (Arrington, Carr, Mayer, & Rao, 2000; LaBerge & Brown, 1989; Posner, Snyder, & Davidson, 1980). Alternative object-based approaches suppose that attention is not allocated to locations in the visual field but rather to objects at these locations. Object-based attention is assumed to involve cognitive resources (i.e. working memory; see Duncan, 1984). Both theories are not mutually exclusive. There is evidence that it is possible to change between location- and object-based attention (Baylis & Driver, 1993; Egly, Driver, & Rafal, 1994; Vecera & Farah, 1994). For example, if the task does not require subjects to characterize stimuli as objects, an attention-demanding object-based allocation of attention is not necessary (Vecera & Farah, 1994). Moreover, results of different studies indicate that the use of object- or location-based attentional allocation depends on the task demands itself (Baylis & Driver, 1993; Egly et al., 1994; Vecera & Farah, 1994).

Different paradigms have been evolved in order to measure visual selective attention by investigating the effect of distracting information on target processing (e.g. Eriksen & Eriksen, 1974; Lavie & Cox, 1997; Treisman & Gelade, 1980). In attention research the “visual search” paradigm is a standard method in order to investigate which visual coping processes need attention and which processes proceed pre-attentive in order to detect and evaluate the mechanisms for efficient target selection and response processes (Wolfe, 1998).

### 1.2.3 Visual Search

In the visual search paradigm, a display is presented in which participants search for a target among an array of distractors (Treisman & Gelade, 1980). The total amount of stimuli in the search display is described as the “display size”. The participants were asked to search for the target, which is either present or absent, and to make a positive (target-present) or negative (target-absent) decision as fast as possible. The reaction time to respond can be plotted as a function of the display size (search reaction time function). Due to the search reaction time functions found in diverse visual search experiments, two mechanisms of visual search have been described (e.g. Treisman & Gelade, 1980): parallel versus serial search. In parallel search, search function increases marginally with an increasing number of search items, due to simultaneous processing of all stimuli in the display. In serial search, attention is directed to one item and stimuli are searched in succession, leading to a linear increase of the search function.

The paradigm of visual search provides evidence that some visual processes operate pre-attentive and in parallel, while others need attention and have to be attended successively (serial), and that in some tasks, both forms are essential for efficient search. Various theories of visual attention tried to clarify this variability in search. The most influential theory of visual attention has been the “Feature Integration Theory” (FIT, Treisman & Gelade, 1980), suggesting a two-stage model of visual attention (Figure 2a) put forward by Neisser (1967). According to the FIT, single attributes of objects can be registered efficiently in a parallel, preattentive manner in the visual field in an initial stage; however, for their binding in coherent object representations and for advanced processing, serial allocation of attention is needed (Müller & Krummenacher, 2012).

Research over the past two decades indicates that a two-stage, linear model is not appropriate. A number of visual search studies could not confirm a simple dichotomy of parallel and serial search, leading to different theoretical approaches in order to explain the contrary results, e.g. the “similarity theory” of Duncan and Humphreys (1989) or the “Guided Search Model” of Wolfe (1994). Duncan and Humphreys (1989) recognized that search efficiency depends on the degree to which a target can be differentiated from distractors – irrespective of search type (feature vs. conjunction search). Wolfe (1994) proposed a Guided Search Model, where a limited set of basic features, derived from an early preattentive stage, can be used to guide the selection of visual stimuli. For example, a blue horizontal target defined by the basic features colour and orientation can be efficiently processed in a parallel and preattentive manner, even if binding of colour and orientation in parallel is not possible on a preattentive stage. According to Wolfe & Horowitz (2004), it is problematic to “envision the guiding representation as a stage in a linear sequence of visual processes, like a filter – even a tunable filter – between early vision and attentional bottleneck” (p. 2). Wolfe and Horowitz (2004) suggest a guidance control component, running from early vision to object recognition (Figure 2b). The control device monitors the access to the bottleneck, but operates not as a filter due to that filters eliminate information (Wolfe & Horowitz, 2004).

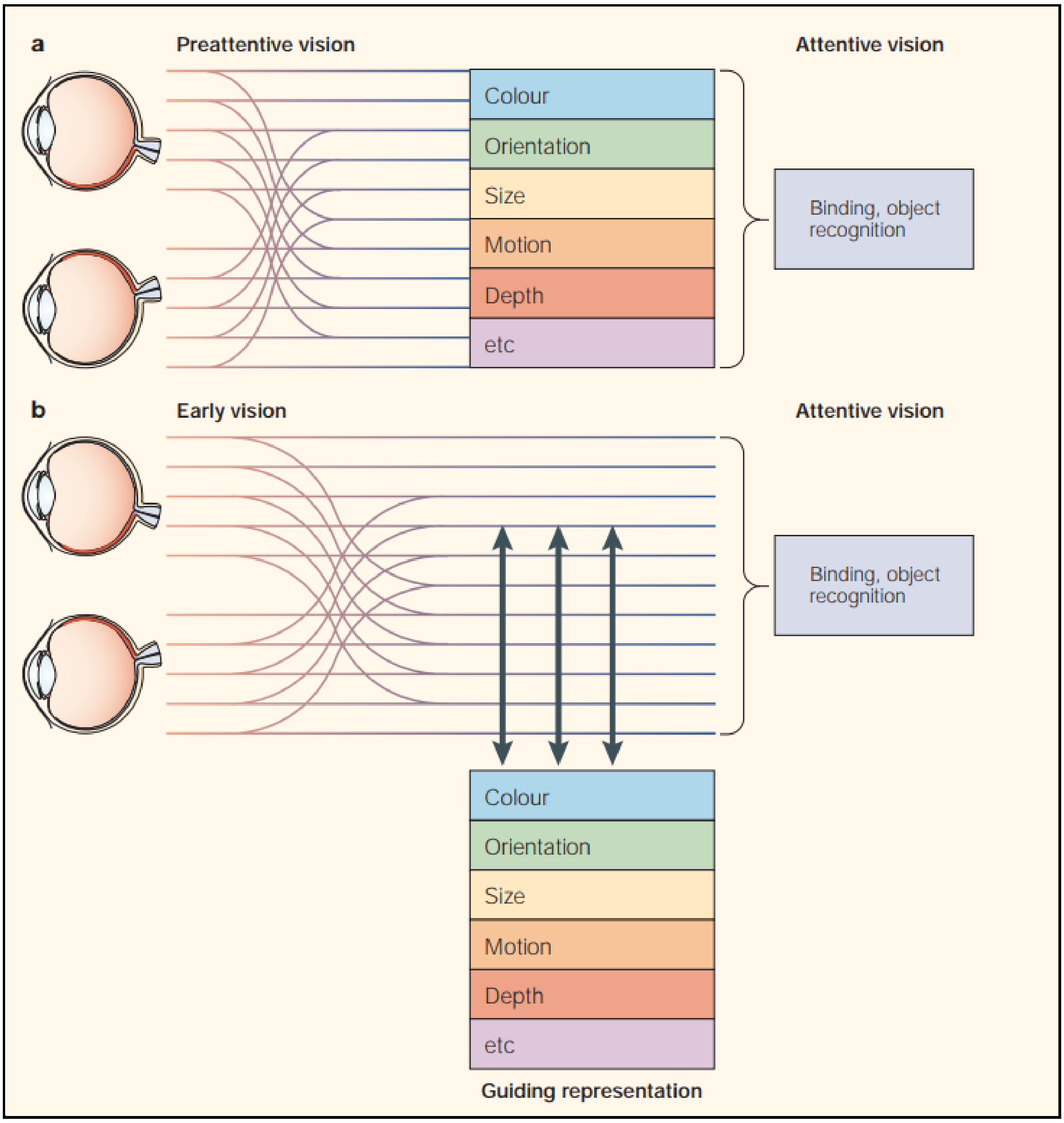

**Figure 2 | Models of visual processing**. a | A standard two-stage model with a parallel front end followed by an attentional bottleneck leading to processes such as object recognition. b | We suggest that it is useful to think of a 'guiding representation' that is derived from the main visual pathway and that guides access to the attentional bottleneck in the pathway but that is not, itself, part of the pathway (see Wolfe & Horowitz, 2004).

### 1.2.4 Summary and conclusions

To summarize, initial theories of vision and attention distinguish between preattentive and attentional processes (e.g. Neisser, 1967; Treisman & Gelade, 1980). According to these theories, preattentive processes operate on early stages of the visual system, whereas attentional processes are more complex and comprise the processing of a particular preattentive outcome.

Due to the processing of the whole visual field, preattentive processes are limited to actions that can be applied in parallel and performed quickly. Experiments on visual search identified two main functions of preattentive processes. One main role is the registration of basic visual characteristics (i.e. colour, orientation, luminance, motion direction; see Wolfe, 1998). Treisman and Gelade (1980) proposed that the preattentive outcome involves a set of feature maps, depicting the location of the basic visual attributes. However, there is evidence that preattentive processes can also register complex structures (e.g. three-dimensional stimuli; Enns & Resink, 1990) and occluded outlines, indicating that the outcome of preattentive processes may also include a presentation of surfaces (He & Nakayama, 1992). The second main mechanism of preattentive processes comprises the guidance of attention to the most significant parts within the visual field (Müller & Krummenacher, 2006). Wolfe and Horowitz (2004) proposed five categories of attributes and grouped them by the probability that they guide the allocation of attention (see Table 1). The first category involves basic guiding features (i.e. colour, motion), which are confirmed by many studies (Treisman & Souther, 1985; D'Zmura,1991; Bauer, Jolicœur, & Cowan, 1996; Rosenholtz, 2001; McLeod, Driver, & Crisp, 1988; as cited in Wolfe & Horowitz, 2004) whereas the last category represents suggested guiding attributes with unsatisfactory evidence.

**Table 1│Attributes that might guide the deployment of attention (Wolfe & Horowitz, 2004)**

| **Undoubted Attributes** * | **Probable Attributes ‡** | **Possible Attributes §** | **Doubtful cases \|\|** | **Probable non-attributes ¶** |
|---|---|---|---|---|
| - Colour<br>- Motion<br>- Orientation<br>- Size (including length and spatial frequency) | - Luminance onset (flicker)<br>- Luminance polarity<br>- Vernier offset<br>- Stereoscopic depth and tilt<br>- Pictorial depth cues<br>- Shape<br>- Line termination<br>- Closure<br>- Topological status<br>- Curvature | - Lighting direction (shading)<br>- Glossiness (luster)<br>- Expansion<br>- Number<br>- Aspect ratio | - Novelty<br>- Letter Identity<br>- Alphanumeric category | - Intersection<br>- Optic flow<br>- Colour change<br>- Three-dimensional volumes (such as geons)<br>- Faces (familiar, upright, etc.)<br>- Your name<br>- Semantic category |

**Attributes are grouped by the likelihood that they are, in fact, sources of guidance of attention. References are representative but not exhaustive. * 'Undoubted' meaning that they are supported by many studies with converging methods. ‡ Less confidence owing to limited data, dissenting opinions or the possibility of alternative explanations. § Still less confidence. || Unconvincing, but still possible. ¶ Suggested guiding features where the balance of evidence argues against inclusion on the list.**

Early research examined particularly perceptual attention attributes. Currently, studies try to explain perception-action coupling (e.g. Hommel, Müsseler, Aschersleben, & Prinz, 2001; Raab, 2015) as well as learning and memory processes in visual search (e.g. Learned feature memory: Navalpakkam & Itti, 2005; Bayesian approach: Torralba, Oliva, Castelhano, & Henderson, 2006; Implicit learning: Chun & Jiang (1998); Associative memory theory: Grossberg, 1994). There still exist a number of questions regarding attentional mechanism, for example, the role of top-down and bottom-up processes in guiding visual search – especially the function of explicit and implicit memory (Müller & Krummenacher, 2006). These issues will be discussed more detailed in the following section.

### 1.3 *Guidance of attention*

Various factors were identified that influence the allocation of attention, which can be generally categorized into bottom-up, stimulus-driven factors (e.g. salient features (Treisman & Gelade, 1980), abrupt onsets (Yantis & Jonides, 1984) and top-down, goal-driven factors (e.g. automaticity effects (Shiffrin & Schneider, 1977) or familiarity effects (Wang, Cavanagh, & Green, 1994)). Bottom-up and top-down factors do not exclude each other. The guidance of visual attention is rather marked by interactions between bottom-up and top-down processes (Duncan & Humphreys, 1989; Wolfe, 2007). Top-down processes are determined by a high level of cognitive control influencing vision and the analysis of sensory information, while bottom-up processes operate more directly and independent of attentional control (Raab, 2015). In the environment, salient bottom-up features can be missing (e.g. a desert, grassland) or too great in number (e.g. heavy traffic street) for an efficient direction of attention. Concluding, bottom-up cues are not always helpful. What other factors may serve to guide visual attention? Chun (2000) suggests a factor which is present in all events of daily perception – the visual context. Some might argue that the context is a reason of information overload. However, context directs eye movements so that relevant aspects of the environment can be fixated and irrelevant facets can be disregarded (Chun, 2000). Indeed, eye-tracking studies (e.g. Loftus & Mackworth, 1978) reported a higher number of eye movements to objects or regions that were evaluated to be useful and informative. The improvement of object or scene recognition may be a further function of the visual context (Olivia & Torralba, 2007). The contextual information of the visual context influences the efficacy of the visual search and object recognition (Hollingworth & Henderson, 1998; Torralba, Olivia, Castelhano, & Henderson, 2006). How visual context directs visual attention will be explored in the following sections.

### 1.3.1 Contextual guidance of attention

As mentioned above, besides the attributes of the objects themselves visual search can be guided by contextual information and the memory of features of our environment. But why is contextual information useful? Contextual information contains essential features of the visual environment (i.e. constant spatial layout information, consistencies in dynamic visual actions) and is therefore useful to recognize objects or to direct visual attention (Chun, 2000).

Chun and Jiang (1998) reported a top-down factor that enables the allocation of visual attention by investigating the spatial relation between target and distractor items in a search display (Lleras & von Mühlenen, 2004). In a series of six experiments, Chun and Jiang (1998) examined whether contextual information can guide the spatial attention more efficiently by modulating the configuration type. In repeated or 'old' configurations targets remained constant in the same spatial configuration throughout the experiment. The targets in 'new' sets appeared in a randomly generated novel spatial configuration. At the end of the search task, a recognition test was performed in order to evaluate the role of memory. Chun and Jiang (1998) identified significantly faster reaction times for repeated than for novel configurations. The contextual cueing effect occurred although subjects could not identify repeated arrays, indicating that repeated spatial contexts can be learned incidentally (i.e. without intention to learn), leading to more efficient search in repeated than in novel displays. The findings of Chun and Jiang (1998) reveal that contextual cueing is an example of instance-based learning (Logan, 2002). The encounter of preceding situations automatically initiates previous actions. Peterson and Kramer (2001) suggest that in the contextual cueing paradigm, “the presentation of a repeated configuration automatically activates past instances of attentional guidance” (pp. 1239) due to the automatic recognition process.

This contextual cueing effect has been supported by a number of studies (reviewed by Chun, 2000; Goujon et al., 2015). Contextual cueing has been observed after as few as five repetitions of a display (Chun & Jiang, 1998) and has been shown to last for up to one week (Chun & Jiang, 2003). Learning of spatial distractor - target configurations occurs rather automatically, even when attention is distracted away from the repeated items (Jiang & Leung, 2005) and when visuospatial working memory is loaded by a secondary task (Annac, Manginelli, Pollmann, Shi, Müller, & Geyer, 2013; Manginelli, Langer, Klose & Pollmann, 2013; Vickery, Sussman, & Jiang, 2010). Both central and peripheral vision contribute to contextual cueing (Brady & Chun 2007; Geringswald & Pollmann, 2015). Contextual cueing is flexible; it occurs even if only part of the target distractor configuration is repeated (Brady & Chun, 2007; Song & Jiang, 2005) or if the trained display is rescaled, displaced, or perceptually regrouped (Jiang & Wagner, 2004) (see Schmidt, Geringswald, & Pollmann, 2018).

To demonstrate the processes leading to contextual cueing, Chun and Jiang (1998) compared the search slopes and intercepts of the repeated and random displays. The slope reflects the search efficiency while intercept was taken as a measure of non-search factors (i.e. perceptual processes, response selection). A downward trend in the search slope over time for repeated displays would indicate that learning processes contribute to the guidance of attention, whereas a decrease in the intercepts for repeated configurations point out that non-search factors guide attention.

In the literature, there is currently a debate about the processes underlying contextual cueing: attentional guidance vs. non-search factors (pre-attentive (perceptual) vs. post-selective (response-related)). Some studies reported a more efficient search performance for repeated displays (Chun & Jiang, 1998; Zhao, Liu, Jiao, Zhou, Li, & Sun, 2012) through the use of the reaction time x set size function (see Figure 3). Search rates (per item) were found to be reduced for repeated display configurations compared to novel arrays, indicating that contextual cueing guides the allocation of visual attention.

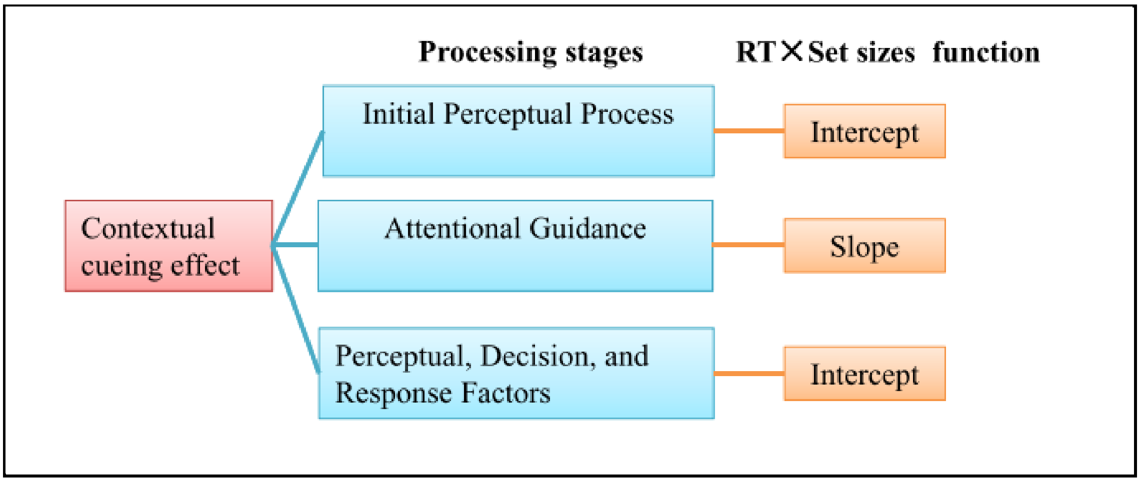

**Figure 3│ Mechanisms of Contextual Cueing effect revealed through RT (see Zhao et al., 2012)**

However, Kunar, Flusberg, Horowitz, & Wolfe (2007) found evidence that guidance may not be the principal mechanism of the contextual cueing effect by detecting differences in the intercepts. In an experiment of Kunar et al. (2007), in which the set sizes were varied to examine search efficiency, no significant reduction in search rates for repeated compared to novel configurations were found; though, Kunar and colleagues (2007) reported a clear difference from intercepts between predictive and random configurations, supporting the assumption that other factors than attentional guidance contribute to the contextual cueing effect. Moreover, when interference (incongruent trials) was introduced to the response selection stage, contextual cueing vanished, indicating that contextual cueing may operate on a late processing stage of response selection. These findings can be supported by eye movement data of Zhao and colleagues (2012), who observed contextual facilitation of response selection. However, with respect to the behavioral results, Zhao et al. (2012) found no differences between predictive and random intercepts. Moreover, Schankin and Schubö (2010) examined electrophysiological if contextual cueing arises when the target location was beforehand peripherally cued. Results reveal that other processes than attentional guidance, such as attentional selection (N2pc) and response-related processes (s-LRP, P3) are involved in contextual cueing and enabled by context familiarity.

Kunar et al. (2007) argued for a decreased decision threshold to generate a response for repeated displays; thus, contextual cueing may contribute partly through faster reactions to target stimuli in familiar contexts. Despite their findings, Kunar and colleagues (2007) do not rule out that other factors contribute to the cueing effect. For example, in a simple visual search experiment (i.e. feature singleton search) there might be a competitive interaction between bottom-up, stimulus driven and top down, memory-driven guidance, in which response selection may be determined by bottom-up guidance processes which prevent memory-based guidance (contextual cueing). However, compound-search tasks applied by Kunar et al. (2007) do not allow to clearly separate between response-based (late) and search-based (early) effects due to certain implicit stimulus-response linkages, even when stimulus and response do not correspond to each other (see Töllner, Gramann, Müller, Kiss, & Eimer, 2008; Geyer et al., 2010). Geyer and colleagues (2010) examined in a simple pop-out detection task whether contextual cueing modifies early perceptual coding processes. Indeed, Geyer et al. (2010) reported improved signal detection accuracy for repeated displays and facilitation in target selection in repeated configurations, indicating that the time (here: 700ms) was sufficient to encode the search display and direct attention. Results suggest that contextual cueing do not depend on ‘serial’ allocation of attention as long there is enough time to encode and learn the presented arrangement of items.

### 1.3.2 Contextual cueing and learning

The high ecological validity of the contextual cueing paradigm cannot be denied - invariant contextual information determines our environment and attention is needed to select essential information (Chua & Chun, 2003; Chun, 2000). However, numerous studies investigating this paradigm used flat (2D) visual search displays (e.g. search for a "T"-shape among "L"-shapes, see Figure 4 for an example), which do not display the complexity of the real world, restricting the generality of contextual cueing.

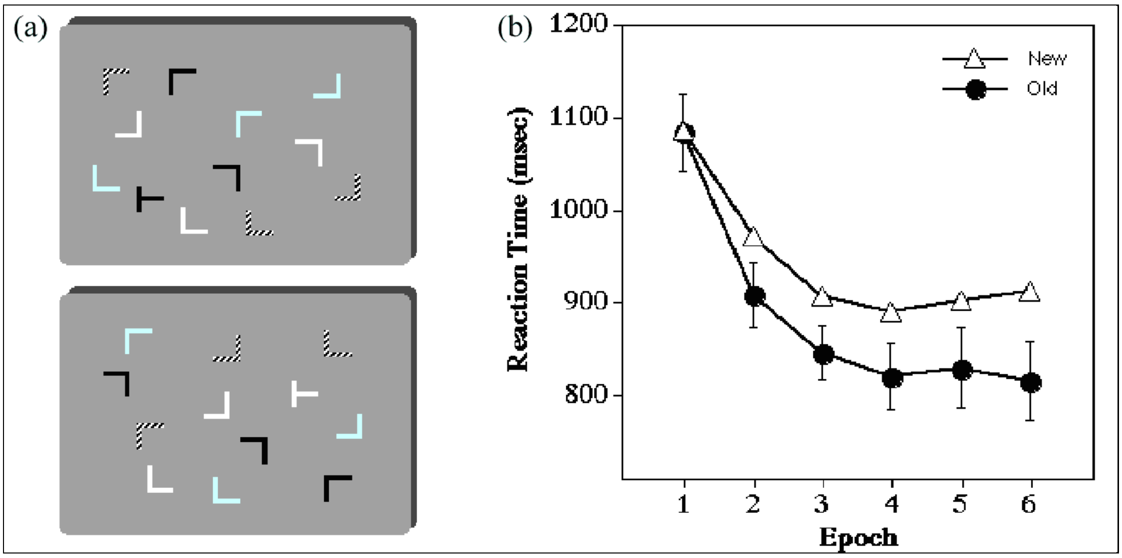

**Figure 4 | Example of a Contextual Cueing display (Chun & Nakayama, 2000).** a | Two sample search arrays of a “T among L” search. b | Search performance as a function of epoch.

Chua and Chun (2003) examined this issue by using pseudo 3-D graphic stimuli to generate an effect of depth (Figure 5b). Their findings confirm that contextual cueing develop within pseudo-naturalistic scenes.

Brockmole and Henderson (2006) utilized photographs of real-world scenes, where a small target letter (“T” or “L”) was inserted. Results demonstrate a reduction in search time for repeated real-world scenes over the course of the experiment, confirming the contextual cueing effect. Brockmole and Henderson (2006) concluded that subjects were sensitive for context-target associations, which may guide attention to pertinent regions in the display even when the relationship between context and target is random.

In an experiment of Rosenbaum and Jiang (2013), participants had to search for a “T” among an array of distractors (“L”) embedded in a natural scene (Figure 5a). Again, a significant contextual cueing effect was found; for example, reaction times were faster for repeated than for novel displays.

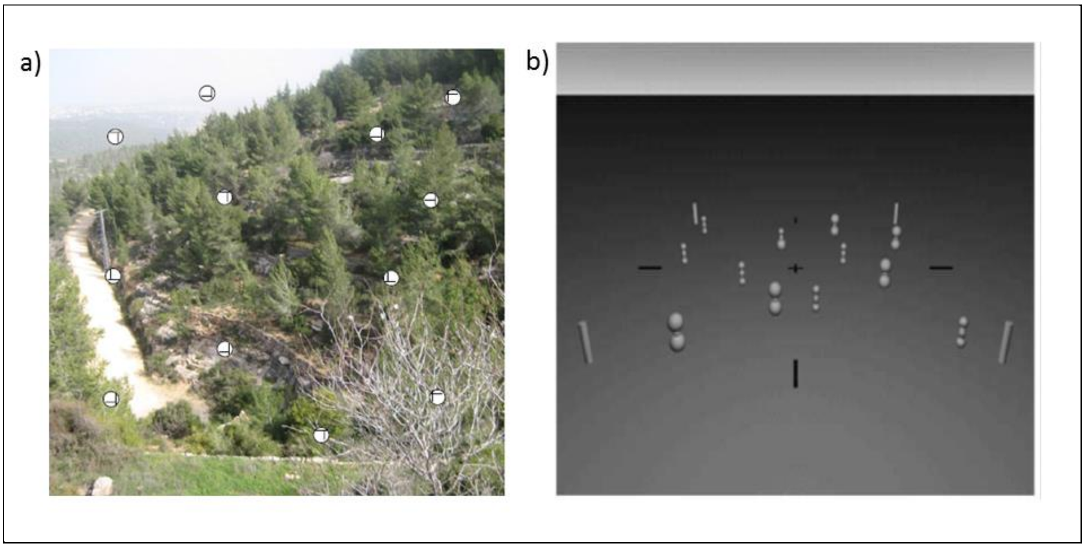

**Figure 5 | Scenes used in contextual cueing experiments.** a | Naturalistic scene with embedded target and distractors (Rosenbaum & Jiang, 2013). b | Pseudo three-dimensional scene (Chua & Chun, 2003).

There is a debate whether explicit or implicit memory processes are involved in contextual learning (Geyer et al., 2010; Rosenbaum & Jiang, 2013). Implicit learning involves learning without awareness, which can progress in the absence of attentional processes (Jiang & Leung, 2005) and working memory (Annac et al., 2013; Manginelli et al., 2013; Vickery et al., 2010), allowing more information to be learned (Berry & Dienes, 1993).

Research reported that learning the spatial context for two-dimensional (2-D) layouts (Chun and Jiang, 1998, 1999) and for three-dimensional (3-D) volumetric shapes (Chua & Chun, 2003) was implicit. Thus, subjects incidentally learned contingencies between the arrangement of distractors and the position of the target (Olivia & Torralba, 2007). Nevertheless, further studies of contextual cueing using real-word scenes to examine attentional guidance have shown that observers can explicitly learn the spatial context (Brockmole & Henderson, 2006; Brockmole, Castelhano, & Henderson, 2006), revealing that observers recognized repeated scenes better than random spatial layouts of search displays. In another experiment of Brockmole and Henderson (2006), where displays were reversed in order to impede recognition, learning decreased indicating that object and context information was applied for attentional guidance. The scene context seems to determine how objects are remembered (Hollingworth & Henderson, 1998; Kristjánsson & Campana, 2010; Olivia & Torralba, 2007; Rosenbaum & Jiang, 2013).

### 1.3.3 Summary and outlook

To summarize, the contextual cueing paradigm demonstrates how the scene context is learned to direct visual attention. The information of the visual context provides observers specific properties of their visual surroundings, supporting the guidance of visual attention, object recognition, and action (Chun, 2000).

Studies of contextual cueing often used flat (2D) visual search displays with artificial objects (e.g. letter stimuli) arranged in an invisible grid. In addition, the contextual cueing effect could also be demonstrated with photographic scenes (e.g. Brockmole & Henderson, 2006, Torralba et al., 2006) or naturalistic scenes (e.g. Brockmole et al., 2006).

Contextual learning of repeated displays is often reported to be mediated by implicit processes, without observers' awareness of the knowledge learned. However, studies of real scenes (e.g. Brockmole & Henderson, 2006) reported that contextual cueing effects were driven by explicit context learning. The implicit nature of contextual cueing means that subjects face surroundings with similar spatial organization repetitively. For example, in team sports, players go through such situations regularly. Team sport players repeatedly encounter game situations where a specific spatial arrangement of players requires a particular action. Thus, it might be that expert performance in a team sport like handball may be accompanied by improved contextual cueing (Kristjánsson, 2013). Therefore, first of all, attentional processes and strategies (conscious and non-conscious) underpinning expert performance in sport will be explored in the following section.

## 1.4 *Attentional Processes and Expert Performance*

### 1.4.1 Sport Expertise

Constant superior performance in a certain sport over an extended time period can be defined as Sport Expertise (Starkes & Allard, 1993). With respect to the level of expertise, there is discrepancy about the criteria used to define the term “elite” or “expert” athlete (Ericsson, Krampe, & Tesch, Römer, 1993; Swann, Moran, & Piggott, 2015). Simon and Chase (1973) proposed a “10-years rule” of constant and specific training to become an expert, which is supported by data from different domains (e.g. music mathematics, tennis; see Ericsson et al., 1993). However, in some studies athletes with just two years of training were defined as “expert” or “elite” athletes (e.g. Welch & Tschampl, 2012). Or the athletes were simply assigned to categories, such as professional performers (Jordet & Elferink-Gemser, 2012) or members of national squads (Bertollo, Robazza, Falasca, Stocchi, Babiloni, Del Percio, & Comani, 2012) without information about the years of constant practice. This inconsistency in the definition of “expert” athletes weakens the validity of expertise research in sport (Swann et al., 2015).

The automation of skills is of main interest in the domain of expertise research, skill development in sport and other performance areas, which deserves further investigation (Abernethy et al., 2007). Knowledge of psychological factors that distinguish elite athletes from novices or less successful athletes has received a large interest by sport expertise researchers in the last decades (Starkes & Ericsson, 2003). Literacy of aspects that restrict and lead to superior performance in sport are essential to apply efficient practice and training to improve performance, to predict the chances of success of the athletes in a certain sport (Williams & Reilley, 2000), and to evaluate skill acquisition and expertise (Williams & Ericsson, 2005; Furley, 2012).

The sporting surrounding requires athletes to adjust to certain restrictions in order to be successful or to prevent reduced efficiency (Davids, Button, & Bennett, 2007). The knowledge where and when to look is essential to succeed (Mann, Williams, Ward, & Janelle, 2007). Athletes must be able to identify relevant visual cues, select a response, and execute the movement in close temporal proximity.

Sports science research has demonstrated that experts are more rapid and accurate in their decisions in time restricted situations (Chamberlain & Coehlho, 1993; Starkes & Allard, 1993; Williams et al., 1999; Mann et al., 2007). This perceptual decision making is an essential characteristic of reactive sports skills (i.e. a counter attack in handball). Such reactive skills are supposed to be a result from instinct or experience (Fadde, 2006). Implicit (procedural) knowledge promotes motor expertise, enabling effective performance when a decision must be made and a successive action need to be executed rapidly. According to Masters, Poolton, Maxwell, and Raab (2008), the coupling of perceptual information and former experience is necessary for sufficient decision making. The coupling requires different cognitive resources according to the complexity of the task (Raab, 2003) and depends on the performance of working memory (Masters et al., 2008). Effective decision making of sport experts may be due to the changing character of the knowledge structures which promote the motor action. Implicit (unconscious) control, which is faster and can be used without awareness (Masters & Maxwell, 2004; Shiffrin & Schneider, 1977; Willingham, 1998), increases over time, whereas explicit (conscious) control declines (Masters et al., 2008). Maxwell, Masters, and Eves (2003) suppose that explicit processes are dependent on working memory to retrieve conscious knowledge, enabling the motor system to control and manage motions online. In contrast, implicit processes do not depend on working memory. Consequently, more resources are available for the performance of further tasks, such as decision making (see Baddeley, 2003), leading to more effective decision making and motor performance in time restricted situations (Masters & Maxwell, 2004). However, Gréhaigne, Godbout, and Bouthier (2001) reported that the benefit in decision making for sport performers is context-specific.

Most sport contexts require multiple attentional demands on athletes. Team sports players must pay attention to their opponent’s strategies and tactics by monitoring activities of several players. For example, in handball, a team comprises seven players with certain offensive or defensive functions. Such an open sport involves several dynamic situations, in which athletes have to operate under time pressure in high-interference situations, requiring rapid reactions and effective decision-making to efficiently select situation-appropriate actions. The ability to recognize situations in which a certain action occurred in comparable preceding situations may be beneficial for athletes. Farrow and Raab (2008) suggest a superior ability to recognize and memorize patterns of play in elite team-players performed by the opposition team. Sometimes athletes may become explicitly aware of such situations. These explicit memory contents may be advantageous for strategic actions

(Alfermann & Stoll, 2005). However, frequently, incidental learning may contribute to the initiation of an action in such situations. Incidental learning is implicitly directed by the spatial context, generating memory traces of comparable previous situations (i.e. contextual cueing).

Farrow and Abernethy (2002) argued that for several perceptual and perceptual-motor skills learning may be particularly implicit due to the restricted role of explicit knowledge during learning. The acquisition of numerous perceptual-motor skills is based on functional levels of organization, which are cognitively unapproachable, limiting explicit learning. Implicit learning is characterized by a profounder encoding of information, improving the retention of the information (Reber, 1989). In addition, there is some indication that explicit learning may hinder implicit learning processes. Therefore, the use of traditional explicit approaches is controversial (see Farrow & Abernethy, 2002).

It has been claimed that the limited research examining implicit learning processes in sports has been not sensitive enough to measure the contribution of both explicit and implicit processes (Shanks & St. John, 1994). Farrow and Abernethy (2002) proposed the use of implicit learning paradigms to generate an implicit learning condition. Moreover, Romeas, Guldner, and Faubert (2016) claim that “it relies on more fundamental, sport context-free, paradigms that confer a cognitive fidelity rather than a physical fidelity with the sport environment” (pp. 2). Thus, the contextual cueing paradigm reported above may be an adequate attentional training approach (Kristjánsson, 2006; 2013).

Because of its incidental nature and its flexibility in utilizing even partial repetitions in an environment, contextual cueing is likely to occur in team sport athletes and may be superiorly developed in elite athletes. There exists no research of contextual cueing in athletes. However, elite athletes demonstrate superior performance than novices in several attention tasks (e.g. Castiello & Umiltà, 1992; Nougier, Ripoll, & Stein, 1989; Pesce-Anzeneder & Bösel, 1998; for reviews see Mann, Williams, Ward, & Janelle, 2007; Voss, Kramer, Prakash, Roberts, & Basak, 2010). For example, elite athletes were better able to shift attention between objects, to sustain attention longer than novices (Pesce-Anzeneder & Bösel, 1998), and to adapt the range of their attentional spotlight in order to direct their attention on several locations (e.g. Nougier, Azemar, Stein, & Ripoll, 1992). Besides, Hüttermann, Memmert, and Simons (2014) reported 25% greater attention breadth in elite athletes compared to novices. However, the spatial distribution of attention for expert athletes varied as a function of the sport type: athletes in sports that require more horizontal distribution of attention (e.g. soccer) demonstrated an advantage for horizontal stimuli. Athletes playing a sport with more vertical demands (e.g. volleyball) showed superior vertical breadth of attention (Hüttermann, Memmert, & Simons, 2014). Moreover, elite athletes demonstrate generally superior use of visual cues, more rapid and accurate decision-making, anticipation, spatial memory, and visual search in sport-specific tasks as found in a meta-analytic review (Mann et al., 2007). The largest effects were observed in anticipation experiments (e.g. Abernethy, Gill, Parks, & Packer, 2001; Mann et al., 2007; Ward & Williams, 2003). Studies using memory recall and recognition paradigms (basketball: Allard, Graham, & Paarsalu, 1980; field hockey: Starkes, 1987; volleyball: Allard & Starkes, 1980; soccer: Helsen & Pauwels, 1993a) have demonstrated that elite athletes were better able to hold, recall, and acknowledge aspects of structured domain-specific game situations than their novice counterparts (for a review in sport, see Abernethy, Burgess-Limerick, & Parks, 1994). Further, recalled patterns of experts from their specific sport are universal in nature and the capability to read the game have been observed to transfer across team sports (Abernethy, Côté, & Baker, 2002; Farrow & Raab, 2008). The result of efficient pattern recognition is anticipation. The ability to anticipate has been shown in several sports, such as badminton (Abernethy, 1988), squash (Abernethy, 1990a), karate (Mori, Ohtani, & Imanaka, 2002), tennis (Williams, Ward, Knowles, & Smeeton, 2002), and football (Williams, 2000). Top athletes used the information more efficiently to anticipate an action by focusing on task-relevant information and neglecting task-irrelevant information. The extensive training of team sport athletes may enhance the utilization of key visual cues, leading to improved performance measures (Abernethy, 1988). Techniques to investigate the information processing of elite athletes are occlusion techniques (for a review, see Williams, Davids, & Williams, 1999), which generally include a large explicit component.

Though, there is a debate how this memory advantage in elite athletes arises. Ericsson and Kintsch (1995) suggest that athletes possess a superior working memory due to enhanced encoding and retrieval processes. Vicente and Wang (1998) propose a constraint-attunement hypothesis. According to this hypothesis, the physical properties of the objects will be automatically associated with actions due to experience. A study of Williams and Davids (1998) reveal recall benefits for athletes compared to fans, indicating that the superior memory performance is not only the result of perceptual processes, but also cognitive benefits. Decision making advantages on game situations that had been presented beforehand were also reported by Zoudji and Thon (2003). However, expert decision time benefits vanished when the game scene was displayed mirror-reversed even when the arrangement of the display remained constant. Zoudji and Thon (2003) suggest that incidental or implicit memory tests may be more suitable and valid to test mechanisms underpinning expert performance in team game situations. Indeed, there is evidence that relevant features of the game can be recognized and encoded without conscious attention to specific aspects (see Weber & Brewer, 2003). It should be noted that all these studies refer to explicit memory. The aim of this study is to investigate if incidental (and potentially implicit) learning is enhanced as well in elite handball players.

However, it is far from clear if elite athletes have improved attentional or cognitive skills that generalize to situations unrelated to sports. Moreover, athletes did not consistently show superior performance in attentional tasks. Memmert et al. (2009) did neither find superior performance of expert handball players in the multiple-object-tracking or the useful-field-of-view task nor less inattentional blindness. Expert basketball players did not show superior visuospatial working memory scores in the Corsi block-tapping task (Furley & Memmert, 2010). Across many studies, sport-specific displays, stimuli, and processing requirements were more likely to demonstrate expert-novice differences (Abernethy, 1987b; Hohmann, Obelöer, Schlapkohl, & Raab, 2015; Swann, Moran, & Piggott, 2015). For example, Hohmann et al. (2015) demonstrated that three-dimensional video-training was the most effective instrument to enhance decision time in handball compared to two-dimensional video training and training with a tactic board. Nevertheless, a meta-analytic review by Voss, Kramer, Basak, Prakash, and Roberts (2010), which examined the relationship between sport expertise and fundamental cognitive skills, revealed superior performance for expert athletes on measures of processing speed and visual attention. A study of Alves Voss, Boot, Deslandes, Cossich, Salles, and Kramer (2013) showed that volleyball-players outperformed non-athletes on two executive tasks (task switching, inhibitory control) and a visuospatial attentional processing task. The superior performance of athletes in comparison to non-athletes in general cognitive skills could also be demonstrated in socially realistic multitasking crowd scenes (Chaddock, Voss, & Kramer, 2012) and for a 3-dimensional multiple-object-tracking (MOT) speed threshold task (Faubert, 2013). In the 3-D MOT task, athletes differ significantly from non-athletes in the processing of neutral complex dynamic visual scenes. Moreover, Romeas et al. (2016) could demonstrate that improvements in a 3-dimensional MOT training in the laboratory could transfer to real game situations in soccer. These studies underpin the assumption that not just sport-specific but also general cognitive enhancements of athletes may be associated with competitive sport training (Voss et al., 2010). These findings are in line with the broad transfer hypothesis, suggesting that adaptations in basic cognitive skills develop due to experience in an activity, such as sports training (Voss et al., 2010) or video game playing (Green & Bavelier, 2003).

Like playing of a team sport, there is evidence that playing a specific type of video game, so called action video games, enhances visual, attentional and cognitive abilities. In the following section, literature investigating the effects of playing action video games will be reviewed and the mechanisms behind these behavioral improvements will be debated.

### 1.4.2 Action Video Game Expertise

Research on action video game playing has aroused broad interest over the past decade due to the assumption that training on action video games enhances perceptual and attentional functions. The interest in the effects of video game playing on perceptual and attentional variables originates largely from the apparent generalization of training effects that contrasts sharply with many other training effects that remain task specific (Green and Bavelier, 2012). It is very likely that the complexity and difficulty of the stimulation and the task affordances of action video games are crucial for the generalization of training. In more controlled settings, this has been demonstrated in perceptual learning (Ahissar & Hochstein, 1997; Fahle, 2005; Harris, Gliksberg, & Sagi, 2012; Liu & Weinshall, 2000; McGovern, Webb, & Peirce, 2012). Perceptual learning involves enhancements in complex perceptual abilities as a consequence of practice (Sowden, Davies, & Roling, 2000) and may be explained by different mechanisms, such as the memorizing or derivation of stimuli and attentional adjustment (Goldstone, 1998).

The genre of action video games includes specific features, such as (a) fast pace, (b) perceptual and motor load, (c) the need to frequently alternate between focused and divided attention, and (d) a high grade of disarray and distraction (Bediou, Adams, Mayer, Tipton, Green, & Bavelier, 2018). According to Bediou et al. (2018) main subtypes of action video games are first-person shooter games (the player acts through the eyes of his or her avatar; e.g., Call of Duty) and third-person shooter games (player views the back of his or her avatar; e.g., Grand Theft Auto).

Most action video games have complex three-dimensional setups and are extraordinarily visually and attentional demanding due to simultaneously processing of multiple items, requiring the video game player to change constantly between focused and distributed attention (Green & Bavelier, 2015). In such virtual realities a good reaction and selection is required to perceive relevant information and to reject irrelevant information efficiently; consequently, as regular action video game players often invest many hours in playing action video games, action video gamers may evolve such abilities (i.e. superior hand-eye coordination, fast response selection, and motor reaction). Moreover, the fact that action video game playing requires a constant state of guiding spatial attention, visuospatial abilities may be improved in action video game players. Indeed, current research reveals superior performance of action video game players in several visual attention tasks (Chisholm & Kingstone, 2012).

In an early study, Subrahmanyam and Greenfield (1994) showed that an action video game improved visuospatial test performance in children. Furthermore, studies examining differences between video game players and non-video game players reported faster response selection (Castel, Pratt, & Drummond, 2005; Clark, Lanphear, & Riddick, 1987), enhanced target detection (Feng, Spence, & Pratt 2007; Green & Bavelier, 2006a), improved visual control, greater attentional capacity, and better spatial allocation of attention in action video-game players (Green & Bavelier, 2003). This led to an enormous increase of interest in the attentional effects of video game playing. Subsequently, superior action video game performance has been linked to different perceptual and attentional benefits (for recent reviews see Green & Bavelier, 2012, 2015). For example, visual search performance and distractor inhibition was improved for action video gamers relative to non-gamers (Chisholm, Hickey, Theeuwes, & Kingstone, 2010; Chisholm & Kingstone, 2012; Green & Bavelier, 2007). Studies reveal that action video game play enhances selective spatial attention in standard visual search (Hubert-Wallander, Green, Sugarman, & Bavelier, 2011) or in the useful field of view (UFOV) task (Bavelier, Green, Han, Renshaw, Merzenich, & Gentile, 2011; Buckley, Codina, Bhardwaj, & Pascalis, 2010). Moreover, improvements in the selection of pertinent information over time (Dye & Bavelier, 2010; Li, Polat, Scalzo, & Bavelier, 2010), during multiple-object tracking (Boot, Kramer, Simons, Fabiani, & Gratton, 2008; Dye & Bavelier, 2010; Green & Bavelier, 2006b) and task switching (Karle, Watter, & Shedden, 2010; Boot et al., 2008) were reported. Greenfield, DeWinstanley, Kilpatrick, and Kaye (1994) has shown in a simple target detection task that video game players had less attentional costs, indicating an improved ability to divide attention in comparison to non-video game players.

The superior performance on behavioral abilities of action video game players has been proposed to reflect transfer effects (Green & Bavelier, 2015). Practice on one task has a beneficial transmitting effect when performing a new task. An alternative explanation, proposed by Green and Bavelier (2015), is that video gamers have ‘learned to learn’ to execute the new task. Indeed, a study of Bejjanki, Zhang, Li, Pouget, Green, Lu, and Bavelier (2014) confirms this alternative approach. Bejjanki and colleagues (2014) reported no performance differences between regular action video game players and non-video game players on the first trials of a new task. However, the performance of action video game players enhanced significant faster compared to non-action video game players, revealing steeper learning functions of action video game players. The ability of ‘learning to learn’ may develop due to improved attentional control in action video gamers, facilitating the oppression of distractors, leading to a more efficient and faster pickup of essential information (Mishra, Zinni, Bavelier, & Hillyard, 2011).

### 1.4.3 Concluding remarks

Contextual cueing has been widely reported being robust to age and general cognitive ability. However, individual search facilitation due to display repetition may vary (Lleras and von Mühlenen 2004; experiment 1). On this background, it makes sense to ask if special groups differ with respect to their strength of contextual cueing. The implicit nature of contextual cueing means that subjects face surroundings with similar spatial organization repetitively. For example, in team sports, players go through such situations regularly. Specific situations are repeatedly encountered during a game and may facilitate selection of the appropriate action. As reported above, a number of studies indicate that explicit learning skills failed under demanding situations (Beilock & Carr, 2001; Gray, 2004; Masters, 1992). In contrast, implicit processes are automatic and may lead to more efficient decision-making and motor performance (Masters, 1992). This is what we examined in this study in a group of high-level amateur handball players. The set of experiments aim to test if high-level team sport athletes have superior context learning skills. Note that superior skills in athletes may be due to training or due to a selection phenomenon (Kristjansson, 2013) and the present cross-sectional data cannot discriminate between these explanations (see Schmidt, Geringswald, Sharifian, & Pollmann, 2018).

Athletes’ performance was compared to that of non-athletes on the one hand and to action video game players on the other hand. Action video game players were selected because enhanced attentional skills have been reported in this group. Like playing of a team sport, action video game playing leads to complex sensory stimulation. An obvious difference is the complexity of visuo-motor demands that is much higher for handball players and may additionally support learning (Kramer, & Erickson, 2007).

To investigate spatial contextual cueing and the contribution of scene learning to attentional processing in these groups, a sport-specific pseudo 3-D contextual cueing task (search of the ball-carrying player in a playing field) and the original contextual cueing paradigm (search of a “T” among “L”-shapes; Chun & Jiang, 1998) were used. The experiments presented in this thesis aim to address three main research questions outlined in Table 2.

**Table 2│Research Questions Addressed in the Thesis.**

| | Research Question | Adressed in |
|---|---|---|
| I. | To what extent is expert performance like handball playing and action video game playing accompanied by enhanced contextual cueing compared to non-experts? | *Experiment 1 – 3* |
| | a. Do handball players and action video game players show superior contextual cueing in sport-specific scenes with pseudo–3-D layouts compared to non-experts? | *Experiment 1* |
| | b. Does handball playing or action video game playing lead to a contextual cueing advantage in arbitrary environments? | *Experiment 2 & 3* |
| II. | How does scene learning can occur for two-dimensional and pseudo 3-D layouts for handball players and action video game players? | *Experiment 1 – 3* |
| III. | To what extent do attentional guidance or non-search factors contribute to the contextual cueing effect in handball players and action video game players? | *Experiment 3* |

Precise hypotheses for each experiment are formulated in their respective introduction.

# 2 General Methods

The following chapter describes all general methods in order to obviate repetitions due to the overlapping methodology of the three experiments. Specific methodological characteristics of each experiment are depicted in the particular methods section.

## 2.1 *Participants*

A total of 240 healthy participants (control: n = 81, mean age = 24.8 years; handball players: n = 81, mean age = 20.7 years; action video game players: n = 78; mean age = 23.9 years) were recruited for this study. The athletes were subdivided into two categories, according to age and years of training: adult and junior. Both adult players from a 3rd league handball team and junior players from the Sportclub Magdeburg playing in the A and B youth national league participated in this study. The junior handball players practice 6-7 days (15 hours) a week, whereas adult players have 3-5 days (8 hours) training per week. Junior handball players had more than 6 years and adult players more than 10 years' handball experience. None of the handball players was a regular video game player, as assessed by interview. Vice versa, none of the action video game players played handball. Controls and video gamers were recruited from the University of Magdeburg. Action video game players had to fulfill the following criteria: action video gamers needed to play action video games (e.g. Call of Duty; Activision, Infinity Ward) for a minimum of five hours a week for at least one year. Participants without any team sport and action video game experience (less than 1 h per week) were classified as controls. In the present study, we needed to rely on open recruiting of semi-professional handball players, because they would not occur frequently enough in a random sample. Due to the restricted availability of the athletes, the focus of the present study was the investigation of incidental contextlearning skills. Informed written permission was acquired prior to the experiments. Subjects were remunerated with course credits or received a payment of Euro 7. Further, subjects were naive about the purpose of the experiment.

All participants had normal or corrected-to-normal vision. The experiments were approved by the Ethics Committee of the University of Magdeburg.

## 2.2 *Behavioral Task: Contextual Cueing*

### 2.2.1 Apparatus

Experiments in the current study were programmed and performed using the OpenGL-Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997) in MATLAB (The MathWorks, Natick, MA, USA). Stimuli were displayed by a projector on a back-projection screen (Experiment 1: 1150 mm (1024 pixels) wide and 800 mm (768 pixels) high; Experiment 2 and 3: 1170 mm (1024 pixels) wide and 850 mm (768 pixels); high vertical refresh rate of 60 Hz). Participants viewed the stimuli from a distance of 126 cm (pixel size of 0.048° x 0.046°). Subjects completed the experiment individually in a dimly lit, sound-attenuated chamber.

### 2.2.2 Procedure of the Behavioral Task

Each session started with a short training period to familiarize participants with the task, followed by the main search experiment and a recognition test. In the training phase, participants were shown 24 randomly generated displays which were not used in the main experiment. The testing phase comprised 20 blocks of 24 trials, 12 for each configuration type (repeated vs. novel displays). The entire experiment lasted approximately 45 minutes.

Each trial started with a blank interval for 500 ms followed by the fixation cross for 1000 ms. After a brief pause of 200 ms, the array of stimuli appeared on the projection screen. Participants were told to respond as fast and accurately as possible. They were further instructed not to apply active search strategies (“be as receptive as possible and let the unique item ‘pop’ into your mind as you look at the screen”) as proposed by Lleras and von Mühlenen (2004). The search display remained on the screen until a response was made by the participants. Auditory feedback was provided for correct (a 500-Hz low-pitch tone) and incorrect answers (a 1500-Hz high-pitch tone). At the end of the search task, the participants performed a recognition test, to evaluate whether repeated displays were explicitly remembered.

The recognition test consisted of 24 trials, including the original 12 repeated and another 12 novel randomly generated configurations, presented in randomized order. Participants had to indicate by keyboard button press whether they had seen the displays during the course of the experiment or not. No feedback was given in the recognition task.

## 2.3 *Statistical Calculations*

All statistical calculations were carried out using R-statistics (R Development Core Team, 2007). Two data exclusion criteria were applied for the search time data. First, all incorrect responses were removed from the data set. Second, trials in which the search time was shorter than 200 ms or larger than 3.5 standard deviations from the participants' average search time in the remaining trials were discarded to remove outliers (fast guesses and extremely long searches that may unduly bias the results).

Experimental blocks were aggregated to four epochs, each containing five blocks, in order to increase statistical power. Analyses of variance (ANOVAs) were performed using Type III sums of squares. For all statistical tests, the alpha level was set to 0.05.

In order to explore the relationship between recognition accuracy and contextual cueing effect, an additional analysis was performed. The individual amount of search facilitation for repeated displays in the last epoch was calculated for each participant by computing the difference in mean reaction times between the novel and the repeated displays. Subsequently, these absolute differences were divided by the mean reaction times of novel displays in order to normalize the contextual cueing effect.

# 3 Experiment 1: Handball players and action video game players did not show superior context learning of pseudo 3-D scenes

The results of this experiment were first published in: Schmidt, A., Geringswald, F., & Pollmann, S. (2018). Spatial Contextual Cueing, Assessed in a Computerized Task, Is Not a Limiting Factor for Expert Performance in the Domain of Team Sports or Action Video Game Playing. *Journal of Cognitive Enhancement*, available online 1. Oct. 2018.

## 3.1 *Introduction*

A general aim of the study was to investigate how the attentional skills of experts (team sport athletes, action video game players) compare with those of non-experts. Research on competitive sports (Mann et al. 2007; Voss et al. 2010) and video game playing (Boot et al. 2008; Green and Bavelier 2003) indicates that attentional abilities may improve by practice and experience (Furley and Memmert 2011). An example for such an attentional training approach may be the contextual cueing paradigm (Kristjánsson 2013). The contextual cueing task may reflect attentional effects, elucidating if handball and action video game playing improves context-learning skills (see Faubert 2013).

Chua and Chun (2003) emphasize the ecological validity of contextual cueing by arguing that contextual information is predominant in our environment, so that attention needs to be focused on relevant aspects and objects to allow effective action in the environment (Chun 2000). However, the two-dimensional stimuli traditionally used in contextual cueing tasks limit the universality of contextual cueing (see Chua and Chun 2003). Chua and Chun (2003) replicated the original contextual cueing task with volumetric pseudo-naturalistic 3-D shapes to represent the depth of the real world in order to improve ecological validity of contextual cueing. Results indicate that contextual cueing can be generalized to pseudo 3-D scenes. In order not to miss contextual cueing advantages that might be tied to handball-specific constellations, we started in experiment 1 with a sport-specific pseudo 3-D contextual cueing task in which our participants had to search in displays that resembled players in a handball field. It is hypothesized that contextual cueing generalizes to sport-specific scenes with pseudo 3-D layouts and that subjects implicitly learn the spatial context in this novel contextual cueing task.

## 3.2 *Methods*

### 3.2.1 Participants

A total of 90 healthy participants (control: n = 31, mean age = 24.8 years (19–34 years, SD = 3.26); handball players: n = 31, mean age = 20.4 years (16–31 years, SD = 5.74); action video game players: n = 28; mean age = 23.1 years (20–28 years, SD = 2.21) was recruited for this study. The athletes were subdivided into two categories, according to age and years of training: adult and junior. Nine adult players (9 women; 23–31 years, SD = 3.37) from a 3rd league handball team and 22 junior players from the Sportclub Magdeburg (18 men and 4 women; 16–17 years, SD = 1.30) playing in the A and B youth national league participated in this study.

### 3.2.2 Apparatus and Stimuli

The stimuli were generated with Blender 2.69 (Stichting Blender Foundation, Amsterdam, Netherlands). The texture of the stimuli was created with GNU Image Manipulation Program (GIMP 2.8). Each search display comprised one target (player with ball in left or right hand) and 11 distractors (players without ball), forminga spatial layout in pseudo 3-D space (Figure 6). The arms of the players could be positioned as follows: both arms up, both arms down, left up and right down, right up and left down. Stimuli subtended a minimum 1.3° x 1.9° and a maximum of 2.1° x 4.3° of visual angle. The ball subtended a minimum 0.2° x 0.2° and a maximum 0.5° x 0.5° of visual angle. The items were presented on a green pitch with a black background. All items were colored in brown (skin), white (shorts) and blue (shirt) to improve visibility. Stimuli were smaller the farther back they were to generate a sense of depth (Chua & Chun, 2003). Display size of the projected display can be seen in Figure 6.

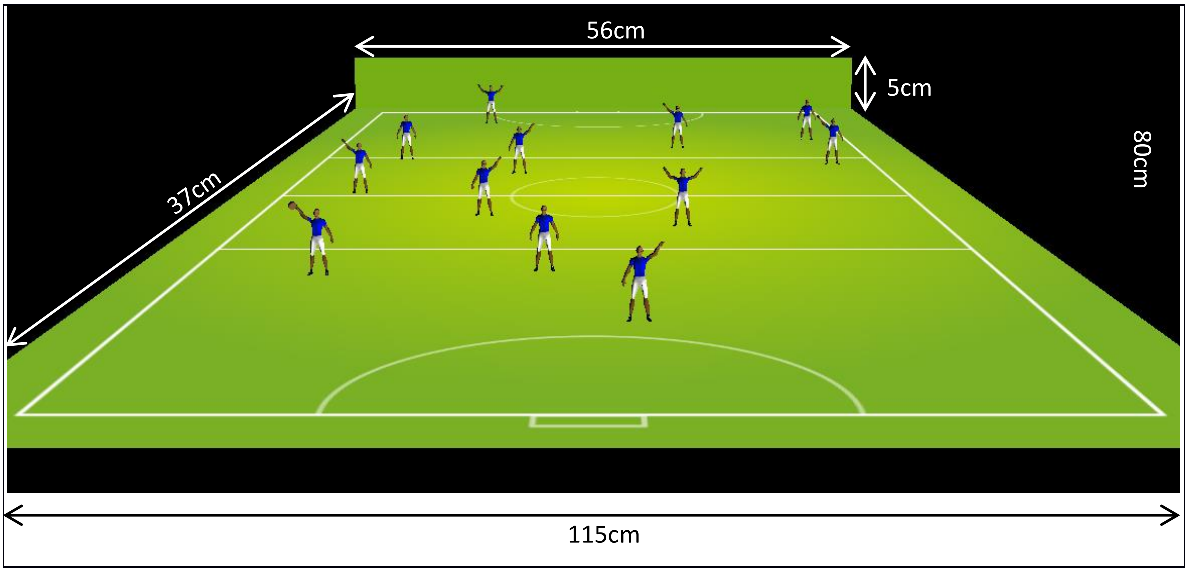

**Figure 6│Display size of the projected display**

Blocks contained 24 trials, 12 for each configuration type (repeated vs. novel). The old displays comprised 12 configurations that were repeated across blocks (1-20). 12 randomly chosen target positions were each paired with unique distractor configurations that remained constant throughout the experiment (repeated condition). The other 12 target positions were paired with distractor configurations that were newly generated for each block (novel condition). The targets in the novel sets appeared, as for the repeated configurations, equally often in one of 12 locations to control for target location repetition effects (Chun & Jiang, 1998). Stimuli were positioned in an invisible 3 column x 4 row grid, for a total of 12 rectangles in which objects could appear. The target positions and the eccentricity (near or far) were balanced across rectangles and conditions. The fixation stimulus was designed as a white cross at the center of the upper goal and subtending an area of 1.6° x 1.6°. The visual angle of the search display on the projection screen extended an area of 49.1° x 35.2°.

### 3.2.3 Procedure

At the beginning of the session, participants had to perform a training block, followed by the main search experiment and a recognition test. Participants searched for the player with the ball (target) among an array of distractor players and indicated the ball's location (left vs. right hand) with left and right arrow keyboard button presses with the right hand.

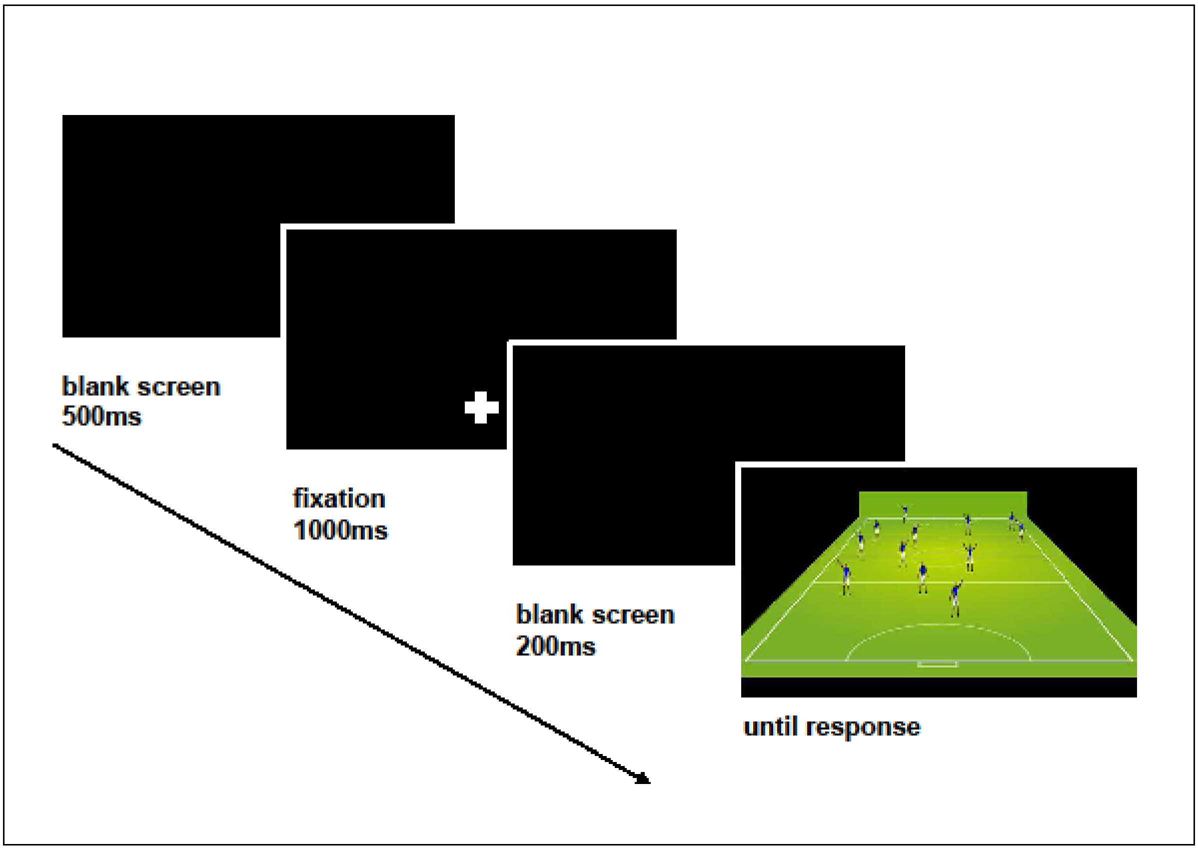

**Figure 7│Procedure of an experimental trial in Exp. 1.** A trial consisted of the presentation of a blank screen [500ms], a fixation cross [1000ms], blank screen [200ms], and the search display [presented until response].

### 3.2.4 Data Exclusion

The two steps of the exclusion procedure led to the rejection of 3.4% (SD = 1.2%) of invalid data for the controls, 4.2% (SD = 1.8%) for handball players, and 4.4% (SD = 2.4%) for action video game players.

## 3.3 *Results*

### 3.3.1 Search Times

For the reaction time analysis, blocks were aggregated into four epochs, each containing five blocks. Averaged reaction times for the four epochs for repeated and novel displays separated by the three groups (control, handball, video) are displayed in Figure 8. A repeated-measures ANOVA with the within-subject factors configuration (repeated, novel) and epoch (1, 4) and the between-subject factor group (control, handball, video) was performed on mean reaction times. The first and the last epoch of the search experiment were contrasted to maximize effects due to learning.

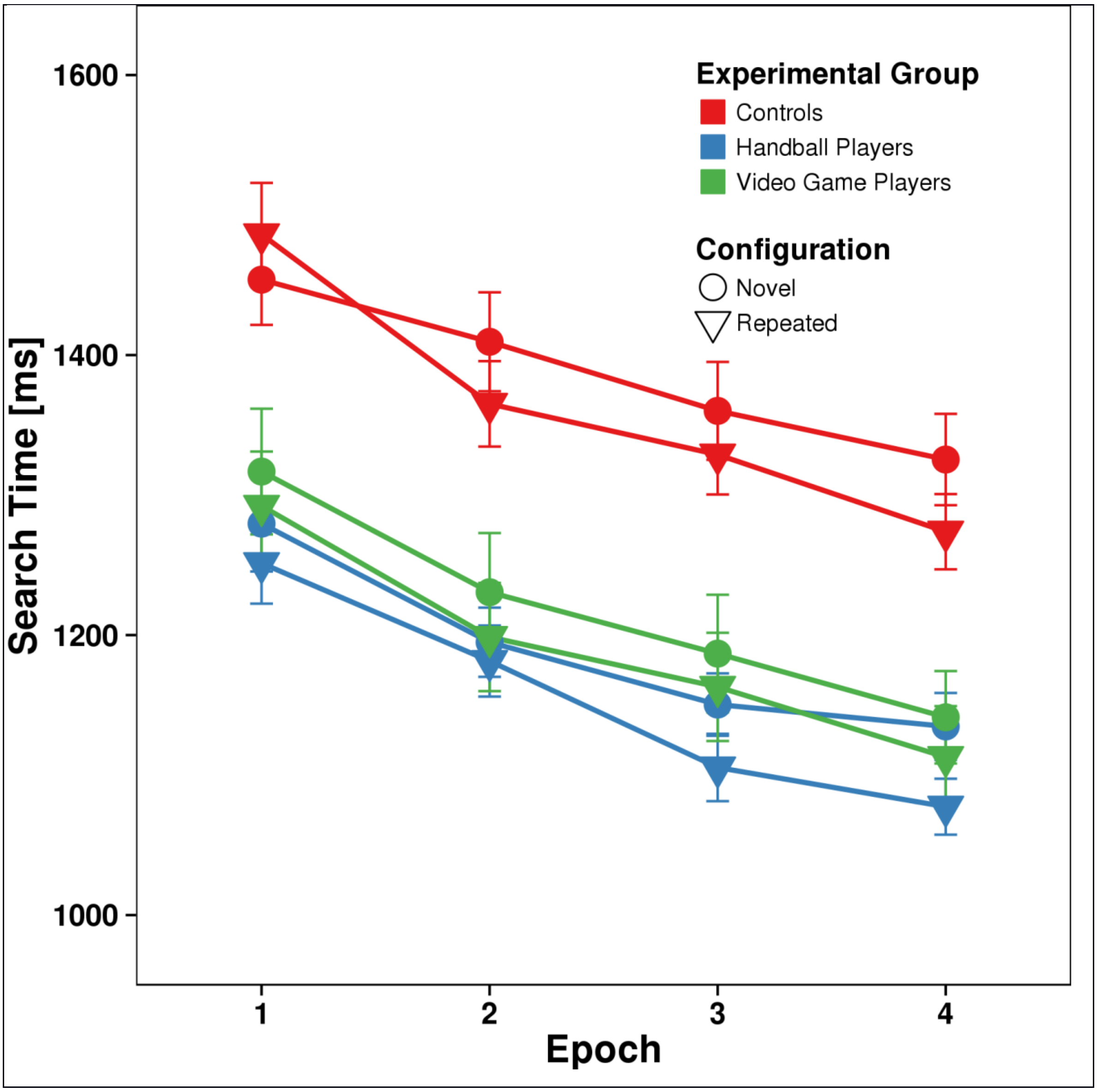

**Figure 8│ Experiment 1. Averaged search times in the visual search task for the three groups controls (red), handball players (blue), and video game players (green) for repeated (triangles) and novel (circles) display as a function of epoch.** Error bars represent the standard error of the mean.

The main effect of group was significant [*F*(2,87) = 13.757, *p* < 0.05, *η2_G* = 0.203]. Post-hoc *t* tests revealed that overall search speed was comparable between handball players (1186 ms) and action video game players (1216 ms) [*t*(47) = 0.701, *p* = 0.49], but both groups outperformed controls [1385 ms, handball players: *t*(58) = 5.404, *p* < 0.05; action video players: *t*(53) = 3.687, *p* < 0.05]. The significant main effect of epoch [*F*(1,87) = 247.014, $p < 0.05$, *η2_G* = 0.187] reflected general learning from the first (1348 ms) to the last epoch (1179 ms). In addition, we observed a significant main effect of configuration [*F*(1,87) = 6.248, $p < 0.05$, *η2_G* = 0.005], indicating that search in the repeated displays (1251 ms) was faster than search in novel displays (1277 ms). The significant interaction of epoch × configuration [*F*(1,87) = 6.997, $p < 0.05$, *η2_G* = 0.003] reflected increasingly faster search in repeated displays over time. While search times decreased by 149 ms in novel displays from the first to the last epoch, the use of contextual cues speeded up search by 189 ms in repeated displays. No other interaction effects were significant [all $F < 2.57$, $p > 0.05$, *η2_G* = 0.002] although the group × configuration × epoch interaction narrowly missed significance [$F = 2.565$, $p = 0.08$, *η2_G* = 0.002].

Contextual cueing benefits in controls could potentially have been inflated by their overall slowed search compared to handball players and action video game players. To eliminate the effect of overall search speed, an additional two-factorial mixed-design ANOVA with the withinsubject factor epoch and the between-subject factor group was performed on normalized contextual cueing effects. Normalized contextual cueing was obtained by dividing the absolute response time differences between novel and repeated displays by the response time of novel displays for each participant and each epoch. The ANOVA revealed a significant main effect of epoch [*F*(1,87) = 9.061, $p < 0.05$], confirming the increase of contextual cueing over time. Neither the main effect of group [*F*(2,87) = 0.909, $p > 0.05$] nor the interaction between epoch and group [*F*(2,87) = 1.239, $p > 0.05$] was significant.The mean differences between repeated and random configurations for all epochs for the three groups are presented in Table 3.

**Table 3│Mean differences between novel and repeated configurations of Experiment 1.**

| | | Mean difference novel-repeated | | | |
|---|---|---|---|---|---|
| | | **Epoch 1** | **Epoch 2** | **Epoch 3** | **Epoch 4** |
| Search time (ms) | Control | -32,37 | 44,36 | 31,25 | 51,57 |
| | Handball | 28,26 | 13,44 | 44,98 | 57,35 |
| | Video | 24,54 | 32,02 | 23,79 | 28,45 |

### 3.3.2 Age Differences

A repeated-measures ANOVA with the between-subject factor group (control, handball, video) was performed on age. Groups differ significantly in age [$F(2,87) = 9.195$, $p < 0.05$].The differences in age can be explained by the age range of the handball group (junior vs. adult handball players). Due to the age range of this group and the proposed ten years or 10.000 hours of experience rule to develop expert performance (see Ericsson et al., 2006), an additional age analysis of the handball players was conducted in order to rule out that younger players without this ten years' experience diminish the contextual cueing effect. Therefore, a comparison of junior versus adult handball players was run. A repeated-measures ANOVA with the within-subject factors configuration (repeated, novel) and epoch (1, 4) and the between-subject factor group (junior handball players, adult handball players) was performed on mean reaction times. Significant main effects of epoch [$F(1,29) = 70.967$, $p < 0.05$, $\eta^2\_G = 0.205$] and configuration [$F(1,29) = 5.864$, $p < 0.05$, $\eta^2\_G = 0.025$] were observed. No group or interaction effects were significant [all $F < 1.20$, $p > 0.05$, $\eta^2\_G < 0.029$], indicating that junior and adult handball players did not differ in the contextual cueing task.

### 3.3.3 Accuracy

Accuracies ranged from 96.7 to 100.0% (average 98.7%) in the control group, from 95.4 to 100.0% (average 98.3%) for the handball players and from 93.8 to 99.8%

(average 98.3%) for the action video game players. An ANOVA on errors with the between-subject factor group (controls vs. handball players vs. videogame players) and the within-subject factor configuration (repeated vs. novel) yielded a significant main effect of configuration [$F(1,87) = 10.976$, $p < 0.05$, $\eta^2\_G = 0.022$] due to higher accuracies for repeated (average 98.6%) than for novel displays (average 98.2%). Neither the main effect of group [$F(2,87) = 1.056$, $p > 0.05$, $\eta^2\_G = 0.019$] nor the interaction between group and configuration [$F(2,87) = 0.593$, $p > 0.05$, $\eta^2\_G = 0.003$] was significant.

### 3.3.4 Recognition Task

The control group reached a mean recognition accuracy of 50.4% (SD = 9.2%). Controls correctly reported repeated displays as 'repeated' (hit rate) on 45.2% (SD = 13.6%) of trials and erroneously categorized 44.4% (SD = 13.7%) of novel displays as repeated (false alarm rate). Hit and false alarm rates were not significantly different [$t(24) = 0.244$, $p > 0.05$], giving no indication that control participants were able to recognize repeated displays. In the control group the standardized contextual cueing effect did not significantly correlate with the recognition accuracy [$r = -0.156$, $p > 0.05$; Kendall's tau].

Mean recognition accuracy for handball players was 48.7% (SD = 13.5%) with a mean hit rate of 48.4% (SD = 19.4%) and a mean false alarm rate of 51.1% (SD = 16.8%). The difference between hits and false alarms was not significant [$t(24) = -0.556$, $p > 0.05$]. The normalized magnitude of contextual cueing correlated negatively with the recognition accuracy [$r = -0.275$, $p < 0.05$].

With respect to action video game players, a mean recognition accuracy of 49.3% (SD = 8.8%) was attained. The mean hit rate (52.1%, SD = 13.9%) was comparable to the mean false alarm rate (53.6%, SD = 14.1%). The comparison between hit and false alarm rates during recognition did not indicate that action video game players recognized repeated arrays [$t(24) = -0.448$, $p > 0.05$]. Recognition accuracy did not correlate with the normalized contextual cueing effect [$r = -0.017$, $p > 0.05$].

### 3.4 *Discussion*

Mean search times in Experiment 1 were shorter for both experimental groups in comparison to the control group. Search performance became faster for repeated relative to novel displays during the course of the experiment, indicating contextual cueing of visual search by repeated target-distractor configurations. However, we did not find increased contextual cueing in either handball players or action video game players compared with controls. Both handball players and action video game players, however, showed faster search times for both repeated and novel displays from the beginning of the experiment. The amount of general reduction of search times for both novel and repeated displays in the course of the experiment, indicating adaptation to the experimental setting, did not differ between groups.

In sum, both team sport athletes and action video game players were faster in detecting the target, but neither was better than the control group in using repeated spatial configurations for search guidance. Handball and action video game players even showed a trend for a smaller increase of the search advantage for repeated displays compared with the control group. This, however, is moderated by the overall faster search times of handball and video game players.

Results of Experiment 1 show that contextual cueing generalizes to sport-specific scenes with pseudo–3-D layouts. Similar findings have been reported by Brockmole and Henderson (2006) with real-world scenes and by Chua and Chun (2003) with pseudo naturalistic three-dimensional search arrays.

Furthermore, evidence for explicit learning of spatial context in this novel contextual cueing task was not observed. These findings are in line with previous research for two-dimensional (2-D) layouts (Chun and Jiang, 1998, 1999) and for three-dimensional (3-D) volumetric shapes (Chua & Chun, 2003). However, the evidence in favor of implicit contextual cueing is only tentative, because the statistical power of the recognition test - limited by the number of repeated displays - was far lower than that of the contextual cueing experiment (Vadillo et al., 2016).

# 4 Experiment 2: Handball players and action video game players did not demonstrate superior learning of arbitrary visuospatial scenes

The results of this experiment were first published in: Schmidt, A., Geringswald, F., & Pollmann, S. (2018). Spatial Contextual Cueing, Assessed in a Computerized Task, Is Not a Limiting Factor for Expert Performance in the Domain of Team Sports or Action Video Game Playing. *Journal of Cognitive Enhancement*, available online 1. Oct. 2018.

## 4.1 *Introduction*

Team sport athletes have shown superior performance in visuospatial attentional processing in a multitude of tasks (Mann et al., 2007). However, investigation with athletes often focus on sport-specific situations (Abernethy, 1991; Timmis, Turnmer, & van Paridon, 2014) making it difficult to infer general underlying processes.

There is a current debate in the expertise literature if basic cognitive skills can be improved as a function of prolonged practice in a certain field of expertise (e.g. sports, video game playing) or whether expert performance is domain specific. According to the narrow transfer hypothesis (Simons & Chabris, 2010), experts in activities such as team sports, action video game playing, or chess merely differ in cognitive abilities associated with their own performance environment (e.g. anticipation of ball directions in sport) and improvements in basic cognitive skills (e.g. memory capacity, intelligence) are not likely. On the other hand, there is evidence that expert performers are able to improve on a general cognitive level due to extensive training (Voss et al., 2010; Vestberg, Gustafson, Maurex, Ingvar, & Petrovic, 2012). This broad transfer hypothesis suggests that prolonged experience enables expert performers to enhance in basic cognitive skills and that those skills are translatable to different domains. Indeed, expert performers acquire specific knowledge in order to cope with specific constraints of their field of expertise (Starkes & Ericsson, 2003; Mann et al., 2007). But the question, if experts improve on a general cognitive skill level is still discussed.

A recent study, however, found improved skills in athletes in a neutral, non-sport specific task with substantial visuospatial demands (Faubert, 2013). In this study, professional team sport players and high-level amateur players showed steeper learning curves in a repeatedly presented multiple object tracking (MOT) task (Pylyshyn, & Storm, 1988) than nonathletic controls. Their superior performance led to the claim that “professional athletes as a group have extraordinary skills for rapidly learning unpredictable, complex dynamic visual scenes that are void of any specific context” (Faubert, 2013, p. 3).

Experiment 2 tested if high-level athletes or action video game players have superior context learning skills in neutral, abstract scenes. While the display in experiment 1 was designed to resemble a handball playing field in order to tap into a potential sport-specific contextual cueing advantage of the handball players, the goal of experiment 2 was to investigate if either handball playing or action video game playing may generalize to a contextual cueing advantage in arbitrary environments. Note, that these abilities were tested in a setting that is not sport-specific to see if athletes show generalized improvements of contextual cueing. In order to test this hypothesis, a "T" among "L" shape search was used (Chun & Jiang, 1998) to investigate contextual cueing.

## 4.2 *Methods*

### 4.2.1 Participants

A total of 75 healthy subjects (control: n=25, mean age = 25.1 years (18-32 years, SD = 4.31); handball players: n=25, mean age = 20.2 years (15-31 years, SD = 6.18); action video game players: n=25; mean age = 23.2 years (20-27 years, SD = 2.55) participated in Experiment 2. Eleven adult players (6 men, 5 women; 21-31 years, SD = 3.74) from a 3rd league handball team and 14 junior players (14 men; 15 years, SD = 0) playing in the A and B youth national league were recruited for Experiment 2. Action video game players (male = 11, female = 14) and controls (male = 22, female = 3) met the same criteria as in Experiment 1. Ten participants already participated in Experiment 1 (3 handball players, 7 video game players). We used two separate samples in Experiment 1 and 2 in order to eliminate learning effects across experiments.

### 4.2.2 Apparatus & Stimuli

Search displays contained one target (90° or 270° rotated T) and 11 distractors (0◦, 90°, 180°, 270° rotated L) with each item subtending 1.9° × 1.9°. An offset of 0.14° between the two segments of the L-shapes was chosen to increase search difficulty. The orientation of the target and the orientation of distractors were randomly chosen for each trial. A black cross (2.4° × 2.4°) at the center of the display was used as a fixation stimulus. Stimuli were black displayed on a gray background. The items were randomly positioned on four non-visible concentric circles with radii of 4°, 8°,12°, and, 16° each corresponding to 4, 12, 20, and, 28 equidistant possible item locations. As in Experiment 1 blocks comprised 24 trials, 12 for each configuration type (repeated vs. novel). The positions of the items were balanced across quadrants (i.e., each quadrant of the display always comprise three search items) and configuration type. The visual angle of the search display on the projection screen extended an area of 49.8° x 37.3°.

### 4.2.3 Procedure

Subjects were asked to search for the target letter T among L-shaped distractors and to specify as quickly and accurately as possible whether the stem of the T was pointing to the left or right by mouse button presses. Each participant completed a training block, one experimental session (20 blocks), and a recognition test. The procedure of Experiment 2 was identical to the first experiment (see Figure 9).

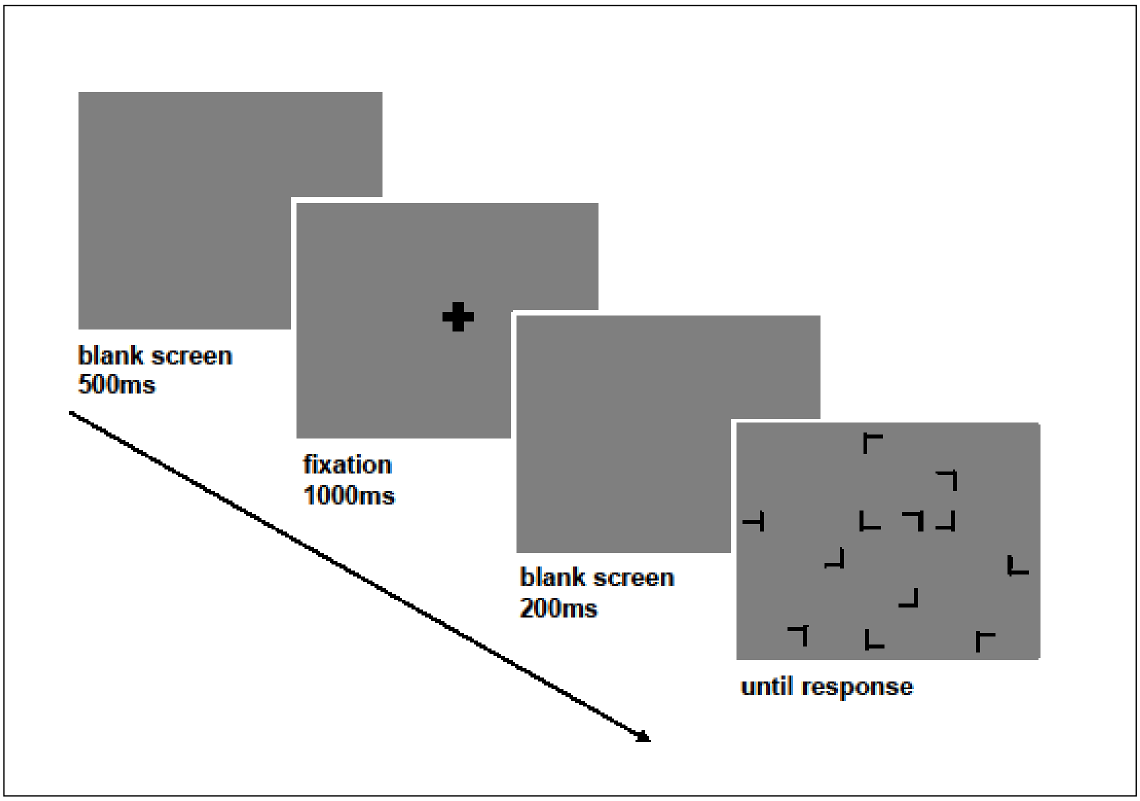

**Figure 9│ Procedure of an experimental trial in Exp. 2.** A trial consisted of the presentation of a blank screen [500ms], a fixation cross [1000ms], a blank screen [200ms], and the search display [presented until response].

### 4.2.4 Data Exclusion

Data exclusion criteria led to the rejection of 3.0% (SD = 1.6%) of invalid data for the control group, 3.4% (SD = 1.5%) for handball players, and 3.4% (SD = 2.4%) for action video game players.

## 4.3 *Results*

### 4.3.1 Search Times

As in Experiment 1, blocks were aggregated into four epochs, each containing five blocks, for the search time analysis (Figure 10). A repeated measures ANOVA with configuration (repeated, novel) and epoch (1, 4) as within-subject factors and group (control, handball, video) as between subjects factor was performed on search times.

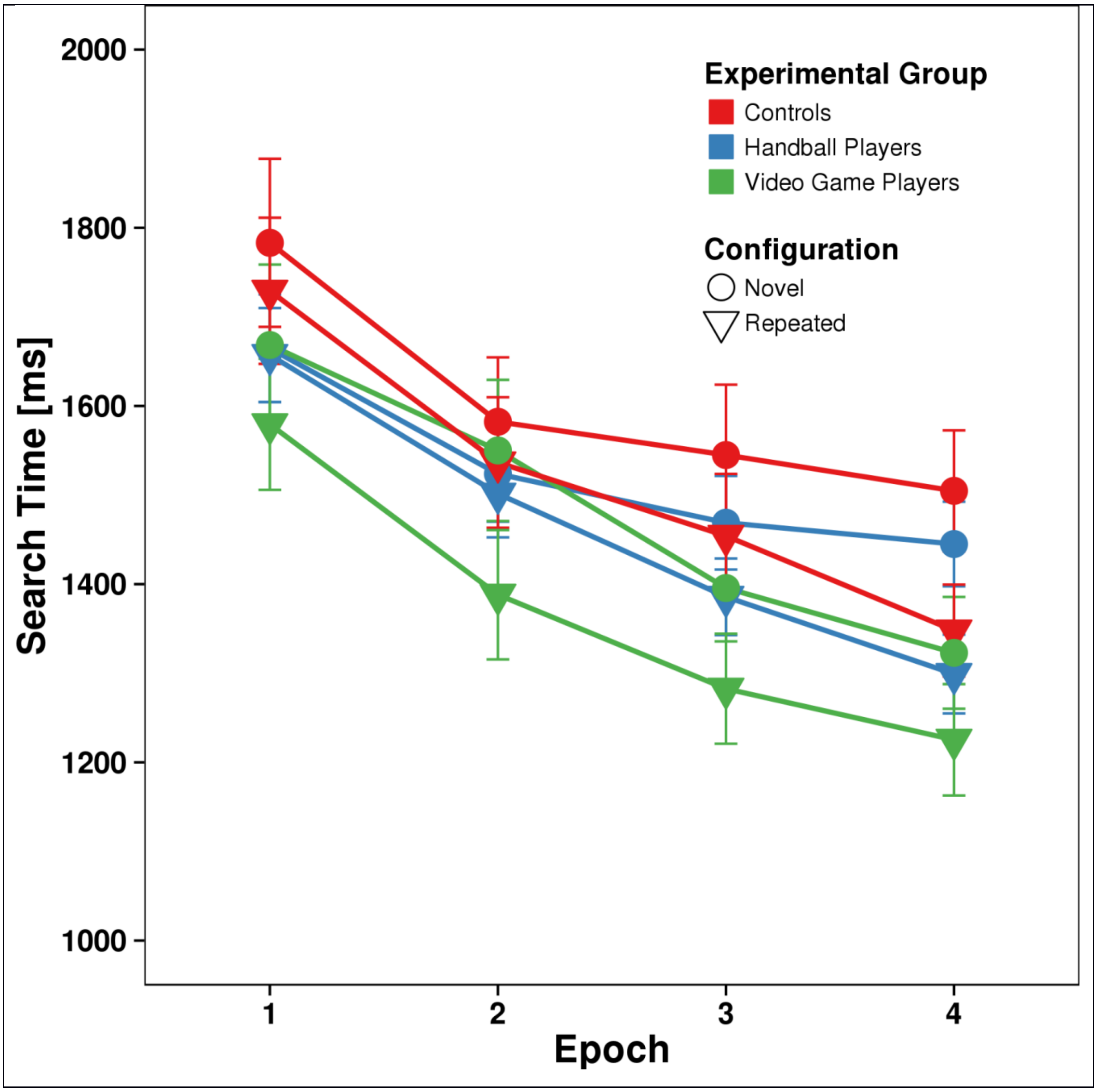

**Figure 10│ Experiment 2. Averaged search times in the visual search task for the three groups controls (red), handball players (blue), and action video game players (green) for repeated (triangles) and novel (circles) display as a function of epoch.** Error bars represent the standard error of the mean.

Significant main effects of epoch [$F(1,72) = 265.934$, $p < 0.05$, $\eta^2\_G = 0.192$] and configuration [$F(1,72) = 47.738$, $p < 0.05$, $\eta^2\_G = 0.019$] were observed. Search times decreased over time and were faster in the repeated displays (1473 ms) than in the novel displays (1565 ms). In contrast to Experiment 1, the main effect of group was not significant [$F(2,72) = 1.249$, $p > 0.05$, $\eta^2\_G = 0.030$], indicating that overall search speed was comparable between handball players (1517 ms), action video game players (1449 ms), and controls (1591 ms). A significant interaction between epoch and configuration [$F(1,72) = 12.872$, $p < 0.05$, $\eta^2\_G = 0.004$)] again reflects the increasing advantage for repeated displays over the course of the experiment. The other interactions were not significant [all $F < 2.78$, $p > 0.05$, $\eta^2\_G < 0.002$], revealing that the development as well as the overall magnitude of contextual cueing was comparable between groups.

In order to investigate if the variation of the search display had a specific effect on the handball players, an ANOVA on search times in Epoch 4 was run - after sufficient familiarization with the respective display type - across Experiments 1 and 2, with Experiment (1, 2) and group (handball, video) as between-subjects factors and configuration (repeated, novel) as within-subjects factor. Ten participants (3 handball players, 7 action video game players) who already participated in the first experiment were excluded in order to eliminate general learning effects across experiments. Significant main effects of experiment (Experiment 1 = 1102 ms, Experiment 2 = 1353 ms), $F(1,84) = 29.018$, $p < 0.05$ ($\eta^2\_G = 0.244$), and configuration, $F(1,84) = 49.176$, $p < 0.05$ ($\eta^2\_G = 0.037$) were observed. The latter again revealing that search in the repeated displays (1174 ms) was faster than search in novel displays (1258 ms). In addition, a significant interaction of experiment x configuration [$F(1,84) = 7.884$, $p < 0.05$, $\eta^2\_G = 0.006$] was found. The other interactions were not significant [all $F < 0.71$, $p > 0.05$, $\eta^2\_G < 0.005$]. In particular, the non-significant interaction between experiment x group, $F(1,84) = 0.489$, $p > 0.05$ ($\eta^2\_G = 0.005$), revealed that the variation of the search display had no effect on the handball players.

### 4.3.2 Age Differences

A repeated-measures ANOVA with the between-subject factor group (control, handball, video) performed on age reveal that groups differ significantly in age [$F(2,68) = 6.799$, $p < 0.05$]. The same age analysis as in Experiment 1 was applied to assess the effect of expertise level. With respect to age differences in the handball group, no group or interaction effects were significant [all $F < 1.39$, $p > 0.05$, $\eta^2\_G < 0.043$], indicating that both groups (junior and adult) did not differ in contextual cueing.

### 4.3.3 Accuracy

The accuracy of the control group ranged from 94.6 to 100.0% (average 99.2%). Regarding the test groups, the accuracies varied from 95.0 to 100.0% (average 98.5%) for handball players and from 87.5 to 100.0% (average 98.6%) for action video game players. A repeated measures ANOVA on errors with the between-subject factor group (control, handball, video) and the within-subject factor configuration (repeated vs. novel) revealed neither significant main effects of group [$F(2,72) = 1.017$, $p > 0.05$, $\eta^2\_G = 0.025$] nor configuration [$F(1,72) = 0.018$, $p > 0.05$, $\eta^2\_G = 0.000$] nor a significant interaction between group and condition [$F(2,72) = 0.162$, $p > 0.05$, $\eta^2\_G = 0.000$].

### 4.3.4 Recognition Task

The control group reached a mean recognition accuracy of 52.7% (SD = 9.5%). The mean hit rate (49.7%, SD = 15.7%) and the mean false alarm rate (44.3%, SD = 17.1%) did not differ significantly [$t(24) = 1.398$, $p > 0.05$]. Recognition accuracy did not correlate with the normalized contextual cueing effect [$r = -0.057$, $p > 0.05$].

Mean recognition accuracy for the handball players was 52.7% (SD = 9.5%) with a mean hit rate of 53% (SD = 11.8%) and a mean false alarm rate of 40.7% (SD = 15.5%). Hit and false alarm rates were significantly different [$t(24) = 3.201$, $p < 0.05$], suggesting explicit learning. The normalized contextual cueing effect, however, did not correlate with recognition accuracy [$r = -0.137$, $p > 0.05$].

Action video game players obtained a mean recognition accuracy of 59.8% (SD = 11.4%). Participants properly categorized repeated displays as repeated on 60.3% (SD = 14.9%) of trials and wrongly classified 40.7% (SD = 19.3%) of novel displays as repeated. The difference of hit rate and false alarm rate was significant [$t(24) = -4.312$, $p < 0.05$]. However, the correlation between the standardized contextual cueing effect and the recognition accuracy was not significant [$r = 0.206$, $p > 0.05$].

### 4.4 *Discussion*

Experiment 2 yielded the typical contextual cueing pattern, with faster search in repeated displays and an increasing search advantage for repeated displays over time across groups.

Thus, contextual cueing was observed in a standard T-among-L search task, in line with the literature on subjects without particular proficiency in sports or action video game playing. Overall, the groups did not differ in the amount of contextual cueing, measured as the search time advantage for repeated over novel displays. The handball players, whose search times in experiment 1 were faster than those of the control group, lost this advantage in experiment 2. This is most likely due to the lack of sport-specific displays in experiment 2. However, the current data revealed that display variation had no specific effect on handball players compared to action video game players and controls. It should be noted that for the specific question of variation of the search display, identical samples that completed both tasks in counterbalanced order would have been more useful. Using identical samples for experiments 1 and 2 might have reduced interindividual variability, but it would also have limited replication.

# 5 Experiment 3: Superior search performance of handball players and action video game players can be attributed to enhanced attentional processing

The results of this experiment were first published in: Schmidt, A., Geringswald, F., Sharifian, F., & Pollmann, S. (2018). Not scene learning, but attentional processing is superior in team sport athletes and action video game players. *Psychological Research*, available online 8. Oct. 2018.

## 5.1 *Introduction*

In addition to this specific scene learning effect, unspecific task learning effects can be assessed by the learning curves across novel and repeated displays in the contextual cueing task (see Chun & Jiang, 1998; Chun & Jiang, 1999; Jiang & Chun, 2001, Zhao et al., 2012). The nature of these learning effects can be broken down even further by assessing the slope and intercept of the search time function (response time as a function of the number of display elements; Kunar et al., 2007).

This analysis is based on a two-stage model of attentional processes, that are active during search and postselective processes that follow target selection. The slope indicates the increase of search times with increasing elements in the search display. It can be quantified as search time per item and thus gives an estimate of attentional processing speed. This should not be taken literally; shallower search slopes can reflect faster sequential search or more parallel search. For instance, the ability to process more items during a fixation (a larger attentional focus) would lead to shallower slopes. In the case of serial and parallel search alike, however, the search slope reflects the efficiency of the search. In contrast, the intercept of the search time function with the y-axis indicates the residual time needed for postselective processes that are independent of the number of display elements, in particular processes for preparing and executing the response.

If athletes or action video game players had an improved capacity for learning visuospatial configurations and using them for memory-guided search, increased search facilitation (reduction of search times) is expected in these groups relative to the control group in repeated compared to novel displays. If, alternatively, team sport athletes or action video game players have superior attentional capabilities independent of memory, they would be faster than controls in searching novel and repeated displays alike and, additionally, search slopes should be shallower than in normal controls. A third potential hypothesis would be improved response (including response preparatory) processes in team sport athletes and action video game players. This would lead to reduced intercept values of the search time function.

## 5.2 *Methods*

### 5.2.1 Participants

A total of 75 participants (control: n = 25 (10 men, 15 women), mean age = 24.4 years, SD = 3.4; handball players: n = 25 (15 men, 10 women), mean age = 21.5 years, SD = 7.1; action video game players: n = 25 (20 men, 5 women); mean age = 25.2 years, SD = 7.1) were recruited from the University of Magdeburg and the Olympic Training Center Saxony-Anhalt/Sportclub Magdeburg. The handball players consisted of 15 adult players (5 men, 10 women) from a 3rd league handball team and 10 junior players (10 men) playing in the A and B national youth league. Video game players and controls met the same criteria as in the previous Experiment. Twenty-one participants already participated in previous contextual cueing experiments, however, with different repeated displays (12 handball players, 9 video game players).

### 5.2.2 Apparatus & Stimuli

The apparatus and stimuli were the same as described in Experiment 2, except that set sizes were varied from 8 to 12 items. Half of the trials had a set size of 8 items, whereas the other half of trials comprise 12 items, presented in randomized order.

### 5.2.3 Procedure

The procedure of Experiment 3 was identical to the previous experiments (see Figure 11).

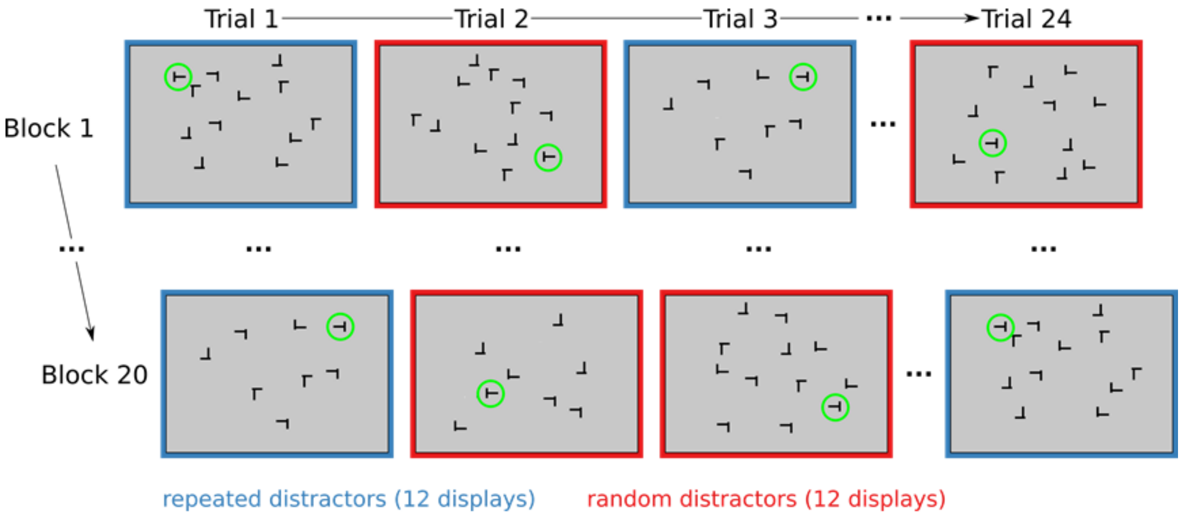

**Figure 11│ Procedure of an experimental trial in Exp. 3.** 20 blocks of 24 trials were presented. Blocks comprised 24 trials, 12 for each configuration type (repeated vs. novel). The red (novel displays) and blue (repeated displays) frames and the green circles indicating the targets are added for clarity, they were not visible during the experiment.

### 5.2.4 Data Exclusion

The same data exclusion criteria were used to analyze reaction time measures as in experiments 1 and 2, which led to the rejection of 4.4% (SD = 2.7%) of invalid data for the control group, 5.1% (SD = 3.9%) for handball players, and 5.6% (SD = 4.2%) for action video game players.

## 5.3 *Results*

### 5.3.1 Search Times

Search time analysis was identical to the preceding experiments. Blocks were aggregated into four epochs, each containing five blocks, for the search time analysis. Averaged reaction times for the four epochs for repeated and novel displays separated by the set sizes are depicted in Figure 12 for the three groups (control, handball, video). A repeated measures analysis of variance (ANOVA) with configuration (repeated, novel), epoch (1, 4), and set size (8, 12) as factors and group (control, handball, video) as between subjects factor was performed on search times.

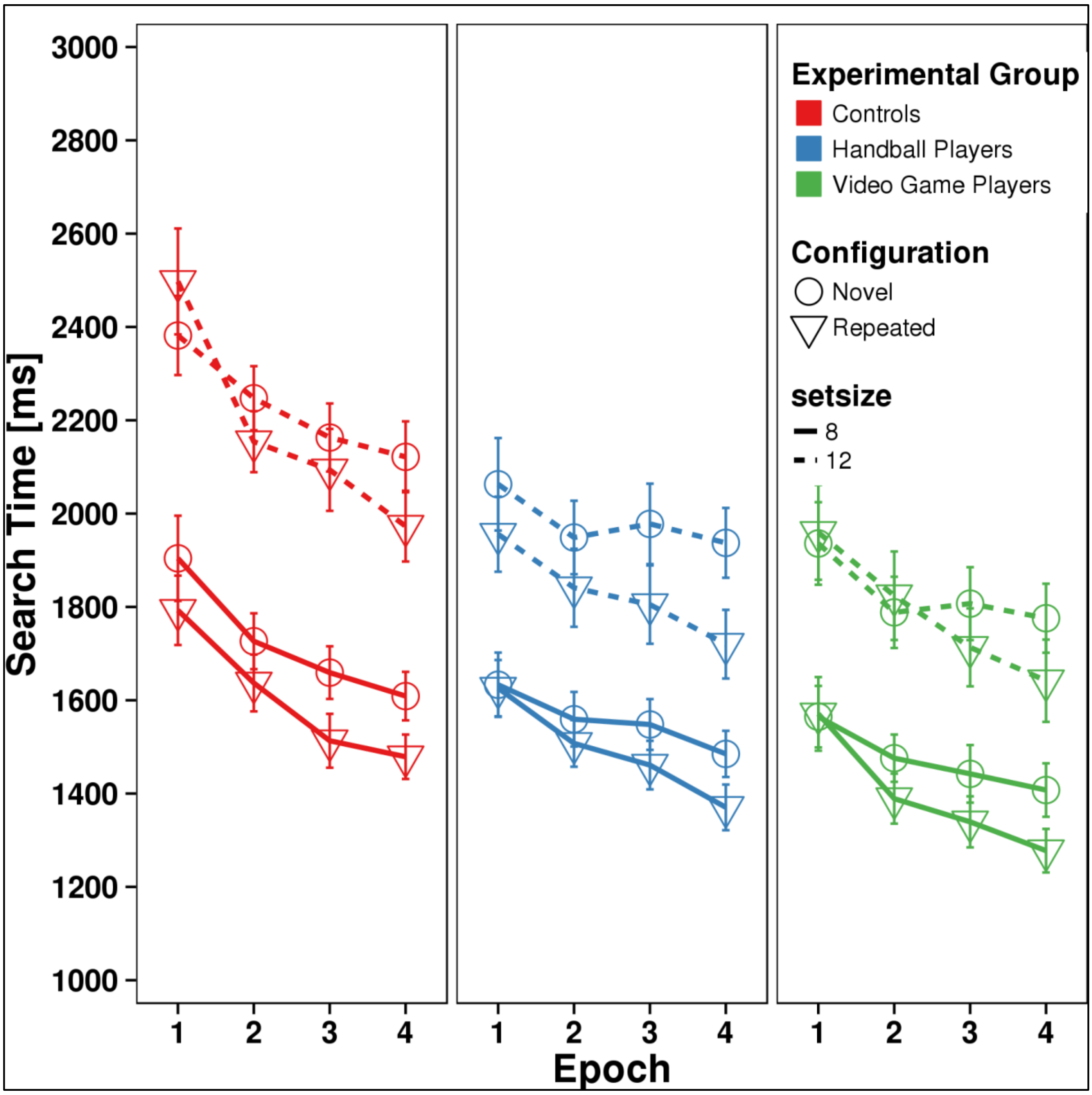

**Figure 12│Experiment 3. Averaged search times in the visual search task for the three groups controls (red), handball players (blue), and video-game players (green) for repeated (triangles) and novel (circles) display as a function of epoch.** Error bars represent the standard error of the mean.

A significant main effect of group [*F*(2,72) = 7.331, *p* < 0.05, *η2_G* = 0.123] was observed. Post-hoc t-tests indicated that overall search speed was comparable between handball players (1808 ms) and action video game players (1773 ms; *t*(47) = 0.909, *p* = 0.37). However, both groups outperformed controls (1998 ms; handball players vs. control: $t(48) = 2.890$, $p < 0.05$; action video game players vs. control: $t(48) = 3.566$, $p < 0.05$). The significant main effect of epoch [$F(1,72) = 97.494$, $p < 0.05$, $\eta2\_G = 0.107$] indicated general learning from the first (2100 ms) to the last epoch (1696 ms). Moreover, significant main effects of configuration [$F(1,72) = 29.047$, $p < 0.05$, $\eta2\_G = 0.011$] and set size [$F(1,72) = 350.173$, $p < 0.05$, $\eta2\_G = 0.257$] were found. Search times were shorter for repeated displays (1811 ms) than for novel displays (1892 ms) and for set size 8 (1557 ms) in comparison to set size 12 (2149 ms). The significant interaction of epoch x configuration [$F(1,72) = 25.287$, $p < 0.05$, $\eta2\_G = 0.008$] revealed contextual cueing.

Search times decreased by 318 ms in novel displays from the first to the last epoch and by 488 ms in repeated displays. Moreover, we observed significant interactions between group x epoch [$F(2,72) = 3.264$, $p < 0.05$, $\eta2\_G = 0.008$] and group x set size [$F(2,72) = 5.631$, $p < 0.05$, $\eta2\_G = 0.011$]. Handball and action video game players, beginning with shorter search times in Epoch 1, showed less search time reduction over epochs than controls. Larger set size slowed search much more in controls than in the other two groups. No other main effects or interactions were significant [all $F \leq 3.16$, $p > 0.05$, $\eta^2\_G < 0.003$].

The non-significant result for the critical group x configuration x epoch interaction - indicative of contextual cueing differences across groups – could be due to either equivalence of contextual cueing scores or lack of statistical power (Dienes, 2014). To investigate this alternative further, a Bayesian repeated measures ANOVA was calculated in JASP (JASP Team, 2018, Version 0.8.2) on the group x epoch interaction of the contextual cueing effect ((RT in novel displays - RT in repeated displays) / RT in novel displays) and obtained a $\mathrm{BF}_{01} = 12.03$, i.e. strong support for equivalence of contextual cueing scores across groups and epochs. Likewise, the group x epoch x set size interaction of contextual cueing scores yielded a $\mathrm{BF}_{01} = 7.28$, i.e. moderate support for equivalence of contextual cueing scores.

Some of the handball players and video game players had taken part in similar experiments before (see methods). To rule out that prior experience influenced the results, in particular the group main effect, an additional ANOVA was run, analogous to the one reported above, in which these participants were excluded (12 handball players, 9 video game players). Due to the reduced sample size, handball players and video game players were combined into one group. The ANOVA yielded a comparable pattern of results as in the main analysis, in particular a significant group main effect [$F(1,53) = 5.622$, $p < 0.05$, $\eta2\_G = 0.068$ ]. The only differences were a non-significant group × epoch interaction [$F(1,53) = 1.859$, $p > 0.05$, $\eta2\_G = 0.003$] and a significant four-way interaction [$F(1,53) = 8.274$, $p < 0.05$, $\eta2\_G = 0.003$], reflecting the strong search time reduction over time for repeated displays of large set size in the control group (Figure 12), as confirmed by separate ANOVAs on search times for the control group and the experimental groups (handball and video game players) with configuration (repeated, novel), epoch (1, 4), and set size (8, 12) as within-subjects factors. In addition to significant main effects of epoch [control group: $F(3,72) = 29.251$, $p < 0.05$, $\eta2\_G = 0.118$; experimental group: $F(3,87) = 22.788$, $p < 0.05$, $\eta2\_G = 0.056$], configuration [control group: $F(1,24) = 19.889$, $p < 0.05$, $\eta2\_G = 0.013$; experimental group: $F(1,29) = 22.288$, $p < 0.05$, $\eta2\_G = 0.013$] and set size [control group: $F(1,24) = 204.587$, $p < 0.05$, $\eta2\_G = 0.359$; experimental group: $F(1,29) = 154.997$, $p < 0.05$, $\eta2\_G = 0.226$], in the control group, significant interactions of epoch × configuration [$F(3,72) = 2.978$, $p < 0.05$, $\eta2\_G = 0.005$] and epoch × condition × set size [$F(3,72) = 2.771$, $p < 0.05$, $\eta2\_G = 0.005$] were found that were absent in the experimental group [all interactions $F \leq 2.60$, $p > 0.05$, $\eta^2\_G < 0.002$].

It might be argued that the lower search times that we observed in Epoch 1 for the athletes and video game players relative to the control group were potentially due to fast learning in Epoch 1 in the former two groups. To analyze this hypothesis, an additional ANOVA was run on the Epoch 1 search times with configuration (repeated, novel), block (1–5), and set size (8, 12) as within-subjects factors and group (control, handball players, action video game players) as between subjects factor. Significant main effects of group [$F(2,72) = 7.474$, $p < 0.05$, $\eta2\_G = 0.093$], block [$F(4,288) = 7.870$, $p < 0.05$, $\eta2\_G = 0.011$], set size [$F(1,72) = 299.923$, $p < 0.05$, $\eta2\_G = 0.153$], and a significant group × set size interaction [$F(2,72) = 7.891$, $p < 0.05$, $\eta2\_G = 0.009$] were observed. The group × condition × set size interaction narrowly missed significance [$F(1,72) = 3.077$, $p = 0.052$, $\eta2\_G = 0.005$]. All other effects were not significant [all $F \leq 1.490$, all $p > 0.16$, $\eta^2\_G < 0.005$]. Thus, importantly, no significant interactions involving group × block was observed that might indicate different learning rates of the groups in Epoch 1. We further investigated potential effects of sex on search time with an ANOVA with sex as between-subject factor and configuration, epoch and set size as withinsubject factors. This analysis yielded no significant main effect of sex [$F(1,73) = 0.138$, $p = 0.71$, $\eta2\_G = 0.001$] and no significant interactions involving sex [all $F < = 2.44$, $p > 0.12$, $\eta^2\_G < 0.003$].

### 5.3.2 Slopes and intercepts

For further analysis of the contribution of attentional and postselective processes contained in the search times, the slopes and intercepts of the search time × set size function (Figures 13,14) were investigated. A repeated measures analysis of variance (ANOVA) with configuration (repeated, novel), and epoch (1, 4) as within-subject factors and group (control, handball, video) as between subjects factor was performed separately on slope and intercept data.

*Slopes*

As an indicator for search efficiency, the slopes of the search time × set size regression lines were calculated. A main effect of group [$F(2,72) = 6.502$, $p < 0.05$, $\eta2\_G = 0.061$] on slopes was observed. No other main effects or interactions were significant (Table 4). Post hoc *t* tests revealed that mean search times per item were higher for controls (135 ms / display item) than for handball players [96 ms, $t(47) = 2.661$, $p < 0.05$] or action video game players [93 ms; $t(47) = 2.990$, $p < 0.05$], but did not differ between handball and action video game players [$t(48) = 0.317$, $p = 0.75$].

Again, the analysis excluding participants with prior experience in contextual cueing experiments was repeated. This ANOVA confirmed the significant group main effect [$F(1,53) = 4.531$, $p < 0.05$]. The only other significance was observed for the three-way interaction [$F(1,53) = 8.274$, $p < 0.05$], reflecting the large decrease of the search slope over time for repeated displays in the control group.

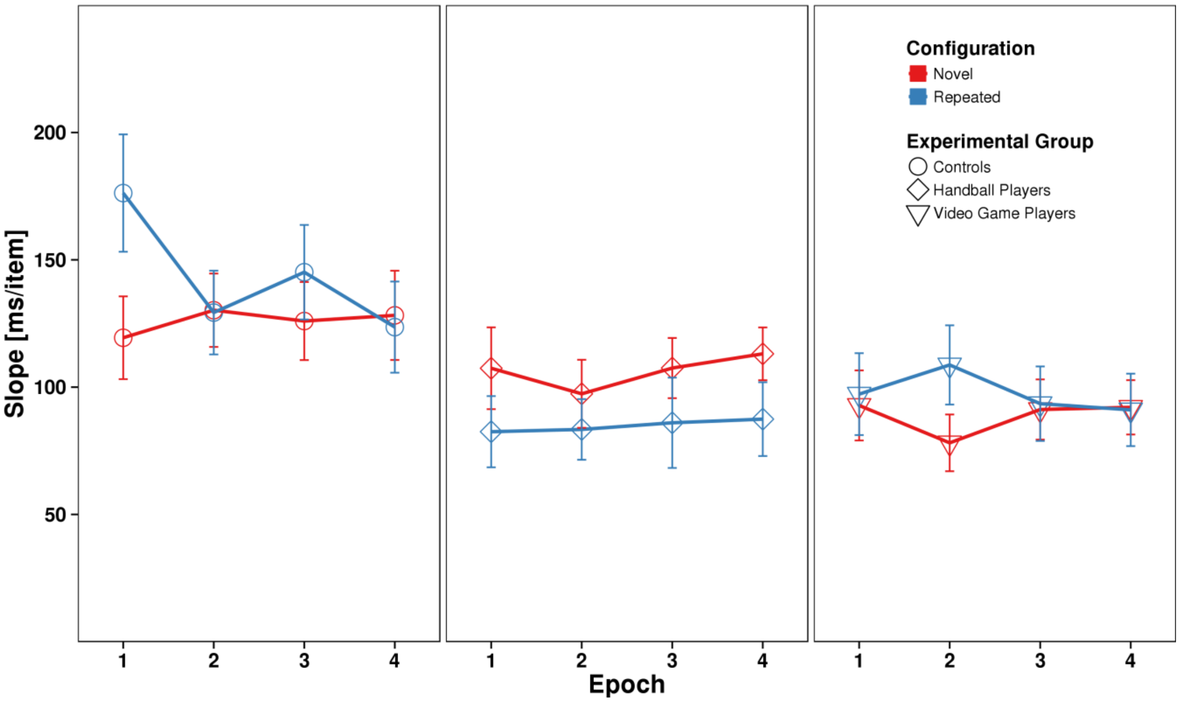

**Figure 13│ Mean search slopes of the regression line of search times.** Error bars represent the standard error of means. Slopes are plotted across epochs, each containing 5 search blocks, for controls (left), handball players (middle) and action video game players (right), separated for novel (red) and repeated (blue) search displays.

*Intercepts*

An analogous repeated measures ANOVA as for slopes was calculated on the intercepts. The intercept analysis revealed a significant main effect of epoch [$F(1,72) = 9.207$, $p < 0.05$, $\eta2\_G = 0.018$], indicating a reduction of intercepts over the course of learning. No other main effects or interactions were significant (Table 4).

An ANOVA excluding participants with prior experience in contextual cueing confirmed the significant main effect of epoch [$F(1,53) = 5.019$, $p < 0.05$]. The only other significant effect was observed for the three-way interaction, reflecting the increase of the intercept from Epoch 1–4 for repeated displays in the control group.

All statistical results of the between-group analyses of contextual cueing for slope and intercept data are reported in Table 4.

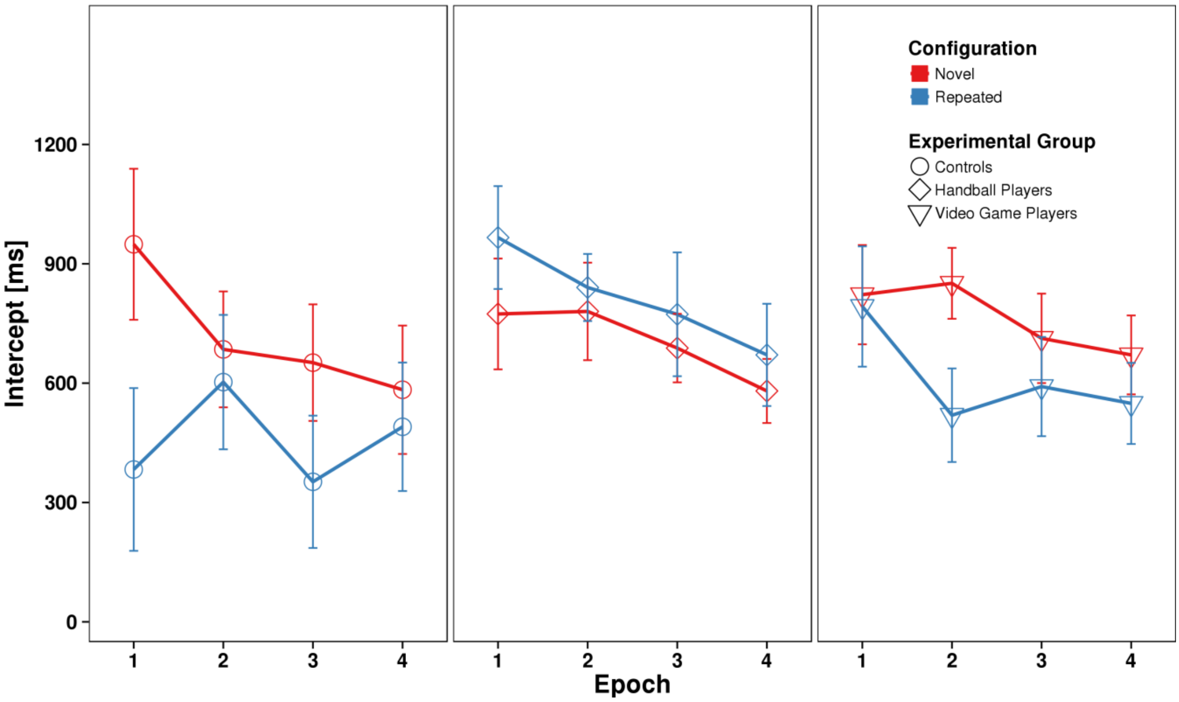

**Figure 14│ Mean intercepts of the regression line of search times.** Error bars represent the standard error of means. Intercepts are plotted across epochs, each containing 5 search blocks, for controls (left), handball players (middle) and action video game players (right), separated for novel (red) and repeated (blue) search displays.

**Table 4│Statistical results for slope and intercept data**

| | Measure | | | | | |
|---|---|---|---|---|---|---|
| | **Slopes** | | | **Intercepts** | | |
| Effect | F | p | $\eta^{2}_{G}$ | F | p | $\eta^{2}_{G}$ |
| Group | 5.63 | **.005** | .061 | 0.77 | 0.47 | .008 |
| Condition | 0.01 | 0.94 | .000 | 0.76 | 0.38 | .004 |
| Epoch | 1.08 | 0.30 | .002 | 9.21 | **.003** | .018 |
| Group:Condition | 1.99 | 0.14 | .018 | 1.82 | 0.17 | .018 |
| Group:Epoch | 1.56 | 0.22 | .005 | 0.28 | 0.75 | .001 |
| Condition:Epoch | 3.16 | 0.08 | .005 | 0.63 | 0.43 | .001 |
| Group:Condition:Epoch | 2.36 | 0.10 | .008 | 2.61 | 0.08 | .009 |

### 5.3.3 Age Differences

Independent samples *t* tests (Welch t test) on mean age between groups reveal significant differences on mean age for control group vs. handball players [$t(41) = 3.143$, $p = 0.003$] and for action video game players vs. handball players [$t(30) = -2.259$, $p = 0.031$]. The t test on mean age between control group and action video game players were not significant [$t(33) = 1.744$, $p = 0.09$]. The age differences between the handball players and the other groups were due to the group of junior handball players (see participants section).

To test for potential age effects on mean reaction times, an ANOVA with the within-subject factors configuration (repeated, novel) and epoch (1, 4) and the between-subject factor group (junior handball players, adult handball players) was calculated. While significant main effects of epoch [$F(1,23) = 16.553$, $p < 0.05$, $\eta2\_G = 0.064$], configuration [$F(1,23) = 13.704$, $p < 0.05$, $\eta2\_G = 0.023$], set size [$F(1,23) = 95.177$, $p < 0.05$, $\eta2\_G = 0.243$] and a significant interaction of epoch × configuration [$F(1,23) = 4.293$, $p < 0.05$, $\eta2\_G = 0.006$] replicated our analyses above, importantly, no significant main effect of group or interaction effects involving the group factor were observed [all $F \leq 3.11$, $p > 0.05$, $\eta^2\_G = 0.034$]. Thus, results reveal no evidence for an age effect.

### 5.3.4 Accuracy

Very high average accuracies were observed for all groups (98.1% for the control group, 97.1% for the handball players and 97.1% for the action video game players; Table 5). An ANOVA on the logit-transformed accuracy data with the between-subjects factor group (control, handball, video) and the within-subject factor configuration (repeated vs. novel) yielded no significant effects [all $F \leq 2.226$, $p > 0.05$]. To test for equivalence, an analogous Bayesian ANOVA on the logit-transformed accuracies was calculated. It yielded a $BF_{01} = 3.71$, i.e., moderate support for equivalence of accuracies between groups (main effect). The group × configuration interaction yielded a $BF_{01} = 6.37$, i.e., moderate support for equivalence of group effects across configurations.

Again, the analysis excluding participants with prior experience in contextual cueing experiments was repeated. High accuracies (96.5%) for the participants without experience were observed. The ANOVA on accuracy for the subgroup without prior experience confirmed the non-significant effects obtained for the whole group [all $F \leq 2.455$, $p > 0.05$].

**Table 5│Accuracy data by group and epoch**

| Group | Epoch | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Control group | 0.976 | 0.979 | 0.983 | 0.984 |
| Handball players | 0.960 | 0.970 | 0.976 | 0.976 |
| Video game players | 0.965 | 0.964 | 0.974 | 0.981 |

### 5.3.5 Recognition Task

The control group obtained a mean recognition accuracy of 58.7% (SD = 10.3%) with a mean hit rate of 58.7% (SD = 17.6%) and a mean false alarm rate of 41.3% (SD = 13.5%). Comparing hit and false alarm rates during recognition a significant difference was found [$t(24) = 4.1903$, $p < 0.05$], indicating explicit learning. However, the correlation between the standardized contextual cueing effect and the recognition accuracy was not significant [$r = 0.095$, $p > 0.05$].

Mean recognition accuracy for the handball players was 56.8% (SD = 13.2%). The mean hit rate of 56.7% (SD = 10.8%) and the mean false alarm rate of 43.0% (SD = 21.3%) differ significantly [$t(24) = 2.594$, $p < 0.05$], suggesting explicit learning. The normalized contextual cueing effect, however, did not correlate with recognition accuracy [$r = -0.047$, $p > 0.05$].

Action video game players reached a mean recognition accuracy of 52.2% (SD = 11.6%). Participants accurately categorized repeated displays as repeated on 49.0% (SD = 18.7%) of trials and wrongly classified 44.7% (SD = 11.8%) of novel displays as repeated. The difference of hit rate and false alarm rate was not significant [$t(24) = 0.933$, $p > 0.05$], revealing implicit learning. Recognition accuracy did not correlate with the normalized contextual cueing effect [$r = -0.615$, $p > 0.05$].

## 5.4 *Discussion*

The aim of Experiment 3 was to investigate if high-level amateur team sport players and action video game players show a superior visual search performance in arbitrary, non-sport specific search configurations. Moreover, to examine if attentive or non-attentive processes contribute to the contextual cueing effect, the original contextual cueing paradigm (Chun and Jiang, 1998) was conducted, in which visual search for a T-shape among arbitrary configurations of L-shaped distractors is tested. In addition, the number of display items was varied in order to calculate the slope and intercept of the regression line as indicators for search efficiency (search time per item) respectively for post-selective response preparatory and response execution processes (Kunar et al., 2007).

As in the previous experiments, all groups showed incidental learning with faster search in repeated displays over the course of the experiment. The groups did not differ overall in the amount of contextual cueing, measured as the search time advantage for repeated over novel displays.

Additionally, it was found that both handball players and action video game players searched faster than controls. This search time advantage was analyzed further in that we calculated search slopes, i.e. search time increase per display item, as a measure of search efficiency. Results of the control group reveal that contextual cueing is supported by a decrease in the search slope for repeated displays in comparison to novel displays rather than a decline in intercept times, indicating that contextual cueing guides spatial attention. Further, search slopes were shallower in both handball players and video game players, indicating that the members of both groups needed less time to analyze the contents of a search display than controls. This is in agreement with previous work that reported shorter search times per item in action video game players than controls in inefficient search tasks such as the one used here (Hubert-Wallander et al, 2011; Wu, & Spence, 2013). While slopes are defined by search duration per item, this should not be taken literally. Shallower slopes could mean faster sequential processing of the search display, but it could also mean faster parallel processing of the display, for instance using a larger attentional focus. We cannot distinguish between this alternative on the basis of the current data. However, this question could be addressed in future work using eye-tracking or reaction time modeling (e.g. Müller-Plath, & Pollmann, 2003). Our interpretation depends on the assumption of two - selective and post-selective - processing stages but other models are of course possible and may lead to different interpretations (Kristjansson, 2015).

In contrast, no difference between groups was observed regarding the intercepts of the search time regression curve with the y-axis. The intercept indicates fixed time "costs" that are independent of display size and may arise due to response preparation or execution. In the context of visual search, slopes and intercepts are usually interpreted as indicators of attentive and post-selective processes (e.g. Kunar et al., 2007). In this framework, the superior search performance of both athletes and video game players could be attributed to superior attentive processing. This pattern was confirmed when athletes with prior experimental experience were excluded from the analysis.

It should be noted that the improved search performance of the handball and action video game players was present from the beginning of the experiment and did not develop further over the course of the experiment. In fact, the control group showed a stronger search time reduction than the two experimental groups. Thus, the handball and action video game players already started with superior attentional capabilities and did not develop them with repeated stimulus exposure, in contrast to what has been reported in very demanding psychophysical tasks (Bejjanki et al., 2014).

# 6 General Discussion

Parts of the general discussion were first published in: Schmidt, A., Geringswald, F., & Pollmann, S. (2018). Spatial Contextual Cueing, Assessed in a Computerized Task, Is Not a Limiting Factor for Expert Performance in the Domain of Team Sports or Action Video Game Playing. *Journal of Cognitive Enhancement*, available online 1. Oct. 2018; Schmidt, A., Geringswald, F., Sharifian, F., & Pollmann, S. (2018). Not scene learning, but attentional processing is superior in team sport athletes and action video game players. *Psychological Research*, available online 8. Oct. 2018.

The experiments presented in this thesis examined if high-level team sport athletes and action video game players have superior context learning skills. A review of the literature on expert performance shows that expert performers such as elite team sport athletes or action video game players evolve superior perceptional, attentional, and cognitive skills through extensive training, improving their efficacy to process information (e.g. Eccles, 2006). These adaptations are required due to the speed of several sports or action video games which may go beyond basic information-processing capacities (Williams, Davids, & Williams, 1999). Implicit learning processes may allow expert performers more efficient decision-making and motor performance (Masters, 1992). Particularly, it may well be that team sport athletes have superior capabilities to learn scenes and use scene memory for attentional guidance when the same or similar scenes are repeatedly encountered. Handball players, for example, need to move in a particular direction or pass the ball to a specific team member in a fraction of a second to be successful players. Handball players face these situations repeatedly during a handball game. Thus, it could be that elite team sport athletes have extraordinary skills in learning spatial contexts and using context-knowledge for efficient attentional guidance in scenes that have been encountered before (Schmidt, Geringswald, Sharifian, & Pollmann, 2018). Recently, it has been claimed that athletes have extraordinary context learning skills that generalize to neutral, non-sport specific situations (Faubert, 2013).

The set of studies presented in this thesis examined if athletes or action video game players had an improved capacity for learning visuospatial configurations and using them for memory-guided search. In particular, we investigated if visual search performance in these groups benefits from superior search guidance and/or context learning abilities. In experiment 1, the search displays resembled a handball field, whereas in experiments 2 and 3, a symbolic T-among-L search (Chun & Jiang, 1998) was utilized.

Spatial configuration learning could be investigated due to the comparison of novel and repeated display configurations. Although context learning was incidental, i.e. participants did not know about display repetition, search times decreased more in repeated than novel displays over the course of the experiment. Thus, in all experiments all groups showed incidental learning of repeated displays, in line with many previous reports on this contextual cueing effect (Chun, 2000). However, handball players and action video game players did not differ from controls (nor from each other) in the amount of search facilitation in repeated configurations. Thus, the current data yield no evidence for superior context learning skills for expert handball players and action video game players.

In experiment 2 handball players and action video game players and in experiment 3 handball players and controls selected repeatedly presented displays with above-chance probability, indicating at least partial explicit memory. However, recognition accuracy did not correlate with the size of the contextual cueing effect (the search time reduction in repeated displays). Thus, there is no indication that contextual cueing was due to top-down controlled search based on explicit knowledge of the target location in repeated displays (Schmidt, Geringswald, Sharifian, & Pollmann, 2018).

Schmidt, Geringswald and Pollmann (2018) propose that the lack of a contextual cueing advantage contrasted with overall faster search times of the handball players in the sport-specific displays indicate that the superior search performance might be an effect from their training in handball rather than from central differences in basic cognitive abilities or any selection effect. However, in the third experiment (Schmidt, Geringswald, Sharifian, & Pollmann, 2018), the set size of the search displays was varied which allowing to differentiate search speed / item from postselective processes like response preparation. The results showed faster search (as an indicator of attentional processes) in handball players and action video game players, compared to controls. This advantage, however, was independent of contextual cueing, which again was not superior in the athletes and action video game players. In this framework, the superior search performance of both athletes and video game players could be attributed to superior attentive processing. Nevertheless, results have to be interpreted with caution. Additional tests of cognitive and/or specific attentional abilities might add to the understanding of the faster search times. For instance, future studies may use response-time modeling and eye-tracking technology to further investigate attentional parameters like attentional focus size, dwell time and movement speed (Müller-Plath, Ott, and Pollmann, 2010). Moreover, the use of separate tests (e.g., computerized cognitive tasks or neuropsychological assessments) might broaden the scope of the findings. However, please note that the focus of the present study was the investigation of incidental context learning skills (Schmidt, Geringswald, & Pollmann, 2018).

The selectively faster search times of the handball players for search in experiment 1 suggest that it was partly successful to create sport-specific displays. However, displays in the current study did not resemble real configurations of players that occur in a handball game. Thus, it cannot be excluded that handball players might have shown improved contextual cueing compared with controls in more realistic handball scenes (e.g. scenes from a real handball game). In fact, several studies in the field of sport (e.g. Mann et al., 2007; Memmert, Simons, & Grimme, 2009) showed that expert advantages often disappear in non-specific settings, suggesting training effects rather than superior sensory or attentional capacity as a cause for the performance benefits of experts. For example, the use of two- and pseudo three-dimensional static displays in the present study may not appropriately reflect the dynamic character of sport due to a limited viewing angle and/or missing peripheral information, which are required for adequate decision making. The use of virtual reality (VR) may improve the ecological validity of stimulus presentations, granting more stimulus control than static displays (see Tenenbaum & Eklund, 2007). Mann and colleagues (2007) found evidence that field-based studies have produced the greatest expert-novices’ differences. Therefore, investigating the dependence of context learning skills in realistic situations (e.g. with VR technology) represents an important future direction. But please note that the purpose of the present study was to investigate if proficiency in handball or action video games goes along with context learning skills that transfer to situations outside of the area of expertise (Schmidt, Geringswald and Pollmann, 2018; Schmidt, Geringswald, Sharifian, & Pollmann, 2018).

Additionally, the response – a button press – that is not a required skill for handball playing may have attenuated or even eliminated a sport-expert advantage in that handball players were not able to adequately link stimulus characteristics to response selection (Mann et al., 2007). Handball players have a different perception-action linkage in an actual game situation, when reacting to the action of another handball player, then in an experiment where the athlete has to look at static displays of a pitch and responds with button presses. Indeed, several studies suggest that the ecological validity of an experiment influences expert performance. For example, Oudejans, Michaels, and Bakker (1997) reported superior expert performance in baseball catching decisions only when real catching was required. Real game situations may have a higher ecological validity to reproduce the expert advantage (Mann et al., 2007). Indeed, Thomas, Gallagher, and Lowry (2003) reported in a meta-analytic review that a high ecological validity of the experimental setting is accompanied by larger effect sizes. The more ecologically valid the stimulus presentation, the higher may be expert-novices’ differences (Tenenbaum & Eklund, 2007).

In addition, effects of expertise in sport may be also modulated by different methodological factors such as sport type, level of expertise, and sex (Nougier, Ripoll, & Stein, 1989). As in previous studies, we had a sex imbalance between groups, mainly due to the male dominance among the action video game players which may potentially influence the results. However, regarding the effect of gender differences, different studies reveal that sport expertise reduces traditional gender effects (Alves et al., 2013; Lum, Enns, & Pratt, 2002). Likewise, gender differences could be nearly removed by video game training (Feng et al., 2007). Regarding the level of expertise, the majority of participants of our study were junior athletes. Thus, it might be argued that their level of expertise was not sufficient to detect potential differences in contextual cueing compared to non-athletes. Likewise, the adult athletes playing at a regional level (3rd handball league) are probably less skilled than athletes performing at a national level and above. Nevertheless, the adult athletes in the current study fulfill the ten years' rule of Simon and Chase (1973). Research on expertise in sport reveal that ten years or 10.000 hours of experience and practice in a certain domain are required to develop expert performance (see Ericsson et al., 2006, for a recent review). Indeed, we could rule out effects of age and prior experience with psychological experiments as factors of influence (Schmidt, Geringswald, & Pollmann, 2018).

In contrast, action video game players had overall shorter search times than controls in experiments 1 and 3 in accordance with previous research (Dye, Green, & Bavelier, 2009b). Improved eye-hand coordination in a computer setting is probably not sufficient to explain the reaction time advantage of video game players (Chisholm et al., 2010). Further contributing factors may be improved allocation of spatial attention (Feng et al., 2007; Green & Bavelier, 2003, 2006a) or superior visuospatial resolution (Green & Bavelier, 2007; Greenfield et al., 1994). Training studies suggested a causal relationship between action video game experience and enhanced visual and cognitive performance (see Green & Bavelier, 2003; Li, Polat, Makous, & Bavelier, 2009) due to enhanced attentional processes and the management of resources (Green & Bavelier, 2012). The greater capacity of attention for action video game players, however, is still debated (see Irons, Remington, & McLean, 2011; as cited in Schmidt, Geringswald, & Pollmann, 2018).

Several caveats should be considered regarding superior performance of athletes or video-game players. In the present study, we needed to rely on open recruiting of semi-professional handball players, because they would not occur frequently enough in a random sample. Selection of special groups, however, may go along with the motivation to perform well (Boot et al., 2011). Particularly, because reports of superior performance, mainly of video game players, have been published in the general media. However, the accuracy data yielded no indication of a speed-accuracy trade-off. Nevertheless, we cannot completely exclude that search speed was more affected by motivation than contextual cueing, perhaps because the former is an evident goal of a search task, whereas display repetition is not announced and often not consciously perceived, or only perceived late during the task.

Moreover, results did not indicate if the superior search performance of the handball players and action video game players is a training or a selection effect. Longitudinal studies would be needed to investigate if handball or action video game training leads to improved search performance. Alternatively, it may be that persons with superior attentional processing skills are more likely to become successful handball or action video game players (Kristjansson, 2013).

Furthermore, the current findings do not imply that handball players may not have better memory-guided search in realistic handball scenes. In fact, across many studies, sport-specific displays, stimuli, and processing requirements were more likely to lead to expert-novice differences (Abernethy, 1987b, 1988; Mann et al., 2007). Results of this study, however, do not support the view that handball players or video game players have better memory-guided search outside of their domains of expertise.

To conclude, previous reports of faster visual search in athletes and in action video game players could be replicated. In addition, it was found that the superior search speed was due to faster attentional processing, whereas response-related processes did not differ from the control group. In contrast, handball players or action video game players showed no better-than-normal attentional guidance by learned spatial contexts (Schmidt, Geringswald, Sharifian, & Pollmann, 2018).

### Practical Implications for Implicit Methods in Sports

In the sports domain, the training of perceptual skills has been mostly encouraged by an explicit mode of learning. Why is it valuable to apply a more implicit form of learning in sports? From an applied perspective, there might be some potential advantages of implicit training in the sports domain. For example, Allen and Reber (1980) argued that the retention of implicitly learned information is enhanced over an elongated period due to profounder implicit encoding, improving the storage of the information (Reber, 1989). Moreover, Masters (1992) found evidence that implicitly learned motor skills were more stable under stressful conditions compared to explicitly learned abilities. Indeed, several studies could demonstrate that explicit learning skills failed under stress (Beilock & Carr, 2001; Gray, 2004; Masters, 1992). Explicit knowledge is rule-based; thus, consciously processing of explicit knowledge may impede automatic processing. Consequently, performance is decelerated and requires much endeavor. In contrast, implicit processes are automatic and independent of working memory. As a consequence, performance is rapid and effortless, allowing more efficient decision making and motor performance (e.g. improved force development; see Masters, 1992). Thus, implicitly learned skills may increase the opportunity that high-level athletes will endure the pressure on an elite level. In addition, Farrow and Abernethy (2002) propose that implicit training may be beneficial during skill acquisition by avoiding an overload of the processing capacities of the performer due to the reduction of explicit rule development. However, the capability of implicit learning approaches still needs to be established in the sports domain.

Generally, this study has extended the contextual cueing and expertise literature and shed some light on incidental context learning in experts, including theoretical and practical implications, and proposing some possible ways for future research on attentional processes underlying contextual cueing.

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