Review

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Fewer fixations of longer duration? Expert gaze behavior revisited

The path to expertise in sports is a fascinating and elusive process which has been studied in a fair number of (sport) scientific disciplines (for current overviews see Baker & Farrow, 2015; Farrow, Baker, & MacMahon, 2013). Research indicates that, in addition to physiological, emotional, and technical skills, skilled athletes develop superior perceptual–cognitive skills which refers to the ability to locate and identify visual information in the environment for the selection and execution of actions (Broadbent, Causer, Williams, & Ford, 2015). In this regard, it has been shown that skilled athletes are better able to anticipate opponents' actions (e.g., Abernethy & Russell, 1987; Ward, Williams, & Bennett, 2002; Williams & Burwitz, 1993) which results in improved decision making (e.g., Hancock & Ste-Marie, 2013; Starkes & Allard, 1993) and motor performance (e.g., Roca, Ford, McRobert, & Williams, 2013; Ward & Williams, 2003; Williams & Ward, 2007). As a fundamental prerequisite, it has been suggested that skilled athletes develop distinct gaze behavior and optimize visual information processing which allows an optimal coupling between perception and action. Thus, studying eye movements in skilled athletes not only might provide practitioners with valuable guidelines for training and diagnosis but also could give unique insights into underlying processes of complex movement behavior. Consequently, over the last few decades eye-tracking research has been increasingly applied in sports (Kredel, Klostermann, Vater, & Hossner, 2017) and in high-level athletes (Hüttermann, Noël, & Memmert, 2018).

It has been found that skilled athletes, indeed, deploy different gaze behavior (for an overview on gaze variables obtained in eye-movement research, e.g., Rayner, 1998) when compared to lesser-skilled athletes. For example, Bard and Fleury (1976) found that experienced and less-experienced basketball players differed in the number of fixations when solving offensive problems in basketball game-play situations. Likewise, Ripoll, Kerlirzin, Stein, and Reine (1995) revealed differences in number but also duration of fixations when comparing experts vs. intermediates vs. novices in a decision-making task in boxing. Moreover, skilled athletes seem to deploy different search strategies as revealed by Vickers (1988) who analyzed gaze behavior in skilled and less-skilled athletes while studying gymnastic sequences as well as by Savelsbergh, van der Kamp, Williams, and Ward (2005) who studied goalkeepers in a soccer-penalty task (for a systematic review on visual perception and gaze behavior in soccer, McGuckian, Cole, & Pepping, 2018). Mann, Williams, Ward, and Janelle (2007) as well as Gegenfurtner, Lehtinen, and Säljö (2011) summarized those findings in meta-analyses and based on more than 250 effect sizes it was concluded that skilled athletes show (1) fewer fixations of (2) longer durations to (3) different and more task-relevant information sources. In addition, skilled athletes were found to show (4) longer quiet eye (QE) durations, i.e., the final fixation or tracking gaze at a task-relevant location prior to the initiation of the final phase of the movement (for a recent overview, Vickers, 2016).

However, there always has been research that could not reveal unique expert gaze behavior (e.g., Abernethy, 1990) and, over the last decade, this number of studies seems to have increased as exemplified by Hossner, Klostermann, Kredel, Schläppi, and Vater (2019) in decision-making tasks (see also Krzepota, Stepiński, & Zwierko, 2016; Loffing, Sölter, Hagemann, & Strauss, 2015; North, Williams, Hodges, Ward, & Ericsson, 2009) and by Fischer et al. (2015) in targeting tasks (see also Klostermann, Panchuk, & Farrow, 2018). In the systematic review by Kredel et al. (2017), it was suggested that due to advancements in eye-tracking methodology sport scientists increasingly strive for high measurement accuracy which still has been shown as a limiting factor in eye-tracking research, in particular when applying video-based eye-tracking technology (Orquin & Holmqvist, 2018). Among others, the number of test trials has been found as a threat to validity in eye-tracking research on decision-making (Schulte-Mecklenbeck, Fiedler, Renkewitz, & Orquin, 2017) which, however, also applies to eye-tracking research in sports (Kredel et al., 2017). Therefore, the increasing ambiguity in the literature might explained by technical advancement in eye-tracking technology and analyses methods which nowadays provide more reliable gaze data (Kredel et al., 2017) and, in addition, allows testing in more representative environments (Hüttermann et al., 2018) which has been found to essentially affect gaze behavior (e.g., Dicks, Button, &

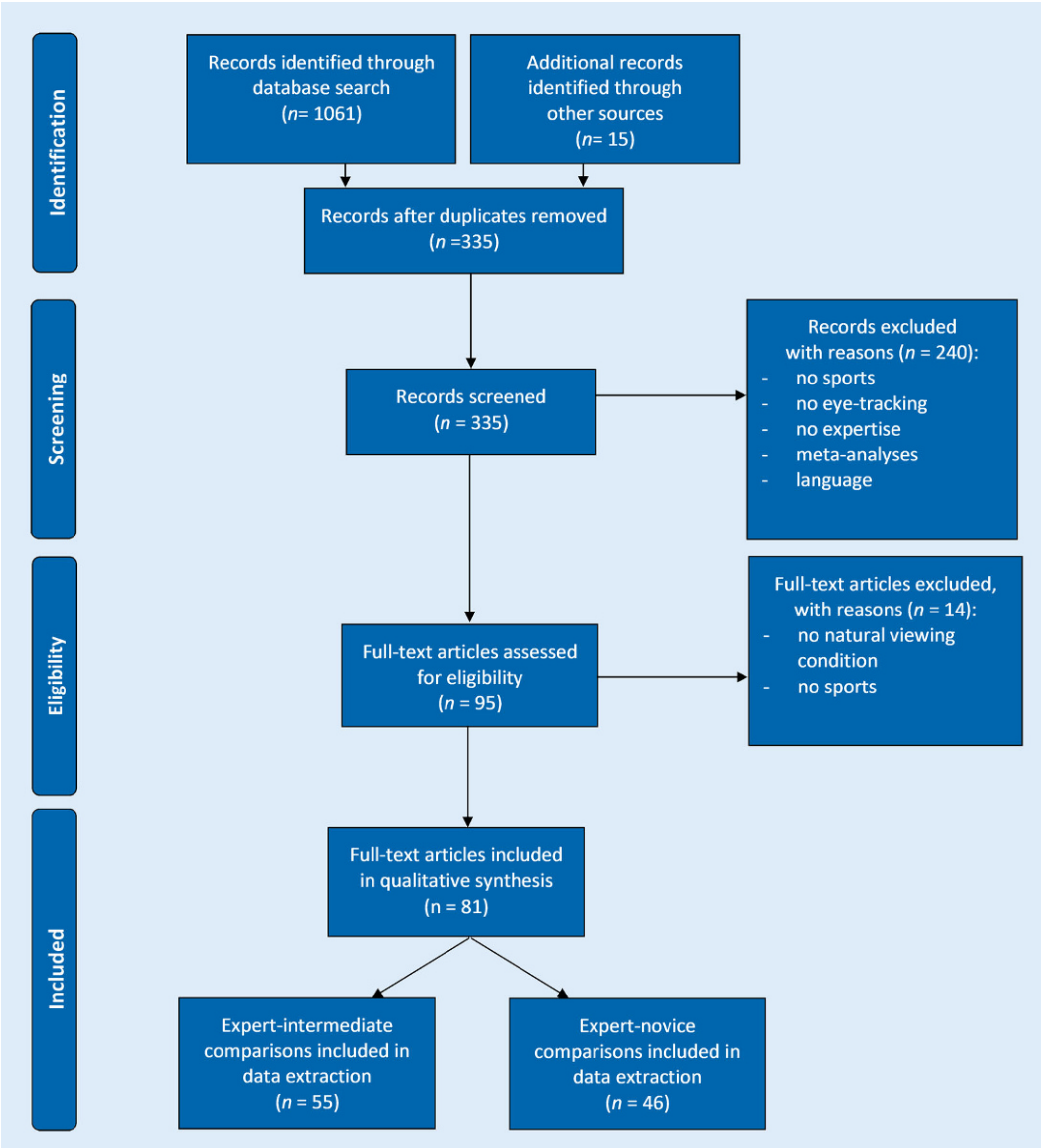

Fig. 1 ◄ Flow diagram depicting the selection of relevant literature from identification to final inclusion of eye-tracking studies on expert gaze behavior (1976–2017). (PRISMA 2015 flow diagram, adapted from Shamseer et al., 2015)

Davids, 2010; Maarseveen, Oudejans, & Savelsbergh, 2015).

Given this and knowing that since the last meta-analysis by Gegenfurtner et al. (2011) the total number of studies on expert gaze behavior in sports increased by more than 40% (Kredel et al., 2017), an updated literature overview on expert-related differences in gaze behavior seems necessary. Consequently, in the current study sports-related eye-tracking literature was reviewed. However, different to other recent reviews and meta analyses that addressed aspects like eye-tracking technology (Kredel et al., 2017), experimental settings in eye-tracking research (Hüttermann et al., 2018) or reviewed eye-tracking only for one sport (McGuckian et al., 2018) and one gaze variable (Lebeau et al., 2016), the current review focused on skill-related differences in the four classical gaze variables fixation duration, number of fixations, gaze location, and QE duration. As in earlier reviews, possible moderation by the factors stimulus and response mode as well as type of sports and type of task were considered. We expected to find a larger number of studies showing (1) longer fixation durations, (2) fewer number of fixations to (3) different locations and (4) longer QE durations for skilled when compared to lesser skilled athletes (e.g., Mann et al., 2007). In addition, it was expected that these differences were mediated by the representativeness of the experimental design, i.e., increased differences between experts and intermediates as well as experts and novices the higher the representativeness of the experimental task (e.g., Gegenfurtner et al., 2011).

Methods

As depicted in **Fig. 1**, this systematic review was conducted following the guidelines of PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses; Shamseer et al., 2015).

Literature search

For the literature search, the following electronic databases were used: Web of Science, PubMed Central, SPORTDiscus and ScienceDirect. In each of these databases, the keyword sport was combined with each of the following keywords: "gaze behavi*r", "eye tracking", "visual search", "visual attention", "eye movement", "visual behavi*r", "quiet eye", "expertise", "expert", and "novice" (March 2017). Further studies were identified as cited references in relevant articles, cross-references, as well as from current literature reviews (e.g., Kredel et al., 2017).

Inclusion and exclusion criteria

For the systematic review, we included studies if they (a) analyzed athletes gaze behavior, (b) compared athletes of different expertise levels, (c) were written in the English language, and (d) were published in peer-reviewed journals. Studies were excluded if they did not study sports, reported meta-analyses and reviews, did not apply eye-tracking, reported perceptual-training studies and studies using non-natural viewing conditions. Non-natural viewing conditions refer to studies that applied occlusion paradigms (e.g., Abernethy & Russell, 1987), moving-window paradigms (e.g., Schorer, Rienhoff, Fischer, & Baker, 2013), and slower as well as faster replay speed in video presentation (e.g., Moreno, Saavedra, Sabido, Luis, & Reina, 2006). These experimental manipulations have been shown to affect gaze behavior (e.g., Ryu, Abernethy, Mann, Poolton, & Gorman, 2013) and, thus, might impact the overall findings.

Identification, screening, and eligibility

With the criteria specified above, 1061 full-text articles were identified from the electronic database search and additional 15 full-text articles through other sources. After removing the duplicates, the abstracts of the remaining 335 full-text articles were screened and removed from further analyses if (a) no eye-tracking was applied, (b) no empirical study

Abstract · Zusammenfassung

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Fewer fixations of longer duration? Expert gaze behavior revisited

Abstract

In the current study, we investigated gaze behavior in sports by reviewing expertise-related differences in fixation duration, number of fixations, gaze location, and quiet eye duration. The review was conducted following the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines and included a total of 101 studies. Applying the vote-counting procedure, differences in gaze variables were aggregated as a function of the total number and the publication year. Moreover, for fixation duration and number of fixations an effect-size analysis was conducted. For gaze location and quiet eye duration, different gaze behavior in experts was found, in particular, when compared to novices. However, for fixation duration and number of fixations the results were less clear. Overall, there were more studies with nonsignificant results than studies with significant (positive and negative) results. These findings were confirmed by the effect-size analysis with average effect sizes in 2017 being small or just above the null effect (fixation duration: $d = 0.21$; number of fixations: $d = 0.01$). There was only minor mediation by the factors representativeness of the experimental design, type of sports, and type of task. Overall, the findings suggest that the empirical evidence on expertise-related differences in gaze behavior declined in recent years. Rather, the expert advantage in cognitive and motor tasks might be better explained with an optimal perception–action coupling.

Keywords

Review · Quiet Eye · Visual search · Elite athletes · Perception

Weniger Fixationen von längerer Dauer? Expertenblickverhalten unter der Lupe

Zusammenfassung

Das vorliegende systematische Review untersucht das Blickverhalten im Sport mit spezifischem Fokus auf expertisebedingten Unterschieden in den Blickvariablen Fixationsdauer, Anzahl Fixationen, Blickort und Quiet-eye-Dauer. Die Selektion der Beiträge erfolgte nach den PRISMA-Richtlinien, und in die finalen Auswertungen konnten 101 Studien eingeschlossen werden. Die Blickvariablen wurden mittels Vote-counting-Verfahren analysiert und in Abhängigkeit von Gesamtzahlen sowie Publikationsjahren aggregiert. Für die Blickvariablen Fixationsdauer und Anzahl der Fixationen wurden zusätzlich Effektgrößenschätzungen durchgeführt. Insbesondere im Vergleich zu den Novizen konnte für die Experten in den Variablen Blickort und Quiet-eye-Dauer ein unterschiedliches Blickverhalten gefunden werden. Hingegen zeigten sich für Fixationsdauer und Anzahl Fixationen keine eindeutigen Expertiseunterschiede, da mehr Studien mit nichtsignifikanten als signifikant-positiven und signifikant-negativen Unterschieden vorlagen. Dieses Ergebnis wurde auch durch die Effektgrößenschätzungen bestätigt, sodass sich 2017 die Effekte nur noch auf einen kleinen Effekt bzw. auf einen Nulleffekt aggregieren (Fixationsdauer: $d = 0{,}21$; Anzahl Fixationen: $d = 0{,}01$). Die Faktoren Repräsentativität des experimentellen Designs, Sportart und Aufgabenart hatten nur einen geringen Einfluss auf diesen Befund. Zusammenfassend kann gesagt werden, dass die empirische Evidenz für expertisebedingte Unterschiede im Blickverhalten in den letzten Jahren zurückgegangen ist. Vielmehr mag der Expertenvorteil in kognitiven und motorischen Aufgaben durch eine optimale Wahrnehmungs-Handlungs-Kopplung-Wahrnehmung erklärt werden.

Schlüsselwörter

Review · Quiet Eye · Visuelles Suchverhalten · Experten · Wahrnehmung

Table 1 Summary of the descriptors

Description	Feature	Definition	Example
Sample	Expertise	Level-of-expertise comparison	E-I
	Size	Means size of the sample for the varying expertise levels	E: 8; I: 8
	Age	Mean age of the sample for the varying expertise levels	E: 23.0; I: 27.1
	Training years	Mean number of training years for the varying expertise levels	E: 11.9; I: 3.8
Research method	Facility	Research facility: lab vs. field study	L
	Stimulus	Mode of the stimulus presentation: I vs. VP vs. IS	VP
	Response	Mode of the response given: W vs. V vs. B vs. R	R
Research task	Sport	Researched kind of sport	Net and wall games
	Task	Researched kind of task	Decision making
Gaze measure	FD	Fixation duration: 1 (experts with significant longer fixation duration) vs. 0 (no significant difference) vs. –1 (experts with significant shorter fixation durations) vs. x (not measured)	0
	NF	Number of fixations: 1 (experts with significant fewer number of fixations) vs. 0 (no significant difference) vs. –1 (experts with significant more number of fixations) vs. x (not measured)	0
	QED	Quiet eye duration: 1 (experts with significant longer QE duration) vs. 0 (no significant difference) vs. –1 (experts with significant shorter QE duration) vs. x (not measured)	x
	GL	Gaze location: 1 (experts with significant different gaze positions) vs. 0 (no significant difference) vs. x (not measured)	1

Stimulus mode: *I* images, *IS* in situ, *VP* video presentation
Response mode: *B* button-press, *R* real response, *V* verbal response, *W* watching
Level: *E-I* Expert-intermediate comparison, *E-N* Expert-novice comparison, *E* experts, *I* intermediates, *N* novices

was conducted, or (c) the manuscript was not written in the English language. Over this screening process another 240 full-text articles were removed. In the eligibility phase, the remaining 95 full-text articles were screened by two independent raters and another 14 studies had to be excluded because of non-natural viewing conditions and because of no sport objectives. Overall, 81 full-text articles were included with 9 articles presenting two studies or more than one experimental condition (Causer, Bennett, Holmes, Janelle, & Williams, 2010; Helsen & Starkes, 1999; Laurent, Ward, Mark Williams, & Ripoll, 2006; Moreno et al., 2006; Reina, Moreno, & Sanz, 2007; Spitz, Put, Wagemans, Williams, & Helsen, 2016; Williams & Davids, 1997; Williams & Davids, 1998; Williams, Singer, & Frehlich, 2002a) and another 10 articles that studied expert–intermediate and expert–novice comparisons (Campbell & Moran, 2014; Hagemann, Schorer, Cañal-Bruland, Lotz, & Strauss, 2010; Flessas et al., 2015; Krezpota, Stepiński, Zwierko, 2016; Raab & Johnson, 2007; Reingold, Charness, Pomplun, & Stampe, 2001; Ripoll et al., 1995; Vaeyens, Lenoir, Williams, Mazyn, & Philippaerts, 2007a; Vansteenkiste, Vaeyens, Zeuwts, Philippaerts, & Lenoir, 2014; Vickers, 1988). Thus, the final number of studies that investigated the gaze behavior of experts vs. intermediates amounts to 55 studies and the final number of studies that investigated the gaze behavior of experts vs. novices amounts to 46 studies.

Data extraction

The totally 101 studies were analyzed with the four different descriptors (1) sample, (2) research method, (3) research task, and (4) gaze measures which are further explained in **Table 1**.

The features of the descriptors were described in terms of number of cases (*n*), averages (*M*), or percentages (%). Moreover, the gaze measures were analyzed as a function of expertise by applying the vote-counting procedure, i.e., comparing the number of studies with significant positive results, significant negative results and nonsignificant results (e.g., Bushman & Wang, 1994). In the current study, significant positive results were counted in case of longer fixation and QE durations, fewer number of fixations, and different gaze locations. Significant negative results relate to shorter fixation and QE durations and higher number of fixations. Finally, nonsignificant results were counted if the inferential statistics revealed no significant differences. These latter data were further aggregated over subsamples of studies determined by different stimulus and response modes and different types of sport as well as task both for expert–novice and expert–intermediates comparisons. Finally, to gain insights into the development of the expertise effect, for fixation duration and number of fixations the results of the vote-counting procedure were added up over publication years starting earlier than 1995 until 2017 (labelled as publication-year analysis).

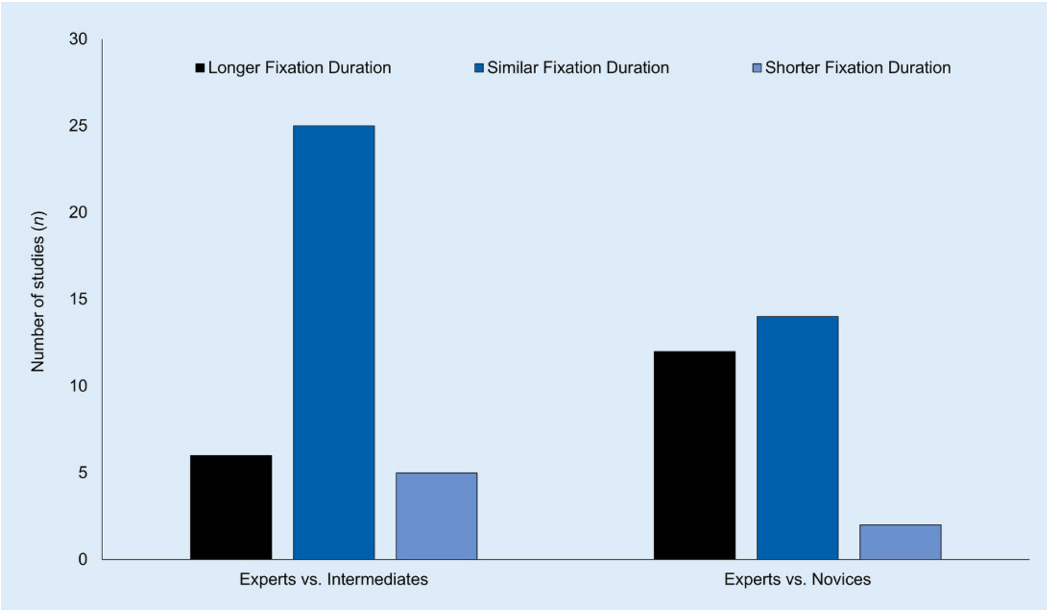

Fig. 2 ◀ Number of studies (*n*) as a function of study outcome (longer fixation duration, similar fixation duration, and shorter fixation duration) for experts–intermediates and experts–novices comparisons

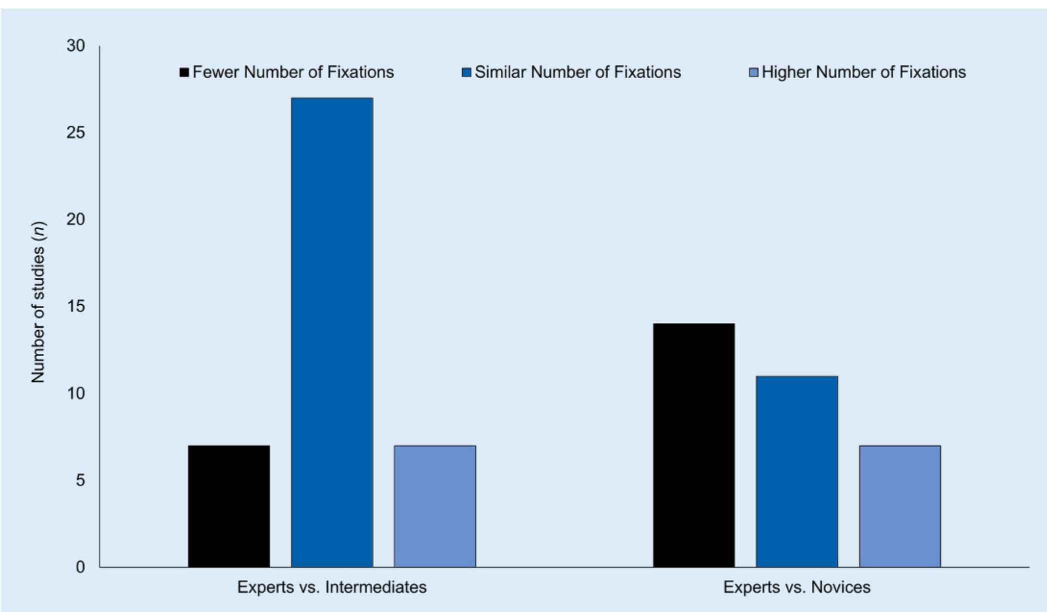

Fig. 3 ◀ Number of studies (*n*) as a function of study outcome (fewer number of fixations, similar number of fixations, and higher number of fixations) for experts–intermediates and experts–novices comparisons

Results

Sample

From the 101 studies that investigated expertise differences in gaze behavior, 55 studies compared experts with intermediates and 46 studies compared experts with novices. The average sample size (experts: $M = 11.1$, $SD = 5.9$; intermediates: $M = 11.1$, $SD = 4.9$; novices: $M = 11.6$, $SD = 6.5$) and age (experts: $M = 25.6$ years, $SD = 6.9$ years; intermediates: $M = 25.0$ years, $SD = 6.9$ years; novices: $M = 22.7$ years, $SD = 4.3$ years) was comparable between the three expertise groups. However, as to be expected, clear differences were found for training years with the most training years for the experts ($M = 11.6$ years, $SD = 3.9$ years), followed by the intermediates ($M = 7.6$ years, $SD = 3.9$ years), and the least experience for the novices ($M = 0.7$ years, $SD = 1.9$ years).

Research methods and tasks

The research methods and research tasks applied in sports-related eye-tracking research can be found in Hüttermann et al. (2018) and Kredel et al. (2017) who, in addition, pursued a more detailed analysis. Therefore, since the current analyses replicated those findings the interested reader is referred to these two publications. Nevertheless, when providing a short overview, it can be said that lab research ($n = 70$) was preferred over research in field conditions ($n = 31$) and

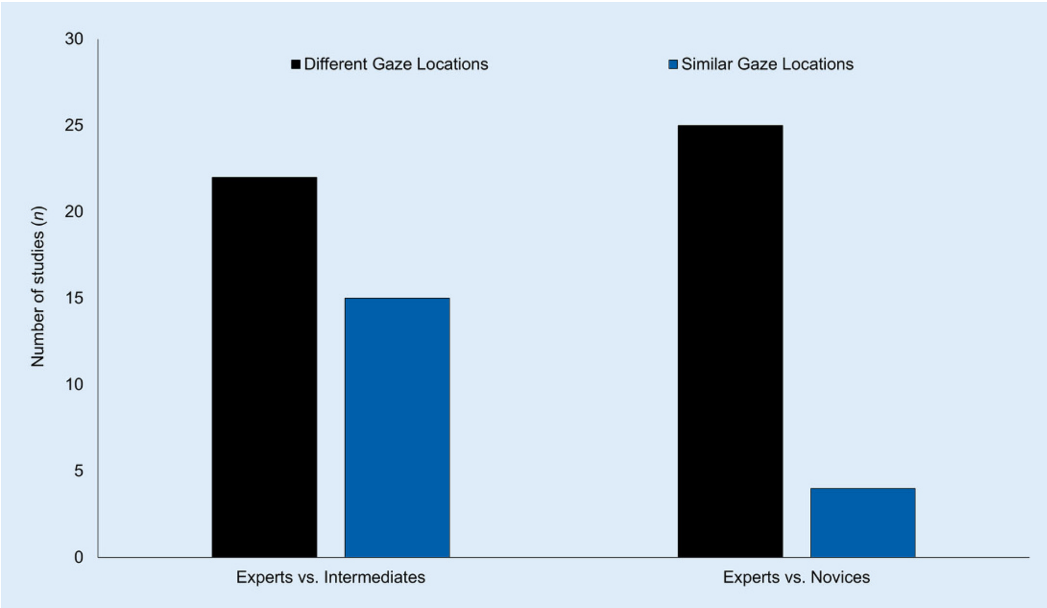

Fig. 4 ◂ Number of studies (*n*) as a function of study outcome (different gaze location and similar gaze location) for experts–intermediates and experts–novices comparisons

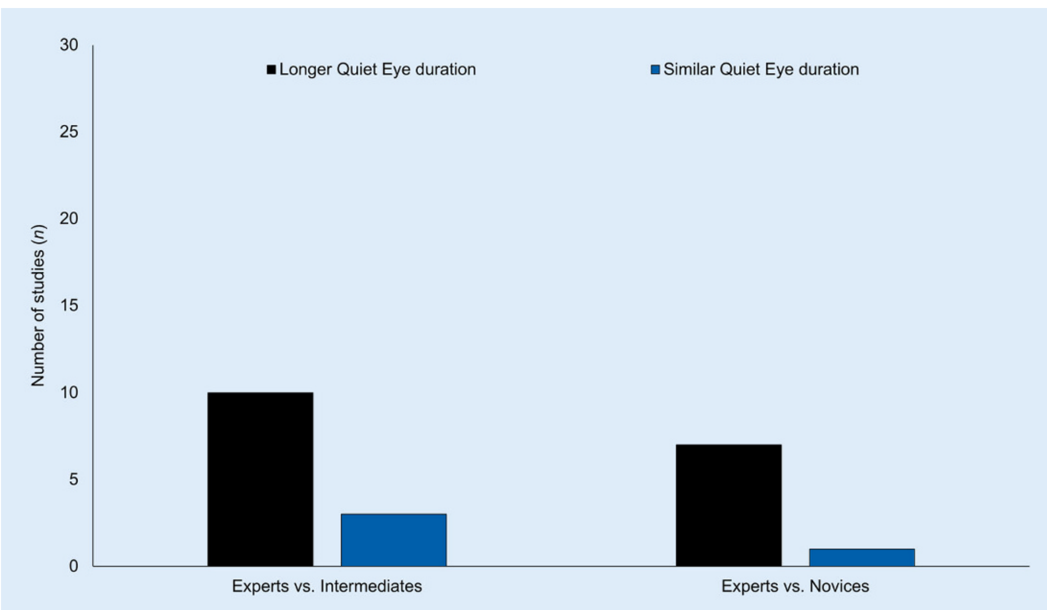

Fig. 5 ◂ Number of studies (*n*) as a function of study outcome (longer quiet eye duration and similar quiet eye duration) for experts–intermediates and experts–novices comparisons

the majority of the studies required actual motor responses ($n = 45$) and presented visual stimuli via video presentations ($n = 65$). Moreover, invasion games (regarding sports classifications, see Butler, Griffin, Lombardo, & Natasi, 2003) and decision-making were the most studied sports ($n = 35$) and tasks ($n = 43$), respectively (for more information see **Table 2**).

Gaze measure

The individual results of the gaze-measure analyses are depicted in **Table 2** in the Appendix. In the majority of all studies, the number of fixations (both 70.3%, $n = 71$) was studied, followed by fixation duration and gaze location (63.4%, $n = 64$). As in earlier reviews (e.g., Mann et al., 2007), the QE was investigated in the least number of studies (20.8%, $n = 21$).

In the following, the four different gaze measures will be further described as a function of the two different expertise-level comparisons (experts vs. intermediates and experts vs. novices) that will be further differentiated by stimulus mode (image, video, and in situ), response mode (watching, verbal, button, and real), type of sports (invasion games, target games, net and wall games, judging, combat sports, striking and field games, individual pursuit, locomotion, remaining), and type of task (decision making, aiming task, recognition task, gross-motor task, judging, watching) if appropriate. Finally, a chronological de-

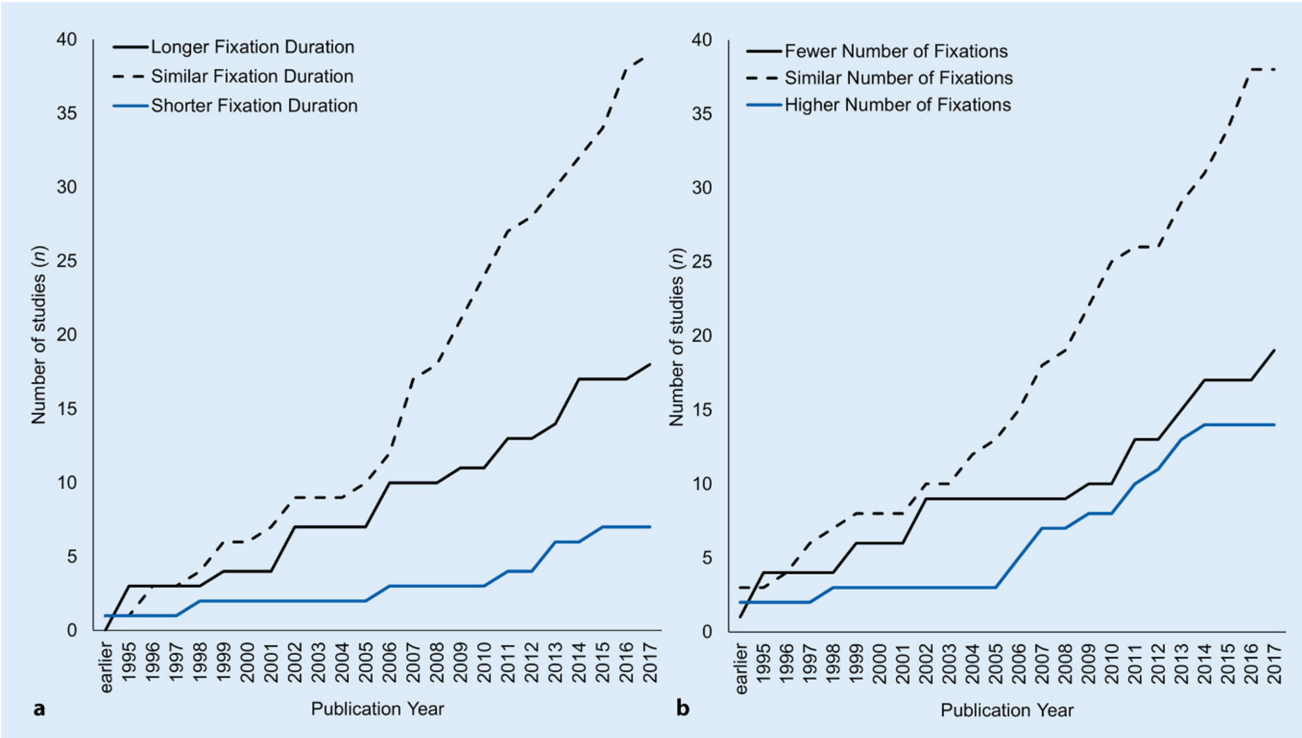

Fig. 6 ▲ Number of studies with longer/fewer, similar, and shorter/higher duration (**a**) as well as number (**b**) of fixations as a function of the publication year (publication-year analyses)

scription of the summarized expertise difference will be provided.

Fixation duration

With regard to fixation duration, there were 36 studies comparing experts with intermediates and 28 studies comparing experts with novices. As can be seen in ◘ **Fig. 2**, the number of studies revealing longer fixation durations for experts when compared to their less-skilled counterparts is rather low, in particular, with regard to the expert–intermediate comparison. There are nearly five times as many studies revealing no difference between experts and intermediates than studies with a significant positive result. Indeed, the expert–novice comparison provides a slightly different picture with 12 studies revealing significant-positive vs. 14 studies revealing nonsignificant results. Nevertheless, there is a higher amount of studies with similar fixation durations. Only few studies reported significant-negative results.

Further differentiation as a function of stimulus and response mode had only little effect. When comparing experts vs. novices there is a trend that the more representative the response mode the larger the difference between significant-positive vs. nonsignificant results (verbal response mode: 1 additional study; real response mode: 3 additional studies). Similarly, there were more positive-significant vs. nonsignificant results in gross-motor tasks (3 additional studies) as when compared to recognition (3 studies less) and decision-making (4 studies less) tasks which showed the exact opposite pattern. Neither the differentiation for type of sport nor for type of task provided further insights.

Number of fixations

For the analysis of number of fixations (expert–intermediate comparison: $n = 41$ studies, expert–novice comparison: $n = 32$ studies) a similar pattern was found as for fixation duration (◘ **Fig. 3**). Moreover, there was even less evidence for the hypothesis of fewer number of fixations in experts when compared to intermediates and novices as the number of studies with significant-negative results equals the number of studies with significant-positive results. A further differentiation for stimulus and response mode as well as for type of sports and task did not change this pattern.

Gaze location

Overall, 37 studies analyzed gaze locations in experts vs. intermediates and 29 studies in experts vs. novices. Different than for number and duration of fixation, the analysis of gaze location (◘ **Fig. 4**) revealed expertise-related differences for the expert–novice comparison (21 additional studies) and (less conclusive) for the expert–intermediate comparison (7 additional studies). When further differentiating for stimulus and response modes, for the expert–intermediate comparison a small positive trend towards higher number of significant-positive results was found the higher the representativeness of the response mode (button response/real response: 4 additional studies; verbal response/watching: 2 additional studies). Moreover, independent of expertise for decision-making tasks twice as many studies were found with significant-positive as com-

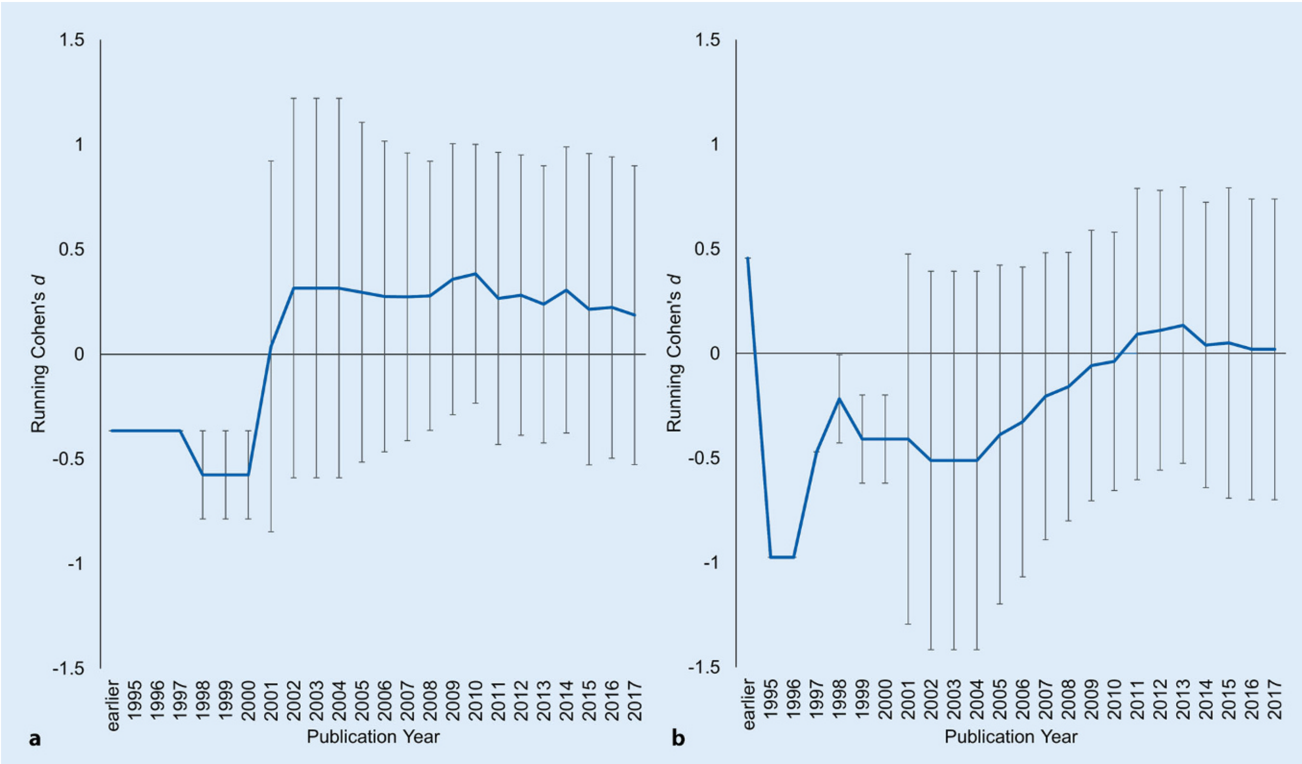

Fig. 7 ▲ Running Cohen's *d* values (*M* and *SD*) for fixation duration (**a**) and number of fixations (**b**) as a function of publication year

pared to nonsignificant results. Smaller differences or even the opposite pattern were found for studies with aiming and recognition tasks as well as watching.

Quiet eye duration

Until now, 13 studies investigated differences in QE duration in experts vs. intermediates and 8 studies in experts vs. novices. As can be seen in **Fig. 5**, the data support longer QE duration in experts when compared to intermediates and novices. Due to the high number of QE studies with the same research design (i.e., in situ "stimulus"/real response/ target games/aiming tasks), a further differentiation was not applicable.

Publication-year analysis

Since similar results were obtained for expert–intermediate and expert–novice comparisons (**Figs. 2 and 3**), unlike the preceding analyses, the data were collapsed across expertise. **Fig. 6** shows for fixation duration and number of fixations different trends for significant-positive and nonsignificant results after the year 2003. In detail, the number of studies with nonsignificant results increasingly overtook the number of studies with significant-positive results, i.e. longer fixation durations and fewer number of fixations. Moreover, with regard to number of fixations over the last years, the number of studies with significant-negative results (i.e., experts with a higher number of fixations) nearly equaled the number of studies with significant-positive results (i.e., experts with lower number of fixations).

Discussion

Research suggests that highly skilled athletes show distinct gaze behaviors that fundamentally differ from that of less-skilled athletes. However, in particular over the last decade it seems that a number of studies could no longer reveal expert advantages and, therefore, in the current study we conducted a systematic review to provide an update on the state-of-the-art on expert gaze behavior in sports by focusing on the four main gaze variables, i.e., number and duration of fixations, gaze location as well as QE duration. Particularly in test conditions with high representativeness, we expected to find fewer number of fixations, longer fixation durations, different gaze locations and longer QE durations in experts when compared to intermediates and novices (cf. Mann et al., 2007).

The results of the gaze-measures analyses were quite heterogeneous. The most distinct conclusion can be drawn for the QE measure. When compared to their less-skilled counterparts the number of studies with significant-positive results was more than 3-times as high as the number of studies with nonsignificant results. For example, Chia, Chow, Kawabata, Dicks, and Lee (2016) revealed about 25% longer QE durations for experts when compared to novices in 10-pin bowling. But also when compared to intermediates, experts exhibit longer QE durations as, among others, revealed by Klostermann, Kredel, and Hossner (2014). In a golf-putting task expert golfers showed about 40% longer QE durations than intermediates. Until now, only 4 out of 21 studies revealed no expertise differences in QE as, for example, in Rodrigues, Vickers, and Williams (2002) who investigated return shots with expert and intermediate table tennis players. Thus, in line with the results of a current meta-analysis (Lebeau et al., 2016), the QE proves to be an expertise characteristic. It should be noted, however, that different to the other gaze measures no study with significant negative results was found. Thus, although recent analyses by Lebeau et al. (2016) could not reveal any publication bias for the QE expertise effect, the overall result should be taken carefully (see also Mann et al., 2007).

Moreover, the expert–novice comparison for gaze locations revealed the predicted pattern. Different than, e.g., in Abernethy (1990) the empirical evidence that experts focus different visual cues when compared to novices is quite strong (**Fig. 4**). For example, Alder, Ford, Causer, and Williams (2014) showed that when anticipating serve locations in badminton, experts predominantly fixated the racket, whereas novices directed their gaze more often at the shuttle location. The empirical evidence seems less strong when comparing experts to intermediates as there were only 7 additional studies with significant-positive results. However, a closer look at the data suggested a mediation by the representativeness of the experimental design. When responding with representative response modes (i.e., motor responses) in tasks that actually require selection of visual information from a number of sources (i.e., decision-making tasks) experts rather show different gaze patterns as when responding with less representative modes and solving tasks that contain few visual cues only (e.g., verbal responses and targeting tasks). For example, Krzepota et al. (2016) found similar gaze locations for expert and intermediate soccer players when watching defensive situations in soccer. In contrast, in the study by Spitz et al. (2016) differences in gaze locations were revealed with expert referees spending longer times fixating on the contact zone (i.e., the area around the possible infringement) and intermediates focusing longer on the non-contact zone during the assessment of foul-play situations. Thus, the representativeness of the experimental task (in the examples above: passively watching vs. actively refereeing) does mediate expertise effects when it comes to gaze locations (see also Gegenfurtner et al., 2011).

Unexpectedly, the empirical evidence supporting the hypothesized 'classical' expert gaze behavior—i.e., fewer fixations of longer durations—seems rather low. In particular over the last few years (**Fig. 6**), the number of studies that revealed nonsignificant results clearly exceeded the number of studies with significant positive results. In 2017, there were twice as many studies with nonsignificant results than studies with significant positive results. Even, when considering that the opposite pattern might also indicate expert gaze behavior (e.g., Maarseveen et al., 2015), the number of nonsignificant results was still larger than the number of studies with significant results, in particular for fixation duration. If anything, tendentially larger expertise differences were found with more external valid testing conditions. Still, the number of studies is rather low.

However, before discussing possible implications, we performed an additional effect size estimation to control for possible deficits which come along with the vote-counting procedure as it only takes statistical significance into account (see also Pike, 2019). To this end, for the gaze variables fixation duration and number of fixations[1], Cohen's d values were estimated from all studies that provided sufficient information (fixation duration: 49.2% of all included studies; number of fixations: 56.5% of all included studies) and aggregated over time. Further details on the statistics applied can be obtained from Appendix A2.

[1] The effect-size analysis was restricted to fixation duration and number of fixation as only for these two variables the results of the vote-counting procedure were in conflict with the hypothesized pattern and thus required validation by a method that is more commonly applied. Moreover, for QE duration Lebeau et al. (2016) only recently presented a meta-analysis such that an update did not seem reasonable.

The resulting running Cohen's d curves are depicted in **Fig. 7**. It should be noted that positive Cohen's d values for fixation duration imply longer fixation durations, whereas negative Cohen's d values for number of fixation imply fewer number of fixations for experts when compared to their less-skilled counterparts. In particular for the number of fixations (**Fig. 7b**), the trend observed in the publication-year analysis is reflected in the effect-size estimation as well. Since 2004, the effect size has constantly decreased and since 2009 it is approaching the null effect (2017: $M = 0.01$, $SD = 0.99$). For fixation duration (**Fig. 7a**) the picture seems slightly different. Whereas in the 1990s, an average negative effect size was found, since 2002 the effect size has become positive. In 2017, the average effect sizes for fixation duration amounted to $M = 0.21$ ($SD = 0.68$). Noticeably, both measures show very large variance and the latest effect sizes are below or not different from a small effect ($d = 0.2$; Cohen, 1988).

Overall, the accumulated evidence from the vote-counting procedure and the effect-size estimation indeed give rise to question fundamental differences in fixation patterns in experts when compared to less-skilled athletes. Why this pattern, indeed, has changed over the last 10 years is difficult to answer. It has been recommended to apply more realistic settings in expert research to detect actual differences in behavior (e.g., Dicks et al., 2010). However, the current data as well as the reviews by Hüttermann et al. (2018) and Kredel et al. (2017) do not suggest a distinct paradigmatic change over the last decade. Rather, in 2015 the percentage of lab studies that used rather dynamic vs. other responses slightly decreased as well as the percentage of field studies (2004: field/dynamic = 42.7%, lab/dynamic = 20.8%, lab/other = 37.5%; 2015: field/dynamic = 39.1%, lab/dynamic = 21.9%, lab/other = 39.0%; Kredel et al., 2017). But, due to technical advancement data quality constantly increased as revealed by the use of more high-frequent and more robust eye-tracking devices and by an increasing number of critical trials (Kredel et al., 2017; see also Orquin & Holmqvist, 2018). Thus, it might be speculated that in 2017, eye-movement research in sports provides more reliable and valid data, thus, making overall a different eye-movement pattern plausible.

The current analyses, however, suggest that different search patterns and in particular a more functional perception–action coupling should be expected in high-level athletes. As a consequence thereof, like in QE research, future research should increasingly seek to study gaze behavior coupled to the action instead of "simply" averaging different gaze behavior over test trials (see also Kredel et al., 2017). For example, time-course analyses should be applied to study gaze behavior over the course of action or with respect to critical moments in time. By means of this method, Hossner et al. (2019) as well as Vansteenkiste et al. (2014) revealed that visual expertise in beach-volleyball defense and volleyball defense can be characterized by increased number and more precise gaze anchors at the future position of the opponent attacker's ball–hand contact. These findings imply that in such situations high-level athletes rather make use of peripheral than foveal information for, e.g., monitoring multiple objects at a given time (for a current review on the functional role of peripheral vision in sports Vater, Williams, & Hossner, 2019). Such analyses, however, require respective methodological advancement and appropriate experimental paradigms as also emphasized by Kredel et al. (2017) as well as by Hüttermann et al. (2018).

Moreover, researchers and practitioners must be aware that the limiting factor might not be an inappropriate visual search (i.e., gaze behavior) but rather the inability to use the visual information (i.e., perception) (Abernethy, 1990). Recent gaze–intervention studies showed that when training novices with expert-like gaze behavior to improve decision making in a handball-penalty task (Abernethy, Schorer, Jackson, & Hagemann, 2012), or in beach-volleyball-defense (Klostermann, Vater, Kredel, & Hossner, 2015), as well as in pattern recognition in soccer (North, Hope, & Williams, 2017) does not provide any advantage when compared to active control and placebo groups, respectively. It should be noted, however, that different results were obtained when applying gaze trainings in tasks which require to anchor gaze at one location (as for example in basketball free-throw shots, Vine & Wilson, 2011). Nonetheless, when training anticipation or decision-making in a complex situation that requires selection of information from multiple sources it is suggested to perform respective perceptual training as opposed to gaze training (see also Hadlow, Panchuk, Mann, Portus, & Abernethy, 2018).

As a limitation, the classification of expertise had to rely on the classification reported by the authors. Although there have been good recommendations on how to solve the issue on defining elite athletes (e.g., Swann, Moran, & Piggott, 2015), with the limited information provided in the current database, it was not possible to follow this classification. Nevertheless, the difference between the numbers of training years allowed to differentiate the three expertise groups and experts accumulated more than 10 years of training which has been associated with the duration to reach an expert status (e.g., Simon & Chase, 1973; but see also, e.g., Ericsson, Krampe, & Tesch-Römer, 1993). As further limitation, although the vote-counting procedure allows summarizing information from a very large sample with low expenditure, the method has drawbacks as it does not consider the actual effect and is susceptible to power problems (Borenstein, Hedges, Higgins, & Rothstein, 2009b). In the current sample, the study by Vickers (1996) is a paramount example because the main effect for expertise just missed the level of significance ($p = 0.07$), thus was counted as nonsignificant result. Therefore, as also suggested by Bushman and Wang (1994) we combined the vote-counting procedure with an effect size estimation. Based on about 50% of the studies of the original sample these analyses, however, basically confirmed the results of the vote-counting procedure.

Based on more than 100 studies including more than 220 gaze measures obtained from more than 2000 participants the current paper provided an update on the current state-of-the-art on expert gaze behavior. The publication-year analyses (**Figs. 6 and 7**) showed that the empirical evidence on general differences in gaze behavior declined over the last few years. Indeed, some gaze measures still were able to differentiate experts from less-skilled athletes. But, taken together we would be more careful in assuming a distinct expert gaze behavior as it has been done in the past. Instead, as matters now stand perceptual–cognitive expertise should rather be assumed to emanate from perceptual performance than from gaze behavior.

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Compliance with ethical guidelines

Conflict of interest A. Klostermann and S. Moeinirad declare that they have no competing interests.

For this article no studies with human participants or animals were performed by any of the authors. All studies performed were in accordance with the ethical standards indicated in each case.

Appendix A

Table 2 Eye-tracking studies included in the analysis of expert gaze behavior

Authors (Year)	Fixation duration		Number of fixation		Gaze location	QE duration	Type of sports	Type of task	Stimulus mode	Response mode	Level
	p	*d*	*p*	*d*	*p*	*p*					
Bard and Fleury (1976)	x	x	1	x	1	x	IG	DM	I	V	E-N
Bard, Fleury, Carrière, and Hallé (1980)	x	x	0	−1.04	1	x	J	JT	VP	V	E-N
Vickers (1988)	x	x	0	x	1	x	R	WT	I	W	E-I
Vickers (1988)	x	x	0	x	1	x	R	WT	I	W	E-N
Goulet, Bard, and Fleury (1989)	x	x	−1	0.75	x	x	NWG	DM	VP	V	E-N
Abernethy (1990)	0	0.68	x	x	0	x	NWG	DM	VP	V	E-N
Williams, Davids, Burwitz, and Williams (1994)	−1	−1.42	−1	1.65	1	x	IG	DM	VP	V	E-I
Ripoll et al. (1995)	1	x	1	−2.34	1	x	CS	DM	VP	B	E-I
Ripoll et al. (1995)	1	x	1	−2.46	1	x	CS	DM	VP	B	E-N
Vickers (1995)	1	x	1	x	x	x	IG	AT	IS	R	E-I
Singer, Cauraugh, Chen, Steinberg, and Frehlich (1996)	0	x	0	x	1	x	NWG	DM	VP	B	E-N
Vickers (1996)	0	x	x	x	x	0	TB	AT	IS	R	E-I
Williams and Davids (1997, Exp 1)	x	x	0	x	0	x	IG	DM	VP	V	E-I
Williams and Davids (1997, Exp 2)	x	x	0	x	0	x	IG	DM	VP	V	E-I
Williams and Davids (1998, Exp 1a)	0	−0.85	0	0.9	0	x	IG	DM	VP	R	E-I
Williams and Davids (1998, Exp 1b)	−1	−0.73	−1	0.19	0	x	IG	DM	VP	R	E-I
Helsen and Starkes (1999, Exp 2)	0	x	1	−1.18	1	x	IG	DM	VP	V	E-I
Helsen and Starkes (1999, Exp 3)	0	x	1	x	1	x	IG	DM	VP	R	E-I
Williams and Elliott (1999)	1	x	0	x	0	x	CS	GM	VP	R	E-N
Janelle et al. (2000)	x	x	x	x	x	1	TG	AT	IS	R	E-N
Charness, Reingold, Pomplun, and Stampe (2001)	0	1.27	x	x	1	x	R	RT	VP	B	E-I
Reingold et al. (2001)	0	x	1	x	1	x	R	RT	VP	V	E-I
Reingold et al. (2001)	0	x	1	x	1	x	R	RT	VP	V	E-N
Kato and Fukuda (2002)	x	x	x	x	1	x	SFG	WT	VP	W	E-N
Moreno, Reina, Luis, and Sabido (2002)	1	x	1	−0.55	x	x	J	JT	VP	V	E-N
Rodrigues et al. (2002)	x	x	x	x	x	0	NWG	AT	IS	R	E-I
Savelsbergh, Williams, Kamp, and Ward (2002)	1	1.66	1	−2.43	1	x	IG	DM	VP	B	E-N
Ward et al. (2002)	0	x	0	x	1	x	NWG	DM	VP	R	E-I
Williams et al. (2002a, Exp1)	1	1.57	1	−1.69	x	1	TG	AT	IS	R	E-I
Williams et al. (2002a, Exp2)	x	x	x	x	x	1	TG	AT	IS	R	E-I
Williams, Ward, Knowles, and Smeeton (2002b)	0	0.21	0	0.58	1	x	NWG	DM	VP	R	E-I
Martell and Vickers (2004)	x	x	0	x	x	x	IG	GM	IS	R	E-I
Nagano, Kato, and Fukuda (2004)	x	x	0	x	1	x	IG	GM	IS	R	E-N

Table 2 (Continued)

Authors (Year)	Fixation duration		Number of fixation		Gaze location	QE duration	Type of sports	Type of task	Stimulus mode	Response mode	Level
	p	*d*	*p*	*d*	*p*	*p*					
Savelsbergh et al. (2005)	0	0.22	0	0.36	1	x	IG	DM	VP	B	E-I
Laurent et al. (2006, Exp1)	0	0.05	−1	x	x	x	IG	RT	VP	B	E-N
Laurent et al. (2006, Exp 2)	0	x	−1	x	x	x	IG	RT	VP	B	E-N
Moreno et al. (2006, front view)	1	x	1	x	1	x	J	JT	VP	V	E-N
Moreno et al. (2006, side view)	−1	x	1	x	1	x	J	JT	VP	V	E-N
Nagano, Kato, and Fukuda (2006)	1	x	0	x	x	1	IGs	AT	IS	R	E-I
Savelsbergh, Onrust, Rouwenhorst, and Kamp (2006)	1	0.29	0	0.1	0	x	IG	GM	VP	R	E-I
Raab and Johnson (2007)	0	x	0	x	x	x	IG	DM	VP	V	E-I
Raab and Johnson (2007)	0	x	−1	x	x	x	IG	DM	VP	V	E-N
Reina et al. (2007, in situ)	x	x	x	x	1	x	NWG	AT	IS	R	E-N
Reina et al. (2007, video)	x	x	x	x	1	x	NWG	AT	VP	R	E-N
Vaeyens (2007a)	0	x	0	x	1	x	IG	AT	VP	R	E-I
Vaeyens (2007a)	0	x	0	x	1	x	IG	DM	VP	R	E-N
Vaeyens (2007b)	0	0.27	−1	0.78	1	x	IG	DM	VP	R	E-I
Catteeuw, Helsen, Gilis, Roie, and Wagemans (2009)	0	x	0	x	1	x	J	DM	IS	B	E-I
Lee, Kim, and Park (2009)	1	1.55	1	x	x	1	TG	AT	IS	R	E-N
McRobert, Williams, Ward, and Eccles (2009)	0	0.46	0	0.44	1	x	SFG	AT	VP	R	E-I
North et al. (2009)	0	x	0	0.61	0	x	IG	DM	VP	B	E-I
Takeuchi and Inomata (2009)	x	x	−1	1.81	0	x	SFG	AT	VP	B	E-N
Catteeuw (2010)	0	0.61	0	0.18	0	x	J	DM	VP	V	E-I
Causer et al. (2010, skeet)	x	x	x	x	x	1	TG	AT	IS	R	E-I
Causer et al. (2010, trap)	x	x	x	x	x	1	TG	AT	IS	R	E-I
Causer et al. (2010, double trap)	x	x	x	x	x	1	TG	AT	IS	R	E-I
Hagemann et al. (2010)	0	x	0	x	1	x	CS	DM	VP	B	E-I
Hagemann et al. (2010)	0	x	0	x	1	x	CS	DM	VP	B	E-N
Van Lier (2010)	0	0.31	0	0.25	0	x	TG	AT	IS	R	E-I
Heinen and Vinken (2011)	1	2.13	−1	x	x	x	IP	GM	IS	R	E-N
Mann, Coombes, Mousseau, and Janelle (2011)	x	x	x	x	x	1	TG	AT	IS	R	E-I
McRobert, Ward, Eccles, and Williams (2011)	0	x	0	x	1	x	SFG	AT	VP	V	E-I
Panchuk and Vickers (2011)	1	x	1	−2.17	1	1	L	GM	IS	R	E-N
Roca, Ford, McRobert, and Williams (2011)	−1	−3.94	−1	5.49	1	x	IG	DM	VP	V	E-I
Van der Kamp (2011)	x	x	x	x	0	x	IG	AT	VP	R	E-I
Afonso, Garganta, Mcrobert, Williams, and Mesquita (2012)	0	0.46	−1	0.35	1	x	NWG	DM	IS	R	E-I
Nibbeling, Oudejans, and Daanen (2012)	x	x	x	x	x	1	TG	AT	IS	R	E-N
Rienhoff, Baker, Fischer, Strauss, and Schorer (2012)	x	x	x	x	x	0	TG	AT	IS	R	E-N

Table 2 (Continued)

Authors (Year)	Fixation duration		Number of fixation		Gaze location	QE duration	Type of sports	Type of task	Stimulus mode	Response mode	Level
	p	*d*	*p*	*d*	*p*	*p*					
Afonso and Mesquita (2013)	1	0.51	0	−0.38	1	x	NWG	WT	VP	W	E-I
Garcia, Muñoz Noval, Grande Rodriguez, Sanchis Almenara, and Sampedro Molinueva (2013)	x	x	−1	1.35	x	x	IG	WT	VP	W	E-I
Hancock and Ste-Marie (2013)	0	−0.3	0	0	x	x	J	DM	VP	V	E-I
Millslagle, Smith, and Hines (2013)	x	x	1	x	x	1	J	JT	IS	V	E-I
Millslagle et al. (2013)	x	x	x	x	x	1	J	JT	IS	V	E-I
Mori and Shimada (2013)	x	x	x	x	1	x	IG	DM	VP	B	E-N
Rienhoff et al. (2013)	x	x	x	x	x	1	TG	AT	IS	R	E-N
Roca et al. (2013)	−1	−1.81	−1	1.81	1	x	IG	DM	VP	V	E-I
Ryu et al. (2013)	x	x	0	−0.42	0	x	IG	DM	VP	B	E-I
Wu et al. (2013)	0	0.42	x	x	x	x	TG	DM	I	V	E-N
Alder et al. (2014)	1	1.33	0	0.27	1	1	NWG	DM	VP	V	E-N
Campbell and Moran (2014)	0	x	0	x	0	x	TG	RT	VP	V	E-I
Campbell and Moran (2014)	1	x	1	x	0	x	TG	RT	VP	V	E-N
Klostermann et al. (2014)	x	x	x	x	x	1	TG	AT	IS	R	E-I
Piras, Pierantozzi, and Squatrito (2014)	−1	x	1	−2.89	1	x	NWG	DM	VP	V	E-N
Piras et al. (2014)	1	1.06	1	−1.5	1	x	CS	GM	IS	R	E-N
Sheridan and Reingold (2014)	0	x	−1	x	x	x	R	RT	VP	V	E-N
Uchida, Mizuguchi, Honda, and Kanosue (2014)	x	x	x	x	1	x	TG	RT	VP	V	E-N
Vansteenkiste et al. (2014)	x	x	x	x	1	x	NWG	DM	VP	R	E-I
Vansteenkiste et al. (2014)	x	x	x	x	1	x	NWG	DM	VP	R	E-N
Fischer et al. (2015)	x	x	x	x	x	0	TG	AT	IS	R	E-I
Flessas et al. (2015)	x	x	x	x	0	x	J	RT	VP	V	E-I
Flessas et al. (2015)	x	x	x	x	1	x	J	RT	VP	V	E-N
Gorman, Abernethy, and Farrow (2015)	0	x	0	x	x	x	IG	DM	VP	B	E-N
Loffing et al. (2015)	0	x	0	0.2	x	x	IG	DM	VP	B	E-N
Van Maarseveen et al. (2015)	−1	−1.06	0	x	0	x	IG	RT	VP	B	E-I
Chia et al. (2016)	x	x	x	x	x	1	TG	AT	IS	R	E-N
Krzepota et al. (2016)	0	0.77	0	−0.84	0	x	IG	WT	VP	W	E-I
Krzepota et al. (2016)	0	0.6	0	−0.38	1	x	IG	WT	VP	W	E-N
Spitz et al. (2016)	0	0	0	−0.5	1	x	J	DM	VP	V	E-I
Spitz et al. (2016)	0	0	0	0.07	0	x	J	DM	VP	V	E-I
Manzanares, Menayo, and Segado (2017)	0	−0.4	1	−0.85	x	x	R	GM	VP	R	E-N
Connor, Crowther, and Sinclair (2018)	1	x	1	x	1	x	IG	DM	VP	V	E-N

The results of the vote-counting procedure, i.e. p, are reported as positive significant (1), negative significant (−1), nonsignificant (0), as well as not analyzed (x)
Effect sizes (d) are reported as Cohen's *d*
Type of sports: *CS* combat sports, *IG* invasion games, *IP* individual pursuit, *J* = judging, *L* locomotion, *NWG* net and wall games, *R* remaining, *SFG* striking and field games, *TG* target games
Type of task: *AT* aiming task, *DM* decision-making task, *GM* gross-motor task, *JT* judging task, *RT* recognition task, *WT* watching task
Stimulus mode: *I* images, *IS* in situ, *VP* video presentation
Response mode: *B* button-press, *R* real response, *V* verbal response, *W* watching
Level: *E-I* Expert-intermediate comparison, *E-N* Expert-novice comparison

Appendix B

Effect-size estimation

From all studies that provided sufficient information, effect sizes were estimated for the two gaze variables fixation duration ($n = 31$; 49.2% of all studies included) and number of fixations ($n = 39$; 56.5% of all studies included). We extracted Cohen's d values either based on the respective values reported in the papers, by calculating the Cohen's d by the means of the data reported ($d = (m_1 - m_2) / s_{\text{pooled}}$; Cohen, 1988), or by means of the results of the F-test and t-tests, respectively ($d = F * \sqrt{\frac{1}{n_T} + \frac{1}{n_C}}$; $d = t * \sqrt{\frac{1}{n_T} + \frac{1}{n_C}}$; Borenstein, 2009). In order to obtain the direction of the effect, the Cohen's d was calculated as relative value. For fixation duration, positive Cohen's d values denote that experts had longer fixation durations and negative Cohen's d values denote that experts had shorter fixations durations when compared to the less-skilled athletes. Likewise, for number of fixations positive Cohen's d values imply a higher number of fixations and negative Cohen's d values a smaller number of fixations for experts vs. intermediates and novices. In case that in one study several data sources were available, the reporting was preferred over the remaining and the calculations by means of the reported data was preferred over the calculations by means of the F-tests/t-tests results. To control for sample size difference between the different studies, the Cohen's d values were weighted by their respective sample size as suggested in Ellis (2010). In order to compare these results with the vote-counting procedure, the Cohen's d values were aggregated over publication years by means of a cumulative mean (i.e., running Cohen's d). This means that the mean value of, e.g., 1997 includes all effect sizes from the studies until 1997. Likewise, we calculated a cumulative standard deviation. Thus, the means and standard deviations in 2017 represent the mean and standard deviations of the sample.

It should be noted that the average Cohen's d values in 2004 are very similar to the effect sizes reported in Mann et al. (2007) who included papers until 2004. In their study, for fixation duration and number of fixations average effect sizes of $r = 0.23$ and $r = 0.26$ were computed which corresponds to $d = 0.47$ and $d = 0.53$, respectively. The average absolute effects sizes in the current study amount to $d = 0.33$ for fixation duration and $d = 0.45$ for number of fixations.

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