

Quiet Eye and Performance in Sport: A Meta-Analysis

Jean-Charles Lebeau,¹ Sicong Liu,¹ Camilo Sáenz-Moncaleano,¹ Susana Sanduvete-Chaves,² Salvador Chacón-Moscoso,^{2,3} Betsy Jane Becker,¹ and Gershon Tenenbaum¹

¹Florida State University; ²Universidad de Sevilla; ³Universidad Autónoma de Chile

Research linking the “quiet eye” (QE) period to subsequent performance has not been systematically synthesized. In this paper we review the literature on the link between the two through nonintervention (Synthesis 1) and intervention (Synthesis 2) studies. In the first synthesis, 27 studies with 38 effect sizes resulted in a large mean effect ($d = 1.04$) reflecting differences between experts’ and novices’ QE periods, and a moderate effect size ($d = 0.58$) comparing QE periods for successful and unsuccessful performances within individuals. Studies reporting QE duration as a percentage of the total time revealed a larger mean effect size than studies reporting an absolute duration (in milliseconds). The second synthesis of 9 articles revealed very large effect sizes for both the quiet-eye period ($d = 1.53$) and performance ($d = 0.84$). QE also showed some ability to predict performance effects across studies.

Keywords: vision, perceptual-cognitive skill, sport expertise, attention

For nearly 4 decades, researchers have sought to better understand the psychological factors underlying expert performance (Starkes & Ericsson, 2003). Deliberate practice, motivation, and mental skills are recognized as crucial factors for attaining expert performance (Ericsson, Krampe, & Tesch-Römer, 1993; Hardy, Jones, & Gould, 1996; Mallett & Hanrahan, 2004). Along with these factors, perceptual-cognitive skills have emerged to be critical for skillful performance. **Perceptual-cognitive skills include pattern recognition, the use and extraction of anticipatory cues, visual search strategies, and signal detection (Janelle & Hillman, 2003).** Initial scientific effort on gaze behavior revealed that experts use fewer eye fixations, for longer durations, than nonexperts across a wide range of sports (Mann, Williams, Ward, & Janelle, 2007; Nieuwenhuys, Pijpers, Oudejans, & Bakker, 2008; Williams, Davids, Burwitz, & Williams, 1993). Gaze behavior has been studied predominantly in terms of location, duration, and frequency of fixations *during* the movement. However, Vickers (1992) claimed that the

gaze behavior before movement initiation, termed the **“quiet eye” (QE)** is a crucial factor differentiating successful from less successful performances and is defined as

the final fixation or tracking gaze that is located on a specific location or object in the visuo-motor workspace within 3° of visual angle for a minimum of 100 ms. The onset of the QE occurs prior to the final movement in the task, and the offset occurs when the gaze deviates off the object or location by more than 3° of visual angle for a minimum of 100 ms, [and] therefore the QE can carry through and beyond the final movement of the task. (Vickers, 2007, p. 280)

It has been suggested that during the QE period task-relevant environmental cues are processed and motor programs are retrieved and coordinated for the successful completion of the task (Vickers, 1996a, 1996b). Some studies have lent support to the motor-programming/preparation function of the QE period (Janelle, Hillman, Apparies, et al., 2000; Janelle, Hillman, & Hatfield, 2000; Mann, Coombes, Mousseau, & Janelle, 2011). Janelle, Hillman, Apparies, et al. (2000) studied rifle shooting and found that experts displayed a longer QE period along with a more pronounced hemispheric asymmetry than nonexperts. In another study with low- and high-handicap golfers, Mann et al. (2011) revealed that the low-handicap athletes exhibited longer QE periods and greater “bereitschafts” potential amplitude (i.e., characteristic of greater movement preparation) than the high-handicap group. Other studies that have manipulated task demands and QE duration (by manipulating the onset

Jean-Charles Lebeau, Sicong Liu, Camilo Sáenz-Moncaleano, Betsy Jane Becker, and Gershon Tenenbaum are with the Department of Educational Psychology and Learning Systems, Florida State University, Tallahassee, FL, USA. Susana Sanduvete-Chaves and Salvador Chacón-Moscoso are with Dpto. Psicología Experimental, Facultad de Psicología, Universidad de Sevilla, Sevilla, Spain. Salvador Chacón-Moscoso also is with Universidad Autónoma de Chile, Temuco, Chile. Address author correspondence to Jean-Charles Lebeau at jml11f@my.fsu.edu.

of the last fixation before movement unfolding) found that more complex tasks required longer QE durations, and only under a high information-processing load was a longer QE duration beneficial (Klostermann, Kredel, & Hossner, 2013; Williams, Singer, & Frehlich, 2002).

Several attempts have been made to explain the effect of the QE period on performance. The first studies on QE examined free throws in basketball and revealed that expert players fixate longer on the target, combined with an early fixation offset as the shooting unfolds (Vickers, 1996a, 1996b). The importance of this sequence of gaze control was conjectured in the location-suppression hypothesis (Vickers, 1996b). Specifically, before shooting, the expert player locates a particular target early and maintains quiet-eye fixation for a full second before initiating the shot. As the hands initiate the shot and the ball enters the visual field, fixation offset occurs and vision is suppressed. Vickers (1996a) explains these results in light of Posner and Raichle's (1997) work that identified three neural networks for optimal vision control. These networks include (a) the orienting attentional network; (b) the executive attentional network; and (c) the vigilance network, which coordinates both systems. The orienting network is responsible for guiding attentional resources to relevant environmental cues. The executive network is implicated in recognizing that a specific cue fulfills a specific goal. After the relevant cue has been identified, the vigilance network maintains attention on this critical cue. Hence, longer QE duration is a reflection of better coordination of attentional resources by the vigilance network. By maintaining attention on the target, an extended QE period prevents performance from being disrupted by irrelevant environmental cues. In addition, studies have shown that under certain conditions, a shift in gaze cannot occur without a preceding shifting of attention (Corbetta et al., 1998). In this manner, the QE duration is a reflection of the organization of critical neural networks necessary for the optimal control of visual attention.

A more recent account of the visual-attention motor networks involved in the QE effect has been provided by Vickers (2012). This explanation takes into account the dorsal attentional network (DAN) and the ventral attentional network (VAN). Both the DAN and VAN send information to the frontal lobes via two different routes (Corbetta, Patel, & Shulman, 2008; Corbetta & Shulman, 2002; Milner & Goodale, 1995). The DAN projects from the occipital lobe to the frontal lobe via the parietal lobe, while the VAN projects to the frontal areas via the temporal lobes. These two distinct neural circuits explain the different but complementary roles of both attentional networks (Vossel, Geng, & Fink, 2014). The main function of the DAN is to maintain focus of attention by blocking any stimuli that may intrude from the VAN system. The VAN includes the hippocampus and amygdala, which are responsible for recording memories and emotional control, respectively. The role of the VAN is to direct attention to unexpected stimuli, similar to a bottom-up control. It has been suggested that a longer QE acts as a mental buffer that prevents intruding thoughts

or emotions arising in the hippocampus and amygdala from distracting attention (Vickers, 2012). By activating the DAN at the expense of the VAN, the QE increases the focus of attention and protects against irrelevant thoughts and emotions.

Maintaining attention on critical external cues under stressful situations is another possible mechanism through which the QE can support performance. An extended QE period may indirectly affect motor performance by helping performers focus attention externally toward a single crucial cue (Vine, Moore, & Wilson, 2011; Wulf, 2007). Vickers and Williams (2007) suggested that the act of directing attention externally to critical task information (via the QE) insulates athletes from the normally debilitating effects of anxiety. A theoretical account of this effect is given by attentional control theory (ACT; Eysenck, Derakshan, Santos, & Calvo, 2007). ACT identifies two attentional systems: the goal-directed system and the stimulus-driven system. The goal-directed system is a top-down system that is influenced by current goals and expectations. Conversely, the stimulus-driven attentional system responds to prominent or noticeable stimuli and is described as a bottom-up system. Under normal (i.e., nonstressful) conditions a balance exists between these two attentional systems. Under stressful situations, human processing resources are diverted toward task-irrelevant and threatening stimuli, and thus anxiety disrupts attention by increasing the influence of the stimulus-driven attentional system at the expense of the more efficient goal-directed system (Eysenck et al., 2007; Wilson, 2008). By directing attention on a task-relevant goal (i.e., the target), the QE period stimulates the use of the goal-directed system and allows for a better balance between the two attentional systems. Directing attention to specific external relevant cues under stressful conditions is thus another plausible mechanism through which QE can help performance.

An alternative theoretical explanation has also been provided from the ecological-psychology and dynamic-system perspectives. Researchers adopting this framework claim that the function of the QE is to facilitate the orientation of the body in space and allow the skilled execution of movements that are adjusted for the temporal and spatial constraints of the task (Oudejans, Koedijker, Bleijendaal, & Bakker, 2005; Oudejans, van de Langenberg, & Hutter, 2002). The QE optimizes optic flow and allows a better orientation of the performer in relation to critical environmental demands. A prolonged fixation helps performance by continuously updating the relation between the athlete and the object, to best determine force, direction, or velocity. This updating is performed at a subconscious level and does not require cognitive processing (Oudejans et al., 2005).

There is currently no consensus in explaining the role of the QE in enhanced visuomotor skills. Vickers (2009) suggested that a successful theoretical model explaining the role of the QE in performance must take into account both rapid dynamic tasks (i.e., less than 200 ms) and "slower" tasks (i.e., more than 200 ms). Cognitive

theories have been relevant to explaining movements over 200 ms because there is adequate time for cognitive processing to occur. In contrast, the ecological models better explain movements under 200 ms in which the time constraints do not allow a major role for cognition (Vickers, 2007). All things considered, Vickers claims that “regardless of the theoretical perspective taken, there is considerable research evidence showing that the QE period is a perception-action variable that defines higher levels of skill and performance” (2007, p. 287).

The Current Synthesis

To our knowledge, only one meta-analysis has partially examined the importance of the QE period (Mann et al., 2007). Mann and colleagues quantified expertise differences on various perceptual-cognitive skills (e.g., response time and accuracy, number and duration of visual fixations, and length of QE period). Six effect sizes (ESs) for the QE period had a moderate-to-large mean effect ($\bar{r}_{pb} = .62$). No moderators were studied because of the small number of studies. After more than 20 years of research on the QE, and with the recent publication of QE intervention studies (e.g., Moore, Vine, Cooke, Ring, & Wilson, 2012; Wood & Wilson, 2012), a meta-analytic review of the QE literature is warranted. We synthesize the findings reporting on the relationship between the QE and performance and explore factors moderating this relationship.

Hypotheses

The literature on the QE is divided into two types of research: (a) nonintervention studies and (b) intervention studies. In an effort to be comprehensive, we consider both types of research but treat them separately. Following roughly the order in which studies arose, nonintervention studies are reviewed first, followed by intervention studies. For the nonintervention studies, we hypothesize that more skillful performers possess a longer QE period than less skillful ones, and that within individuals successful performance is associated with a longer QE period than is unsuccessful performance. For the intervention studies, we hypothesize that QE training will result in longer QE durations and enhanced performance compared with the control condition. We also predict a positive correlation between degree of QE-period improvement and performance outcome.

Moderating Variables

Several moderators were identified from the literature. These are source of data, setting, design, manipulation of anxiety/pressure, type of motor task, and QE measurement.

Source of data. Publication bias is a primary source of unreliable results in meta-analysis and a threat to its validity (APA [American Psychological Association]

Publications and Communications Board Working Group on Journal Article Reporting Standards, 2008; Rothstein, 2008; Shadish, Cook, & Campbell, 2002). We examined whether the study’s status (i.e., published or unpublished) leads to a statistically different QE and/or performance ESs.

Setting. Studies on the QE took place both in the laboratory and on the field. Because laboratory studies control for external variables potentially affecting performance, we tested whether different effects emerged in studies taking place in a controlled environment versus on the field.

Design. In studies without an intervention (i.e., in which participants were not trained to improve their QE period), two types of contrast were identified: the within-individual contrast and the between-individuals contrast. The within-individual contrast compares the lengths of QE periods for successful and unsuccessful performance outcomes of each participant. In contrast, the between-individuals ES compares QE periods between two separate groups, experts and nonexperts. We tested whether these two designs lead to differences in ESs.

Manipulation of anxiety/pressure. Anxiety and pressure were sometimes manipulated in studies both with and without interventions. As noted, anxiety has been widely reported to shift gaze behaviors toward threatening stimuli (Eysenck et al., 2007), thus increasing the influence of the stimulus-driven attentional system to the detriment of the goal-directed system (Eysenck et al., 2007; Wilson, 2008). We expected QE duration to be lower while performing under anxiety, leading to smaller ESs under anxiety conditions compared with normal conditions.

Type of motor task. Perceptual strategies of experts and novices are task dependent (Williams & Davids, 1995; Williams, Davids, Burwitz, & Williams, 1993, 1994). A common classification of sports is based on whether the task is self-paced (e.g., the performer controls the rate at which the skill is executed) or externally paced (e.g., the performer must react to external events to control his or her movement). Most research on the QE has focused on self-paced sports (e.g., golf putting, basketball free throws). Only a few studies have examined externally paced skills such as volleyball-serve reception and goal keepers’ responses to penalty kicks (soccer) or to shots (ice hockey). Athletes typically cannot control the duration of the preparation period in externally paced sports, leaving them with less opportunity to control their QE period. Thus, we tested whether the type of motor task (i.e., self-paced vs. externally paced) influenced the QE duration.

QE measurement. The method by which the QE is measured is an important variable to consider. The technology used (i.e., eye-tracker brand) was similar across all studies; thus, we did not expect differences deriving from the measurement tool. However, Vickers (1996a, 1996b)

introduced a specific paradigm, vision-in-action (VIA) to measure the QE period. This paradigm aims at increasing the reliability of the QE measure by synchronizing recordings from an external camera (capturing physical movement) to those from the eye-tracker camera. We coded this measurement paradigm to test whether it has an impact on the respective QE ESs.

In addition, the QE period was measured using two different methods: absolute or relative. The absolute measure of the QE period corresponds to the time (in milliseconds) between the QE onset and QE offset. Alternatively, the relative measure corresponds to the QE duration divided by the total time of the action (i.e., QE period plus movement time). This represents the percentage of the time that the athlete is engaged in the QE relative to the duration of execution of the entire skill. Since motor skills vary in duration and complexity, it was deemed important to account for this variable.

Finally, because of the evolution of the QE definition, the authors noticed some discrepancies in terms of fixation definition and the operationalization of the QE offset. In particular, fixation duration was set at either 100 ms or 120 ms and the visual angle from the target was selected at either 1° or 3°. We compared these different values to test whether they impacted the QE ES. The operationalization of the QE offset also differed across studies, with some authors using the beginning of the movement as a criterion and other authors selecting the target-fixation offset that can happen after the final movement started. Both operationalizations of QE-period offset were also tested to see whether they account for differences in ESs.

Method

Literature Search and Inclusion Criteria

The literature search was conducted using seven databases: SPORTDiscus, ScienceDirect, EBSCO, PsycNet, Web of Science, ResearchGate, and Scopus. SPORTDiscus was chosen because it is considered the most comprehensive and relevant database for sport studies providing full text for indexed journals; ScienceDirect, EBSCO, PsycNet, and Web of Science are considered high-quality and commonly used databases in this research area. One of the main experts in QE research, Dr. Joan N. Vickers (University of Calgary), suggested the inclusion of ResearchGate and Scopus. In addition, we searched book chapters, references from key studies and reviews, and gray literature: dissertations and theses, conference presentations that reported primary research, and other unpublished material obtained from several prominent authors (André Klostermann, Lee Moore, Samuel Vine, and Mark Wilson) who study QE. The search strategy combined the following terms: *quiet eye AND sport, gaze control AND sport, gaze AND sport, and gaze behavior*. These keywords were searched in full documents. The criteria for inclusion were that the study (a) was published before July 2014; (b) was written in English, Chinese, French, or Spanish; (c) was sport related (e.g., medicine

and law enforcement were excluded; nevertheless, two studies involving throwing and catching a ball were included because the motor elements of these tasks are a part of many sports); (d) provided QE and performance data; (e) used independent samples (i.e., multiple studies were not performed with the same participants); and (f) included sufficient data to calculate ESs. Next, studies were divided into two categories: (a) those that did not include QE training or any intervention but compared novices'/less successful performance to experts'/successful performance (included in Synthesis 1) and (b) those that presented QE training interventions (included in Synthesis 2).

The search generated 36 studies, of which 27 were finally included in Synthesis 1, yielding 38 ESs. Nine articles were included in Synthesis 2 yielding 15 ESs for QE and 14 ESs for performance. All the articles were written in English, except one included in Synthesis 2 that was written in Chinese. In addition, three articles were unpublished. Figure 1 describes the different steps of the selection process.

Data Extraction

Two raters (C. S.-M. and J.-C. L. for Synthesis 1; S. L. and J.-C. L. for Synthesis 2) independently coded all the studies. The variables in the coding sheet were first elaborated using a focus group involving five raters (C. S.-M., J.-C. L., S. L., S. S.-C., and S. C.-M.). The first draft was then tested on three articles by the first three raters separately, and the categories were further adjusted. The final coding sheet included the following dimensions: extrinsic characteristics, setting, participants, methodology, measures, and results (coding sheets are available from the authors upon request). The extracted data were entered into an Excel file and checked by two different raters (S. S.-C. and S. C.-M.). Interrater reliability was calculated using Cohen's kappa coefficient for each variable. Values higher than .7 were considered appropriate. Discrepancies were resolved by discussion.

Quality Assessment

The methodological quality of each article included in Synthesis 1 or 2 was evaluated using the 12 items presented in Appendix A. Studies were evaluated by two coders (J.-C. L. and S. L.). Interrater reliability for each item was calculated using Cohen's kappa coefficient. Values higher than .7 were considered appropriate. Discrepancies were resolved by discussion.

ES Calculation

In the present review, values from Cohen's *d* family of ES were calculated because of the comparative nature of our research question. Cohen's (1988) standards were used in interpreting our ESs. Specifically, ES values of .2, .5, and .8 were interpreted as small, medium, and large ES, respectively. To calculate ESs and their associated

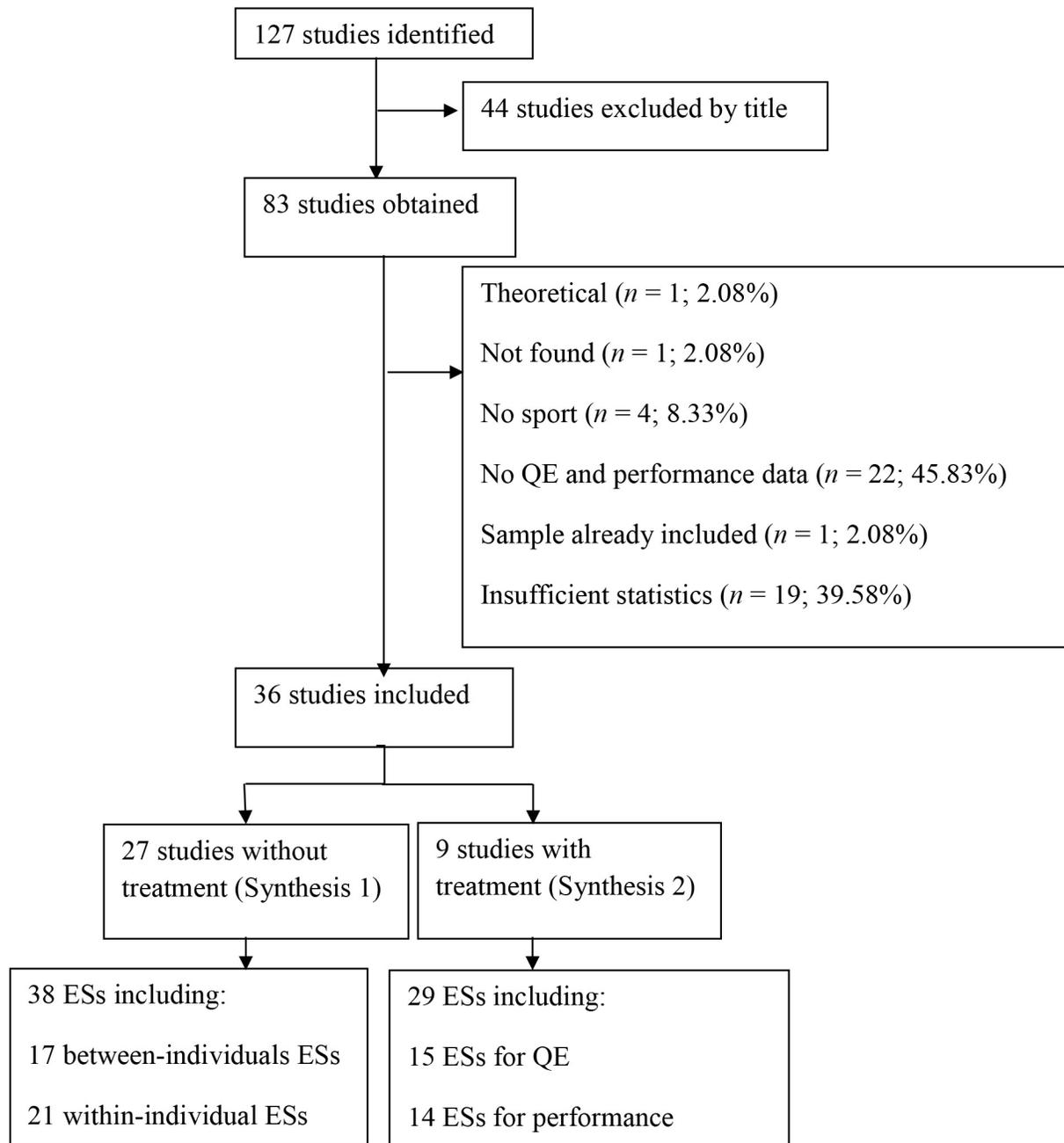


Figure 1 — Identification of studies included in the meta-analysis.

variances, descriptive statistics (i.e., means, *SD/SEM* values, and *n*) were collected by either searching the article or contacting author(s). In cases where neither method led to data, we used the ruler function of Adobe Acrobat Reader X Pro to obtain values from graphs. Hedges’s (1981) correction was employed to eliminate bias from all calculated ES estimates. Three special cases arose in the ES calculation process. **First**, when growth scores from intervention studies were used, we standardized the difference in the mean gain scores between the treatment

and control groups using the average of the pretest and posttest SDs. This produced an ES that accounted for pretest differences but that also was in the score-scale metric (not the gain-score metric). **Second**, when multiple measures of the same construct were available, we used different strategies for obtaining means and standard deviations. The mean was always the average of all the means measured. For example, when intervention studies had measures at baseline, Retention 1, and Retention 2, Retention 1 and 2 means were collapsed and compared

with the baseline measure. For standard deviations, the larger standard deviation value was selected when two standard deviation measures were reported, whereas the median standard deviation value was chosen when more than two standard deviation estimates were available. Last, 14 studies generated multiple ESs (including 7 papers from Synthesis 1 and 7 papers from Synthesis 2).¹ Specifically, 7 studies produced ESs in situations with and without pressure manipulation; 1 golf study produced one ES on level green carpet and another ES on sloped green carpet; 2 studies made available both absolute and relative measures of the QE ES; 1 study yielded six ESs because it consisted of three different samples and each sample produced both a within-individual ES (successful vs. unsuccessful performance) and a between-individuals ES (expert vs. novice); and, finally, 3 studies produced ESs on both self-paced and externally paced motor tasks.

Statistical Analysis Strategy

We used the *Metafor* package for R (R Core Team, 2014) and followed Borenstein, Hedges, Higgins, and Rothstein's (2011) recommendations for conducting the analysis. Specifically, we chose the random-effects model a priori because of the diversity of study characteristics (e.g., sport studied). We also calculated Q statistics to test our model assumptions. Once the model was supported, the between-studies variance parameter τ^2 was estimated using the restricted maximum-likelihood method. We checked for publication bias using both the *Egger test* (Egger, Smith, Schneider, & Minder, 1997) and the *trim-and-fill* procedure (Duval & Tweedie, 2000a, 2000b). A funnel plot based on trim and fill illustrated the possible missing studies. Last, potential predictors for between-studies variance were examined using a meta-regression model (i.e., mixed-effects model). When the Q test failed to support our random-effects model assumptions, we stayed with random-effects models (because of the diversity of study characteristics) followed by publication-bias checks and exploration of meaningful moderators.

Among the 38 ESs of Synthesis 1, 17 represented between-individuals ESs and 21 were within-individual ESs. Accordingly, ESs were grouped and analyzed separately. For Synthesis 2, 15 ESs for QE and 14 ESs for performance were calculated. QE ESs and performance ESs were also analyzed separately, and their relationship was explored.

Results

Interrater Reliability

Appendices 2 and 3 present the reliability coefficients obtained for the different coded variables across non-intervention and intervention studies, respectively. All the values obtained were acceptable; concretely, for nonintervention studies, 29 reliability coefficients were considered very good and 7 substantial (Landis & Koch, 1977); and for intervention studies, 43 were very good and 5 substantial.

Appendix D presents the reliability coefficients for the variables used to measure the methodological quality of the studies. All variables showed very good reliability coefficients, except for the type of controls used and the use of imputation for intervention studies, which obtained only substantial coefficients. We studied the relationship between the variables representing quality and ESs.

Synthesis 1: Nonintervention Studies

Study Characteristics and Quality Assessment

The main features of the studies included in Synthesis 1 are listed in Table 1. Studies were published between 1996 and 2014. The topic seems to have received much interest recently, with more than 50% of the included studies published in 2009 or later. One study was a doctoral thesis, while the other 26 were published articles.

Appendix E presents the main methodological characteristics of the studies included in Synthesis 1. In all studies, at least one dependent variable was standardized; all dependent variables were measured at all measurement occasions, and there was no follow-up period. Participants were not randomly assigned because groups were formed based on inherent characteristics (e.g., skilled and less-skilled players); nevertheless, some extraneous variables were controlled to enhance the equivalence between groups (e.g., handedness, normal vision). In 70.4% of studies the inclusion and exclusion criteria for selecting participants were provided. Fixation was well defined in 55.6% of studies (i.e., specifying angle and time on target for the QE period) and at least vaguely defined in 18.5% of studies (i.e., specifying only angle or time on target). The most common designs involved one group that provided repeated measures (48.1%) or more than one group that also provided repeated measures (44.4%). There was more than one measurement occasion in 92.6% of studies. Measurement occasions ranged from 2 to 10 ($M = 3.37$, $SD = 1.86$) and were averaged to get a mean value. In 84.6% of occasions, a control technique was applied; 73.1% of studies used constancy (i.e., maintaining constant the procedure and measurements in both experimental and control groups).

Statistical Analysis

Between-individuals studies. A significant homogeneity test was observed for between-individuals ESs (see Figure 2a), with $Q(df = 16) = 34.39$, $p < .005$. I^2 showed that 53.55% of the total variability of the between-individuals ESs could be attributed to true between-studies differences. Therefore, choosing the random-effects model was supported, and model parameters were estimated. The weighted mean effect was large, at $d = 1.04$ ($SE = 0.17$, $p < .001$), with $\hat{\tau}^2 = 0.26$. The population standard deviation of the true effects, $\tau = 0.51$, suggests

Table 1 Main Characteristics of Coded Studies Without Interventions

Study	Sport	N	Loc	Anx	VIA	Mot	Res	QE
Behan & Wilson (2008)	Archery	20	F	Yes	No	S	W	R
Campbell & Moran (2014)	Golf	45	L	No	No	S	B	A
Causer et al. (2010)	Shooting	16	F	No	No	S	BO	R
Causer, Holmes, Smith, et al. (2011)	Shooting	16	F	Yes	Yes	I	W	A
Janelle & Hillman (2000)	Rifle shooting	1	L	No	No	S	W	A
Janelle, Hillman, Apparies, et al. (2000)	Shooting	25	L	No	Yes	S	B	A
Kim et al. (2007)	Badminton	14	F	No	Yes	I	B	R
Lee et al. (2009)	Pistol shooting	10	F	Yes	Yes	S	B	A
Mann et al. (2011)	Golf	20	L	No	No	S	B	A
Martell (2010)	Basketball	11	L	No	Yes	S	W	A
McPherson & Vickers (2004)	Volleyball	5	F	No	Yes	I	B	A
Nagano et al. (2006)	Soccer	8	L	No	Yes	S	W	A
Nibbeling et al. (2012)	Dart-throwing	20	L	Yes	No	S	B	A
Panchuk & Vickers (2006)	Hockey	8	F	No	Yes	I	W	A
Panchuk & Vickers (2009)	Ice hockey	8	F	No	Yes	I	W	R
Park (2005)	Tennis	8	L	No	Yes	I	W	R
Piras & Vickers (2011)	Soccer	7	F	No	Yes	I	W	A
Rienhoff et al. (2012)	Dart-throwing	29	L	Yes	No	S	B	A
Rienhoff et al. (2013)	Archery	20	L	Yes	No	S	W	R
van Lier et al. (2008)	Golf	6	L	No	Yes	S	W	A
Vickers (1996b)	Basketball	10	L	Yes	No	S	W	A
Vickers & Adolphe (1997)	Volleyball	12	F	No	Yes	I	B	A
Vickers & Williams (2007)	Biathlon shooting	10	L	Yes	Yes	S	W	A
Vine et al. (2013)	Golf	50	L	Yes	Yes	S	W	A
Wilson & Percy (2009)	Basketball	26	L	No	No	S	B	A
Wilson et al. (2009)	Basketball	16	L	No	Yes	S	W	A
Wilson et al. (2013)	Throwing/catching ball	32	L	No	No	BO	B	A

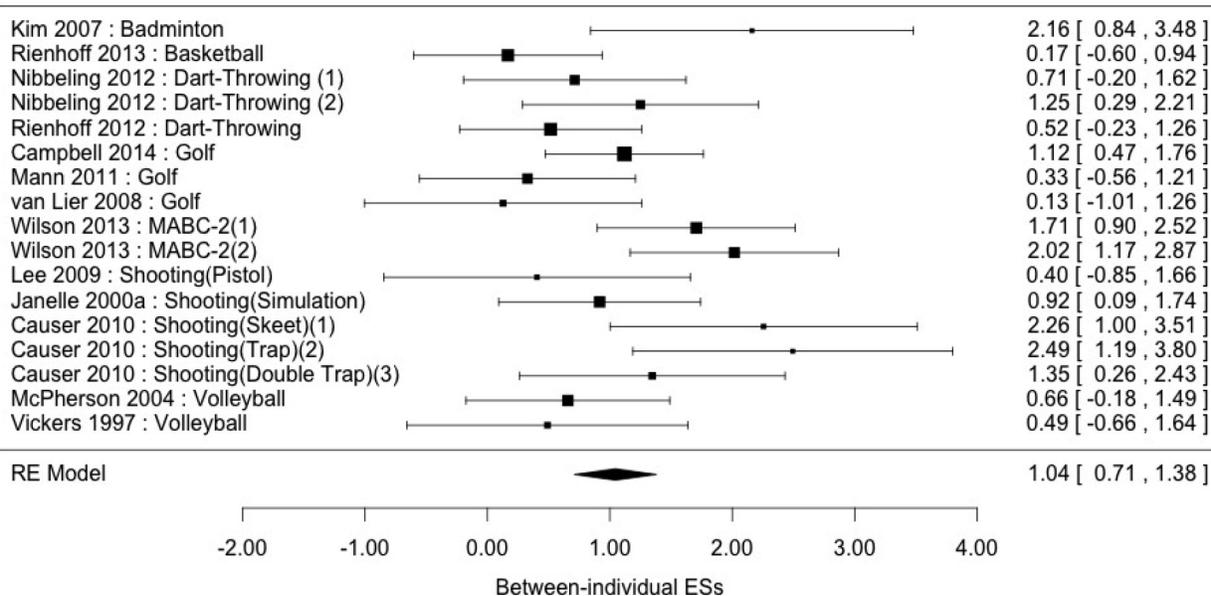
Note. N = sample size; Loc = study location (F = field where the sport takes place; L = laboratory); Anx = pressure situations are introduced as a mean to manipulate anxiety; VIA = use of vision-in-action; Mot = motor task (S = self-paced—motor skills are initiated by the athletes; I = interceptive—the athletes have to react and intercept an object; BO = both); Res = type of research (B = differences between experts and novices or high- and low-skills athletes are studied; W = within—only experts or novices participate, and their best and worst performance is compared; BO = both); QE = quiet-eye period measure (A = absolute—quiet-eye duration is the time-lapse measure in milliseconds or seconds; R = relative—absolute quiet-eye duration over the total time of the movement, representing the percentage in which an athlete was engaged in the quiet eye over the duration of the whole skill).

that 95% of the true between-individuals ESs will lie within approximately ± 1 around the mean, or between 0.04 and 2.04. This is a wide range of true effects, but all are positive.

Egger's test was nonsignificant ($p > .16$), suggesting symmetry in the funnel plot, a graphical display for the detection of publication bias. The trim-and-fill method also suggested no missing studies in the funnel plot, implying little chance of publication bias. Given the consistent results of both the Egger test and the trim-and-fill method, publication bias was not considered to

be likely for the between-individuals ESs of Synthesis 1. The analysis of the mixed-effects models for study features revealed *absolute* (i.e., reporting an absolute QE duration in milliseconds vs. as a percentage of the entire movement duration) as a significant predictor of the between-individuals ESs (see Table 2), with studies using absolute measures reporting ESs that were 1.18 standard-deviation units smaller than those in studies using relative measures. No other moderators reached significance. The mixed-effects model for *absolute* accounted for almost half (49.97%) of the between-individuals ES variability.

2a



2b

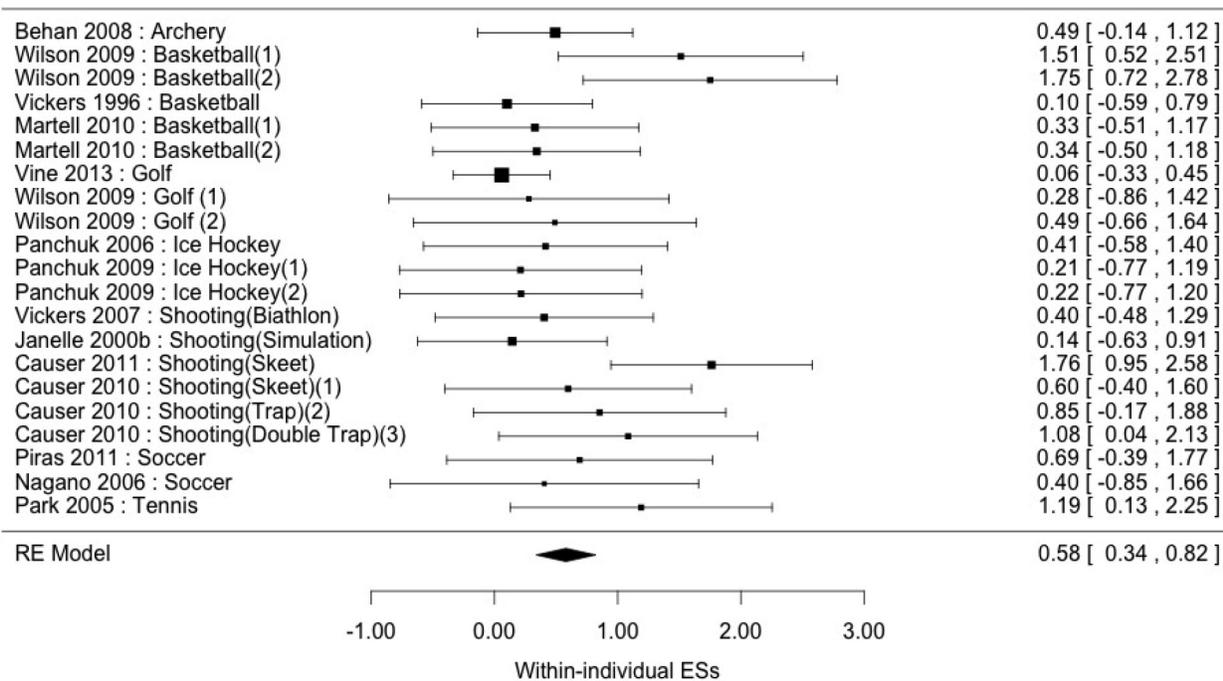


Figure 2 — Forest plots of random-effects (RE) model for between-individuals (a) and within-individual (b) effect sizes (ESs) of Synthesis 1. The ESs are sorted according to sport type. Multiple ESs from individual studies are marked by numbers in parentheses. MABC-2 = Movement Assessment Battery for Children, Second Edition.

Table 2 Final Mixed-Effects Model for Between-Individuals Effect Sizes of Synthesis 1

Variable	Regression model		Overall model statistics	
	Estimate	SE	Index	Value
Intercept	2.01***	0.36	$Q_{\text{residual}} (df = 13)$	22.91
Absolute	-1.18**	0.40	$Q_{\text{model}} (df = 1)$	8.82**
R^2				49.97%

Note. Absolute = absolute measure of quiet-eye period.
 ** $p < .01$. *** $p < .001$.

Within-individual studies. The homogeneity test for the within-individual ESs was not significant (Figure 2b), with $Q(df = 20) = 30.40, p > .06$. However, I^2 suggested that 36.21% of the total variability of within-individual ESs came from between-studies differences. We adhered to the random-effects model for parameter estimation. The mean effect was significantly different from zero, with $\bar{d} = 0.58 (SE = 0.12, p < .001)$, and the between-studies variance of $\hat{\tau}^2 = 0.11$ suggests that 95% of the true effects likely fall between -0.07 and 1.23. This is a narrower range than was found for the between-individuals effects.

The Egger test reached significance ($p < .04$). The trim-and-fill method suggested adding 2 studies on the right side of the funnel plot of the data. With this addition, the size of the mean effect increased from moderate to moderate-to-large. The adjusted mean was $\bar{d} = 0.68 (SE = 0.12, p < .001)$, with $\hat{\tau}^2 = 0.16$. Thus, consistent evidence supported that publication bias was likely for the within-individual ESs in Synthesis 1, and the pattern of potential missing values led to stronger effects than the sample data showed. The analysis of mixed-effects models revealed no significant predictors of the within-individual ESs. Appendix F shows the intercorrelations among the moderators of Synthesis 1. Because the highest correlation was $r = -.59$, moderators do not appear highly confounded with each other in our analysis.²

Study Characteristics and Quality Assessment

All the studies included in Synthesis 2 were published between 2010 and 2014. The main features of these articles are listed in Table 3. Description of the samples was highly detailed (see Table 3), with mean age and sport specified in all studies, and the age standard deviation reported in 88.9% of studies. Characteristics of the intervention were also made explicit, such as the period (100%), intensity (88.9%), whether the intervention targeted individuals or groups (88.9%), and exclusion criteria (100%).

Concerning methodological characteristics (see Appendix G), inclusion and exclusion criteria for units were provided in all studies. The design was experimental in 77.8% of studies, while the remaining 22.2% were quasi-experiments with some extraneous variables controlled. Attrition was not noted in 55.6% of studies;

in other studies, attrition ranged from 18.52 to 33.33% of the original sample. Differential-attrition information between groups was provided in one study, and in only one study did authors use statistical methods for imputing missing data. Follow-up periods ranged from 0 to 2 months. Moreover, 88.9% of studies had more than one measurement occasion; this variable ranged from 1 to 9 ($M = 3.56, SD = 2.35$); all the variables were measured on all the occasions. In most cases (88.9%), at least one dependent variable was standardized, and in 77.8% of the occasions, the variables were clearly defined.

Statistical Analysis

Quiet-eye effects. The homogeneity test for the QE ESs was nonsignificant, $Q(df = 14) = 10.61, p = .72$, and I^2 indicated that less than 0.01% of the total variability of the QE ESs comes from between-studies differences. However, a random-effects model was still chosen to estimate parameters. The mean ES was very large at $\bar{d} = 1.53 (SE = 0.13, p < .001)$, with $\hat{\tau}^2 < 0.01$ in the population of QE ESs (see Figure 3a). This value of $\hat{\tau}^2$ suggests that 95% of the true effects will lie within a band of approximately ± 0.20 around the mean, or between 1.33 and 1.73.

Egger’s test resulted in a nonsignificant effect ($p > .31$), and the funnel plot based on trim and fill revealed only one potential missing study, on the left. Therefore, the average effect was reestimated as $\bar{d} = 1.49 (SE = 0.13, p < .001)$, with $\hat{\tau}^2 < 0.01$, a very large ES similar to the previous estimate (i.e., $\bar{d} = 1.53$). Analyses of mixed-effects models identified no significant predictors of QE ESs.

Performance effects. The homogeneity test for performance ESs also failed to reach significance, $Q(df = 13) = 9.61, p < .73$, and I^2 suggested that less than 0.01% of the total variability in performance ESs came from the between-studies differences. Consistent with previous analyses, we used a random-effects model to estimate parameters. We found a large mean effect, $\bar{d} = 0.84 (SE = 0.12, p < .001)$, with $\hat{\tau}^2 < 0.01$, in the population of performance ESs (see Figure 3b). Egger’s test was marginally significant with $p = .052$. The funnel plot based on trim and fill suggested four missing studies on the left. Incorporating these potentially missing studies, the mean effect was adjusted from a large ES (i.e., $\bar{d} = 0.84$)

Table 3 Main Characteristics of Coded Studies With Interventions

Study	Sport	N	Loc	Anx	VIA	Mot	Res
Causer, Holmes, & Williams (2011)	Shotgun shooting	20	L	No	Yes	I	B
Lan & Dai (2010)	Basketball	35	L	No	No	S	W
Miles et al. (2014)	Catching	16	F	No	Yes	S	W
Moore et al. (2012)	Golf	40	F	Yes	No	S	W
Vine et al. (2011)	Golf	22	F/L	Yes	Yes	S	B
Vine & Wilson (2010)	Golf	14	F	Yes	Yes	S	W
Vine & Wilson (2011)	Basketball	20	L	Yes	No	S	W
Wood & Wilson (2011)	Soccer	20	F	Yes	No	S	B
Wood & Wilson (2012)	Soccer	20	F	Yes	No	S	B

Note. N = sample size; Loc = study location (F = field where the sport takes place; L = laboratory); Anx = pressure situations are introduced as a mean to manipulate anxiety; VIA = use of vision-in-action; Mot = motor task (S = self-paced—motor skills are initiated by the athletes; I = interceptive—the athletes have to react and intercept an object); Res = type of research (B = differences between experts and novices or high- and low-skills athletes are studied; W = within—only experts or novices participate, and their best and worst performance is compared.)

to a moderate-to-large one (i.e., $\bar{d} = 0.69$, $SE = 0.11$, $p < .001$, with $\hat{\tau}^2 < 0.01$). Based on the bias impact criterion (Borenstein et al., 2011), the QE ESs were more resistant to publication bias than were the performance ESs. Analysis of mixed-effects models identified no significant predictors of the performance ESs.

The correlation between the QE ES and performance ES was also explored (see Figure 4). An outlier was identified because of its distance from the regression line. A closer examination revealed that this data point is the only one (among 14 pairs) whose performance ES is larger than its QE ES. Because we expected the trained variable (i.e., QE) to show a larger change than the outcome variable (i.e., performance), we performed a sensitivity analysis. For the complete data set the correlation coefficient between the QE ES and the performance ES was $r = .45$ ($p = .12$). After removing the outlier from the data set, a significant and strong correlation coefficient was observed ($r = .58$, $p = .049$). To help interpret the QE–performance relationship across intervention studies, we ran a weighted regression based on the outlier-free data. The regression treated the performance ES as outcome and QE ES as predictor. The weighted regression analysis revealed that QE is a marginally significant predictor of performance across intervention studies, $\hat{\beta} = .40$ ($SE = .24$, $p = .060$).

Discussion

The aim of this study was to provide a quantitative synthesis of the literature on the QE in sports settings by analyzing both intervention and nonintervention studies. In Synthesis 1 we examined nonintervention studies and estimated the magnitude of the difference in QE duration between expertise levels and between successful and unsuccessful performances within the same individuals. In Synthesis 2, we estimated the magnitude of the QE duration and performance differences between

individuals who received QE training and those from comparable control groups (or following ordinary training regimens). In addition, we analyzed the relationship between the QE duration and performance effects. In both syntheses we fit meta-regression models to examine potential moderators. The review of the intervention studies and the examination of potential moderators expand on the QE literature that was previously reviewed quantitatively by Mann and colleagues (2007) or narratively by Wilson, Causer, and Vickers (2015). This review constitutes, to our knowledge, the first meta-analysis specifically targeting the QE period in sports.

Synthesis 1: Nonintervention Studies

A large mean ES ($\bar{d} = 1.04$) was found for the between-individuals differences in the QE period. This ES is larger than the moderate-to-large ES reported by Mann et al. (2007) in their meta-analysis, and in line with previously reported expert–novice differences (Janelle, Hillman, Apparies, et al., 2000; Vickers, 1996a, 1996b). Overall, experts use a substantially longer QE period than do novices, across sports. Moreover, within-individual differences were moderate ($\bar{d} = 0.58$) but substantially smaller than the average difference between experts and novices. In addition, this average ES is smaller than the mean obtained by Mann and colleagues (2007).

Several explanations can account for the smaller ES found in the within-individual studies compared with the between-individuals studies. First, inconsistency among QE researchers in defining and selecting successful/unsuccessful trials within participants may have resulted in a lower ES. For example, many studies have participants keep performing until an equal number of successful and unsuccessful trials have been reached. Participants in some studies (e.g., van Lier, van der Kamp, & Savelsbergh, 2008) performed 45 trials, whether they were successful or not. Another study (Vine, Lee, Moore, & Wilson, 2013) had golfers putt until they missed one,

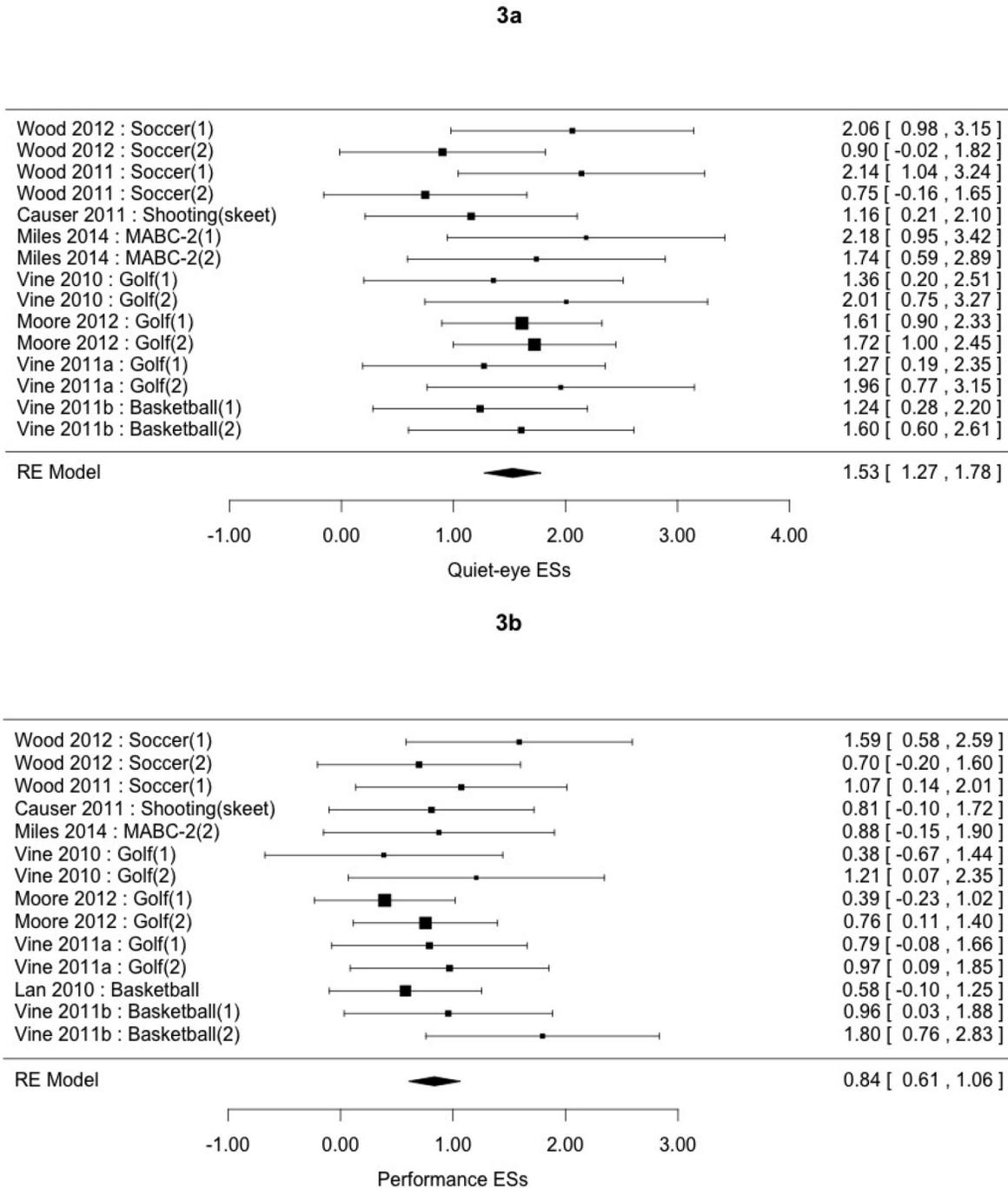


Figure 3 — Forest plots of the random-effects (RE) model for quiet-eye (a) and performance (b) effect sizes (ESs) of Synthesis 2. The ESs are sorted according to sport type. Multiple ESs from identical studies are marked by numbers in parentheses. MABC-2 = Movement Assessment Battery for Children, Second Edition.

and considered the single missed putt as an unsuccessful outcome. Using one trial versus the mean of several trials can lead to QE durations of different quality and possibly different lengths, especially when it comes to short durations of less than a second. The reliability of a measure based on just one trial is clearly questionable. Second,

greater differences are expected between participants than in intraindividual fluctuations. This is especially true when the between-persons comparisons contrast participants of different skill levels. Furthermore, motor-learning research (Schmidt & Lee, 2011) has maintained that as performers accumulate more experience on a

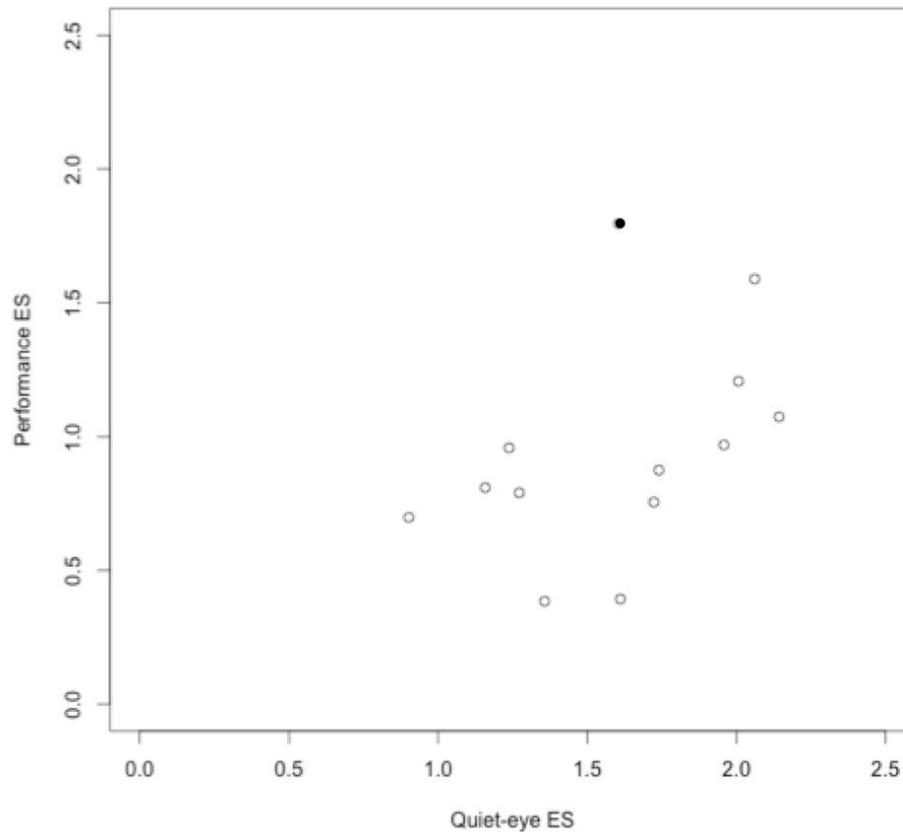


Figure 4 — Scatterplot showing relationship between the quiet-eye and performance effects. The solid dot represents the suspected outlier. ES = effect size.

certain task, intraindividual differences (i.e., variability) decrease substantially. Last, publication bias may have led to a deflated ES, as the trim-and-fill method suggested an additional 2 studies should appear above the mean, which raised the ES from 0.58 to 0.68.

A moderator analysis performed for the between-individuals studies revealed that the method of measuring the QE duration accounted for almost half of the QE-effect variability. Studies reporting a relative measure of QE duration (i.e., a percentage of the total movement time) had a larger mean ES than studies reporting an absolute duration (in milliseconds). Perhaps the tasks studied required relatively short movements (usually less than a second, e.g., putting in golf, kicking a ball, or shooting a rifle); an absolute measure of the QE period (hundreds of milliseconds) may be less sensitive than measures of percentages of the total movement time for such tasks. More scientific effort is needed to explore the QE periods for longer movement times and to compare absolute to relative measures within the same study. Contrary to our hypotheses, none of the other moderators (i.e., setting, manipulation of anxiety, type of motor task, and VIA measurement paradigm) were found to be statistically significant. The relatively small number of studies of the QE phenomenon, combined with rather low power,

may account for this finding. Indeed, for the moderator analyses, post hoc power analyses (Hedges & Pigott, 2004) showed that the highest level of power was only .429, for the one-tailed test of the effect of using anxiety inducements. All other power levels for nonsignificant moderator tests were at least .10 lower.

Synthesis 2: Intervention Studies

Nine studies with QE interventions were reviewed, and two types of ES were extracted. The first type measured the mean difference between training and control groups on the length of the QE period. The second tapped the difference in performance between the two groups. Large mean ESs were found for both the QE and performance outcomes; however, the former was larger than the latter (i.e., $d = 1.53$ vs. $d = 0.84$). This difference between the effects for the QE period and for performance is expected because the QE period is the intended target of the interventions. The observed performance enhancement is a by-product of having a better focus of attention on a single external cue and overall better motor preparation for the movement (Vine et al., 2011; Wulf, 2007).

The large average QE ES suggests that the QE training is a successful intervention to prolong the final

fixation of gaze before the initiation of movement. These results are in line with the literature showing not only that the QE period has an effect on performance but also that gaze behavior can be learned and trained (e.g., Vine et al., 2011; Wood & Wilson, 2011).

The moderate-to-large mean ES obtained for the performance indicates that interventions aimed at prolonging the QE period also indirectly affect task performance. A marginally significant regression coefficient ($\hat{\beta} = .40$, $SE = .24$) of QE ES on performance ES across studies offers insight on the overall quantitative connection between the two variables, at least within the ES range studied. That is, performance tends to improve by almost half of a standard deviation with an increase of one standard deviation in QE duration. Furthermore, the meaningful influence of QE on performance was also supported by individual studies. For example, Nibbeling, Oudejans, and Daanen (2012) showed that, under a high-anxiety condition, the final visual fixation of dart-throwers predicted over 63% of performance variance.

The promising results obtained for the intervention studies call for including QE training as part of the training regimen in practice because athletes show considerable room for QE improvement (i.e., $\bar{d} = 1.53$). Although access to eye-tracking technology is not universal because of its price and complexity, the idea of experimentally manipulating the beginning and the end of the last fixation before movement initiation (as in Klostermann et al., 2013) can be a useful training method to enhance performance. Moreover, the study by Vine et al. (2013) opens the door to studying the QE period after movement—what was termed the “*quiet-eye dwell time*” (Vickers, 1992). Their study showed that QE durations for golfers during and after putter movement were negatively related to disruptions in attentional control, and short durations were associated with subsequently hampered performance. Furthermore, Klostermann and colleagues (2013) developed a paradigm for examining QE as an independent variable, allowing corroboration of earlier findings on a possible causal link between QE and performance. In addition, they found that QE played a fundamental functional role in the facilitation of information processing, especially in conditions with increased task demands.

The results obtained in this meta-analysis signify the QE period as a key perceptual-cognitive variable affecting performance. By extending the final fixation before movement initiation, performers are better able to retrieve and coordinate motor programs for the successful completion of the task (Vickers, 1996a, 1996b). During the QE period, the performer is actively picking a specific target and maintains the focus on that single target. This period of focused attention leads to less susceptibility to attentional disruption caused by irrelevant cues (Posner & Raichle, 1997). This allows for stronger performance even under anxiety or high cognitive load (Vickers & Williams, 2007). Coupled with these gains in attention and focus, the prolonged fixation allows the performer to

better prepare for action execution (Mann et al., 2011), which ultimately enhances performance.

The finding that only one potential moderator variable was related to the size of the QE effects can be viewed in two ways. To the extent that we assume the set of studies reviewed is complete and representative, the lack of significant moderators testifies to the robustness and generality of the QE effect. This reflects what Cook (1993) refers to as “heterogeneous irrelevancies”—factors that vary but do not impact our study outcomes. Finding heterogeneous irrelevancies supports broader generalizations. On the other hand, the power of this synthesis to detect moderator effects was relatively low. More studies, or larger studies, would enable stronger assessments of the moderator effects.³

Limitations and Future Research Directions

One limitation of the present meta-analysis is the focus on sport performance. Some studies have examined the relation between the QE period and performance in other domains (e.g., law enforcement, surgery). It may be of interest to compare the current results with QE findings in domains outside of sport and to explore whether our findings generalize across domains.

A nonsignificant homogeneity test was found for the intervention studies, indicating that they were very consistent, and no significant moderators emerged. In addition, most of the intervention studies were designed similarly (e.g., having baseline, training, Retention 1, transfer, and Retention 2 time points), and the populations studied were very similar (i.e., young adults). The majority of the studies used a sample size of 10 participants or fewer per group. Hence, more intervention studies are needed with larger and more diverse samples and domains to identify potential moderators affecting training to lengthen the QE period.

Although most of our intervention studies (with the exception of Wood & Wilson, 2012) used a QE-training protocol targeting only gaze behaviors, no information on the effectiveness of each component of the protocol is provided. Also no follow-ups have been performed in these studies, which leads one to wonder whether the benefits are maintained in the long term.

Another limitation of the extant QE literature is the existence of some variability in the definition of fixation duration (either 100 ms or 120 ms) and deviation angle from the target (1° or 3°). Even if the fixation definitions of the studies included in this review are consistent with Vickers’s (2007) definition of the QE, the results might vary in the case of a small target. We tested both fixation durations and angles as moderators in all our models, and neither of them revealed a significant effect on the results. Nonetheless, we suggest developing a common, clearer, operational definition of fixation duration and angle from the target that defines the QE period. Future studies can address this issue by directly comparing the data obtained from different fixation definitions within the same study.

While our cross-study comparisons are informative, and these definitional variations are not confounded with other study features, within-study comparisons would provide stronger evidence on this matter.

Furthermore, the QE literature can also benefit from a consensus on the operationalization of the offset of the QE period. Because of the evolution of the QE definition, some authors used the beginning of the final movement as the offset of the QE while other authors used the target fixation offset that can happen after the final movement started. Twenty-six of the 36 studies included in this review used the beginning of the final movement as the QE offset because of the natural constraints of the tasks. Ten studies use the fixation offset as the end of the QE period, as useful information was still available after the final movement starts. These 10 studies represent 5 sports, and only studies on shooting and basketball⁴ show inconsistency in their operationalization of QE offset. Hence, only 2 sports (out of 11) differ in their definition on the end (but not the beginning) of the QE period. Together with the fact that 26 out of 36 studies were consistent in their definition of the QE, the agreement within and between sports is large, but a complete consensus has not been reached yet. Such a consensus will also facilitate the comparison of QE duration across studies. These differences in QE offset operationalization did not, however, relate to the size of the QE effect in our data.

The results obtained in this meta-analysis are in line with our main hypotheses. Higher level athletes used a longer QE period, and longer duration is associated with enhanced performance. This relationship between the QE duration and performance not only is true when experts and novices are compared but also is evident when successful and less successful performances within the same participant are contrasted. Our results extend those found in the previous review of the QE literature (Mann et al., 2007) by identifying different ESs based on the use (or not) of an intervention protocol and the isolation of the measurement method of the QE period (i.e., absolute vs. relative) as a moderator. Finally, we found that intervention programs designed to lengthen the QE period are effective in extending the gaze behaviors, which ultimately lead to performance improvement.

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Notes

¹We ran a sensitivity analysis to check whether such a dependence issue would bias the results. The results of the sensitivity analysis supported that all the effect estimates are robust given the dependence between multiple ESs.

²Although the correlation coefficient between *Degree1* and *Duration100* is fairly large at $-.59$, a high correlation is expected

from the QE definition and neither moderator shows high correlations with other moderators.

³One such moderator that would require investigation is the type of sport task. Processes underpinning performance in self-paced and externally paced tasks are somewhat different and the QE period might have a different role in these two kinds of tasks.

⁴In the basketball free throw task, the basketball enters the visual field of elite shooters near to the eyes, and occludes the hoop thus perturbing fixation on the target before the end of the movement. The constraints found in the task are what lead to an early QE offset in elite shooters.

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References marked with an asterisk indicate studies included in the meta-analysis. One asterisk indicates papers included in Synthesis 1; two asterisks indicate papers included in Synthesis 2.

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