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Perceptual-Cognitive Processes in Sport: the Role of the Sports Task on Quiet Eye

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Contents

Table of Abbreviations

ACT	Attentional Control Theory
ANOVA	Analysis of Variance
AOI	Area of Interest
BPSM	Biopsychosocial Model of Challenge and Threat
CSAI-2	Competitive State Anxiety Inventory-2
DAN	Dorsal Attentional Network
DRES	Demand and Resource Evaluation Score
EEG	Electroencephalography
EMG	Electromyography
EOG	Electrooculography
ET	Eye Tracking
FIP	Italian Basketball Federation
FIPM	Italian Federation of Modern Pentathlon
HP	High-Pressure
HR	Hear-Rate
MRF-3	Mental Readiness Form-3
MRF-L	Mental Readiness Form-Likert
NOPP	No Performance Pressure
NOTP	No Time Pressure
PP	Performance Pressure
QE	Quiet Eye
QED	Quiet Eye Duration
QEO	Quiet Eye Onset
RPE	Rating of Perceived Exertion
RQED	Relative Quiet Eye Duration
SMI	Sensomotoric Instruments
SMI ETG 2	Sensomotoric Instruments Eye Tracking Glasses 2 System
SPSS	Statistical Package for Social Science
STAI-Y2	State Trait Anxiety Inventory-Y2
TP	Time Pressure
VAN	Ventral Attentional Network

Chapter 1: Introduction

1.1 The quiet eye

Researchers have been focused long-standing on uncovering the various factors that influence athletes' performances. One of the primary ways to investigate such factors was to study the characteristics of skilled and experts athletes, given that they fulfill in a consistent way maximum sports performances (Starkes, 1993). According to Janelle and Hillman (2003), an expert is an individual that has high competencies in physiological, technical, emotional, and cognitive domains. Studies identified perceptual-cognitive skills as a critical component among the various cognitive factors that can influence high-performance achievement (for a complete overview, cf. Baker & Farrow, 2015; Tenenbaum & Eklund, 2007). Marteniuk (1976) defined these skills as identifying and processing environmental information, integrating it with existing knowledge to select and execute the appropriate action. Perceptual-cognitive skills include pattern recognition, using and extracting anticipatory cues, signal detection, and visual search strategies (Janelle & Hillman, 2003). The studies on the visual search strategies of athletes during their sports performances showed that expert athletes performed fewer and longer eye fixations than non-experts athletes (Mann et al., 2007). Moreover, the studies revealed that a peculiar fixation, named as "Quiet Eye" (QE), is a hallmark of superior expertise and performances across several sports which require aiming tasks (Vickers, 2007). The QE is defined as "a fixation or tracking gaze that is located on a specific location or object in the visuomotor workspace within 3° of visual angle for a minimum of 100 ms" (Vickers, 2007). The initiation of the QE (i.e., QE onset) occurs before the critical phase movement of the task. The end of the QE (i.e., the QE offset) occurs when "the gaze moves off the location by more than 3° of visual angle for a minimum of 100 ms" (Vickers, 2016b). Accordingly, the initiation of the QE is determined by the onset of a specific movement in the task (Vickers, 2007). The literature outlines that an earlier onset and a longer quiet eye duration (QED) correlates with greater athletes' expertise and best performances (Lebeau et al., 2016; Mann et al., 2007; Rienhoff et al., 2016); in addition, QE training positively affects task performance (for a meta-analysis, see Lebeau et al., 2016). Notwithstanding a substantial amount of literature that describes QE as a critical phenomenon for aiming tasks performances, the underlying mechanisms of this fixation are not entirely understood. Several hypotheses have been postulated through the years, attempting to comprehend better QE nature and its relation with the highest expertise and performance levels.

1.2 An overview on (possible) quiet eye mechanisms

1.2.1 Programming and online control functions

In one of the first QE studies, Vickers showed that élite basketball players had a longer QED than near-élites during free throws. Moreover, élites exhibited longer QED in their successful throws than unsuccessful ones (Vickers, 1996). Vickers proposed that such a prolonged fixation aimed to promote movement's programming and parameters, such as "the location and distance to the target, the trajectory on the ball, the optimal forces needed throughout the action, the timing, and the coordination of the limbs" (Vickers, 1996). Accordingly, the QE has been defined as a period exploited by athletes before the critical phase of the action to program and optimize the movement parameters to achieve optimal aiming performances (Williams et al., 2002). The first experimental study supporting this speculation has been conducted on billiard players (Williams et al., 2002). The authors observed that players engaged in increasing difficulty shots augmented their QED depending on the increase of shot complexity (e.g., by requiring players to "pocket" the ball with direct shots or by exploiting the table's edges; Williams et al., 2002; cf. Horn, Okumura, et al., 2012, and Walters-Symons et al., 2018). Other studies exhibited similar findings also in different sports than billiards (e.g., golf, basket, darts, bowling; Horn, Alexander, et al., 2012; Klostermann et al., 2013; Walters-Symons et al., 2018), suggesting that the QE is a critical period to pre-plan movement parameters before the crucial phase of the movement (Vine, Moore, & Wilson, 2014; for a recent review examing the response programming role of the QE, see also Gonzalez et al., 2017). Other findings that support the QE programming hypothesis come from studies that investigated QE in tasks characterized by time constraints or externally-paced tasks (in which athletes cannot decide the timing of the action due to factors outside their control; Kent, 2007). These researches have shown that expert athletes under these peculiar conditions anticipate the beginning of the QE (i.e., QE onset), a strategy related to high performances (Joe Causer et al., 2010, 2011; Panchuk & Vickers, 2006). Instead, failure to anticipate the QE onset led to poor performances (Williams et al., 2002). Given such findings, the authors proposed that anticipating the QE is a strategy to gain more time to program the movement parameters before the critical movement of the action, with a positive role in aiming performances, in line with the QE programming function.

In summary, following the programming hypothesis, the literature showed that QED depends on the amount of processed information required to fine-tune the motor parameters for successful performances. This process occurred before the initiation of the critical movement of the action.

Although several findings support the QE programming hypothesis, some authors have hypothesized that QE can fulfill the monitoring of the ongoing motor action by using environmental visual information to adjust the action that is taking place (Vine et al., 2017), the so-called *online control hypothesis* (Oudejans et al., 2002). This hypothesis underlines the relevance of the portion of the QE that occurs after the initiation of the critical movement of the action.

Despite the contrast between *programming* and *online control* functions, recent studies highlighted that QE could fulfill both (Causer et al., 2017). For example, Causer and colleagues (2017) manipulated the vision of golfers (i.e., occluding the vision of the golf club and ball as the backswing began), showing that QE was strategically adapted depending on the vision condition through anticipation of the QE onset or delay of the QE ending (i.e., QE offset). Given that many empirical findings support both the programming and online function of the QE, many authors suggested considering not only the total duration of the QE but also its initiation (QE onset) and ending (QE offset) according to the specific sport-movement occurred (Causer, Hayes, Hooper, & Bennett, 2017; Vine, Lee, Walters-Symons, & Wilson, 2017; Vine, Lee, Moore, & Wilson, 2013; Rosanna Walters-Symons, Wilson, Klostermann, & Vine, 2017).

1.2.2 Visual attention control: the top-down and bottom-up networks

Employing a neuro-behavioral perspective, Gonzalez and colleagues (2017) suggested that QE may be involved in attentional control processes, given the overlap between brain areas involved in attentional processes and eye movements (cf. Goldberg et al., 1986; Moore & Fallah, 2001; Moore & Fallah, 2004; Rizzolatti et al., 1987). According to Corbetta & Shulman (2002), the visual environmental information is computed through two neural pathways that continuously interact with each other: the dorsal attentional network (DAN or top-down control network) and the ventral attentional network (VAN or bottom-up control network). The first path elaborates information according to internal goals, allowing for easier identification of environmental cues related to the internal plans (i.e., goal-directed attentional system). The second pathway is a stimulus-driven attentional system, responding to relevant and unattended stimuli through the so-called "attention-grabbing effect" (Corbetta et al., 2008; Corbetta & Shulman, 2002). In other terms, if salient stimuli arise, as distracting or anxiety-inducing ones (Vickers, 2016), VAN acts as a "circuit breaker" towards DAN, enabling the shift of the attention focus towards the new relevant cues (Corbetta & Shulman, 2002). Several authors suggested that the QE could aid the attention allocation process fulfilled by the top-down control network. To test for this hypothesis, the authors studied the effect of performance pressure on QED, defined as "any factor or combination of factors that increase the importance of performing well" (Baumeister, 1984, p. 610). Accordingly, scholars implemented ego-threatening challenges or competition prizes (e.g., public rankings or financial rewards to best athletes; Eysenck & Wilson, 2016) that would permit, following the attention-grabbing effect, the stimulus-driven system to impair the goal-directed one.

The first studies on this topic about QE reported that high-performance pressure conditions influence QE characteristics (Behan & Wilson, 2008) by reducing QED (e.g., Vickers & Williams, 2007). However, more recent studies showed an opposite effect of high-performance pressure conditions on QE, with an extension of the QED (e.g., Brimmell et al., 2019; Ducrocq et al., 2017; Moore et al., 2013). The athlete's task evaluation may explain these opposite findings. Indeed, results showed that a task evaluated as challenging could extend the QED, whereas a threatening task could reduce the QED (Brimmell et al., 2019; Moore et al., 2013). Referring to the broader theoretical framework of the biopsychosocial model (BPSM) of challenge and threat (cf. Blascovich, 2008), the evaluations depend on the perceived task demands and the perceived resources to perform the task. In detail, a very higher level of perceived resources than the perceived task demands could lead to a very low task engagement; vice versa, athletes would consider a task as threatening; lastly, a match of perceived resources and perceived task demand would lead to a challenging state (Blascovich, 2008 p.438; Seery, 2013). A challenging state would make the use of the top-down attentional network easier. In contrast, a threat state would increase the likelihood of disrupting the goal-directed attentional system. In a biathlon study, Vickers and Williams showed that athletes who augmented their QED in high-pressure conditions did not experience performance degradation (i.e., choking). Altogether, these findings suggest a potential protective function of an extended QED for performances in threatening conditions (Vickers & Williams, 2007; cf. Vickers, 2016a; Samuel J. Vine et al., 2014). Note that the relation between QE and goal-directed attention system is in line with programming and online QE functions since both could support the top-down attentional network by acquiring visual information (Gonzalez et al., 2017).

1.2.3 Quiet eye and expertise: the "efficiency paradox"

All the QE hypotheses described so far well explain the relationship between this fixation and aiming performances. However, a recent theoretical debate raised questions regarding the association between long QED and high expertise athletes' level (i.e., the "QE efficiency paradox"; Mann, Wright, & Janelle, 2016). According to the literature on QE, this fixation represents the duration of information-processing cognitive processes (cf. Gonzalez et al., 2017; Moran et al., 2019).

Given that the literature on cognitive processes showed a better efficiency of sports experts than non-experts (Garland & Barry, 1990; Mann et al., 2007; Maslovat et al., 2011; McMorris & Graydon, 2000; Milton et al., 2007; Nakata et al., 2010; Voss et al., 2010), results refer to the relationship between highest levels of expertise and the employment of a long period of information-processing before the critical movement of a motor action through the QE seem counterintuitive. A recent hypothesis on QE, postulated by Klostermann and colleagues (2014), tried to explain this efficiency paradox. This alternative speculation was the "*inhibition hypothesis"* (Klostermann, 2014; Klostermann et al., 2014), and it describes the duration of the QE as the time required to inhibit all the noneffective task solutions and to select only the optimal one, to prevent interferences on the ongoing action (Klostermann et al., 2014). Due to the large number (i.e., extension) and closeness (i.e., density) of motor solutions held by the experts for each motor task, the selection-for-action process requires a longer time for experts than novices, leading to a longer QED. Klostermann (2019) exhibited that élite basketball players increased the QED during their free throws, a distance in which they are highly trained, compared to other less-trained throw-distances. This result could refer to an increment of inhibition demands in the free-throw distance, compared to different distances, given the high density of task solution for a skill in which élites are highly trained (Klostermann, 2019). Moreover, experts did not exhibit a transfer of the QED in tasks in which they are not experts (basketball: Rienhoff et al., 2013; dart players: Flindall et al., 2020). Through this hypothesis, the same authors also questioned the relationship between QED and performance, suggesting considering a "ceiling effect" to explain this association (Klostermann et al., 2018). According to the authors, the QE represents a process with the sole purpose of selecting the optimal motor response while inhibiting the others. Accordingly, an excessive QE duration would not bring any advantages to this mechanism (Klostermann et al., 2018).

1.2.4 Quiet eye and quiet body: a postural stability function

To conclude this synthesis about possible QE underlying mechanism, Gallicchio and colleagues proposed a postural-kinematic hypothesis, suggesting that experts could take advantage of a longer QE duration to improve postural stability and get a smoother movement kinematic. In detail, Gallicchio and colleagues employed an electrooculography (EOG) measure to assess the movement range of eyes (i.e., "eye quietness") in golf puttings. Their results showed that golf experts delay the QE offset than novices, with a more extended QE late time component, and that QED was related to smaller eye movements (i.e., greater eye quietness). Finally, swing duration was both associated with the late QE time component and with eye quietness. As the authors suggested, experts could use the QE to improve ocular quiescence and postural stability, leading to smoother movements (Gallicchio et al., 2018; Gallicchio & Ring, 2019).

1.3 The present work

Lebeau et al. (2016) reported that the QE's role could depend on the type of sports tasks. Accordingly, the relatively large number of functions attributed to the QE and reported in this introductory chapter could be due to the specificity of each sport task. Given the singularity in the kinematical and timing aspects of each sport task, such characteristics could affect the type of function that the QE fulfills in that specific task.

On this premise, the current doctoral thesis aimed to understand the QE underlying processes, focusing on:

- Comprehend state of the art on QE in terms of its role in sport aiming tasks, the variables that affect this fixation, and the sports tasks explored by previous literature.
- Investigating the relationship between QE, performance, and expertise in novel sport aiming tasks;
- The employment of experimental manipulations to well-known tasks in QE literature to comprehend the functions that QE could fulfill in that task.

In light of this and following the previous bullet points, the thesis will show the results related to:

- The published paper regarding a review about the use of eye-tracking in targeting sports and the studies on the QE (published on the *Smart Innovation, Systems and Technologies* book series);
- The published paper related to the study of the QE of modern pentathletes in a novel aiming task, the "laser run" event (published on *Journal of Cellular Physiology*);
- The published paper regarding the study of the QE in basketball free-throws, employing time pressure and performance pressure (published on *Psychology of Sport and Exercise*)
- The submitted paper regarding the study of the QE in basketball three-point shots, employing time pressure and performance pressure (currently in revision on *Brain Sciences*)

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Chapter 2: Study 1 - The Use of Eye Tracking (ET) in Targeting Sports: A Review of the Studies on Quiet Eye (QE)

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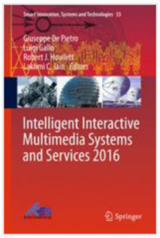

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The Use of Eye Tracking (ET) in Targeting Sports: A Review of the Studies on Quiet Eye (QE)

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2.1 Abstract

The Quiet Eye (QE) consists of the final visual fixation before the initiation of a critical phase of the movement and functionally represents the time needed for the precise control of movements. The aim of the manuscript is to provide a mini-review of the studies analyzing through Eye Tracking (ET) the Quiet Eye phenomena in ecological sport settings in the last decade. Using Scopus database was performed a search (January 2005–December 2015) including a combination of “Eye Track*” with “Quiet Eye” and with “Sport” as keywords, and extracting only original research including adult athletes and focused on targeting sports (e.g., shooting, golf, etc.). Overall, 30 studies were reviewed, confirming that ET was a useful instrument to address different research issues within the sports domain. However, new studies need to confirm these results and to combine ET with other instruments in order to deeply understand the processes underpinning successful performance in sport.

Keywords

Eye tracking, Targeting sports, Quiet eye, Ecological settings

2.2 Introduction

Eye tracking is the process of measuring the point of gaze (where one is looking) and the motion of the eyes (typically divided into fixations and saccades). Eye Tracker (ET) is a device able to register eye positions and eye movement. The ET has been successfully applied in a wide variety of research domains (e.g., marketing, medicine, etc.), including psychology. The research in psychology has been used ET to investigate how eye movements are related to cognitive processes during different tasks (Mele & Federici, 2012).

In the past years, the use of ET was limited since some of them were very complex (e.g., manual calibration, image optimization), time-consuming both for researchers and participants, and quite expensive. Additionally, ET was typically used in laboratory settings, limiting the possibility of studying the phenomena in ecological settings. Over the last two decades, however, remarkable improvements in ET technology have been made. A new generation of portable ETs with more automatic (and user-friendly) settings (e.g., calibration) and analysis procedures (e.g., eye movement tracking, fixations duration, etc.) allows researchers nowadays to set up a quick and portable eye analysis both in a laboratory and in ecological settings, studying participants' eye movements directly in real-life situations.

At the same time, different studies (Mann et al., 2007) have dealt with understanding the role of visual strategy in sport. Athletes need to be able to pick up some important information in a very complex and changing environment. The best athletes know the best way to collect this information from the surrounding environment. For an excellent performance, athletes need to know "*where*" and "*when*" look since this awareness enables more efficient use of their time. The ETs allowed researchers to explore and analyze the visual strategies of athletes during their sports performances. Within this research line, empirical evidence with ET suggested that gaze control was critical for skills requiring precise cue selection, optimal timing, and the ability to focus for long durations under extreme performance conditions (Vickers, 2011). Scholars suggested that the final fixation made by a performer must not only be located on the target but must also be of a long enough duration to ensure accuracy (Vickers & Williams, 2007; Williams, Singer & Frehlich, 2002). Vickers (1996), analyzing with ET the athletes' performance of targeting sports (e.g., basket shooting), evidenced the presence of a typical visual fixation strategy, the so-called Quiet Eye (QE). The QE is defined, for a given motor task, as the final fixation or tracking gaze directed to a single location or object in the visual motor work-plan within 3° of visual angle (or less) for a minimum of 100 ms (Vickers, 1996).

Here, we provide a mini-review of the studies analyzing through ET the Quiet Eye phenomena in ecological sport settings.

2.3 Materials and Methods

This study was performed using the guidelines set out by the preferred reporting items for systematic reviews (Moher et al., 2009). A broad search was performed using the Scopus database in the date range from January 2005 to December 2015, and including a combination of “Eye Track*” with “Quiet Eye”, and with “Sport” as keywords. Once the main articles were identified, a second search was carried out using the citations within each article to supplement the already mentioned search terms.

We considered only original research articles, including adult athletes, and focused on targeting sports (e.g., shooting, golf, etc.). Non-English-language studies and reviews were excluded. After a screening based on the full-text review, 30 articles were included. The main data (e.g., sample, sport, experimental conditions, ET, and QE parameter used and results) from each study were reported in Table 1.

Table 1

Studies Selected and Data Extraction

First author	Sport	Sample	Experimental Conditions and Design	ET used and QE parameters measured	Other measures	Main results related to QE
Causer (2010)	Shooting	24 elite 24 sub- elite shooters	No conditions	Mobile Eye II (ASL,Waltham, MA) - QED and QEO	-Gun barrel kinematics - Performance	-Elite shooters had both earlier QEO and longer QED -Longer QED and earlier QEO during successful trials for both groups.
Causer (2011)	Shooting (skeet)	20 international level skeet shooters	-Perceptual training (PT) group - Control group Pretests and posttests along with an 8-wk training	ASL Mobile Eye II (ASL,Waltham, MA) - QED and QEO	-Gun barrel kinematics - Performance	-Athletes of the PT group significantly increased their QED, used an earlier QEO, and recorded higher shooting accuracy scores from pretest to posttest.
Causer (2011)	Shooting (Skeet)	16 elite level shooters (skeet)	2 counterbalanced conditions -low anxiety (practice round) -high anxiety (competition round).	ASL Mobile Eye II (ASL,Waltham, MA) -QED and QEO	-Anxiety (MRF-3) - Mental Effort (RSME) -Gun barrel kinematics - Performance	Athletes under the high anxiety condition showed shorter QED, less efficient gun motion, along decreased performance.
Fischer (2015)	Basket (free throws) and dart	14 medium-age 7 older-aged less skilled. 15 medium-age 15 older-aged skilled players	2 different tasks: -basketball free throws -throwing darts (transfer task)	Lightweight head-mounted ET system (Arrington Research, Inc., Scottsdale, AZ) -QED	-Throwing accuracy	No significant differences in QED across the skill or age groups in either task, indicating that expertise in a perceptual-motor task (such as the basketball free throw) can be retained in older athletes
Horn (2012)	Dart	24 novices players	Assignment to 2 conditions: -Random targets -Blocked targets	ASL 5000(ASL, Bedford, MA) - QED	-Throwing Accuracy: Radial error	-Longer QED during trials of the random targets group -No relation between QED and accuracy.
Chia (2017, In press)	Bowling	6 expert 6 novice players	2 Conditions: - Easy (1 pin) - Hard (10 pins)	Mobile Eye-XG movement system. (ASL,Waltham, MA) - QED	-Perceived task difficulty and confidence	-Expert had significantly longer QED in both conditions. - No relation between QED, accuracy, and task condition.
Klostermann (2014)	Golf (Putting)	12 expert 12 near-expert golfers	2 focus-of-attention instructions: -Movement-related instruction (MI) -Effect-related instruction (EI)	VICON ET system (EyeSeeCam, 220 Hz). - QEO, QED, and QE offset	-Performance -Head movement initiation	-Experts showed an overall later QE offset, longer QED, than near-experts -Larger QE offset differences between experts and near-experts in the MI compared with the EI condition.

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First author	Sport	Sample	Experimental Conditions and Design	ET used and QE parameters measured	Other measures	Main results related to QE
Mann (2011)	Golf (Putting)	10 expert 10 near expert players	No conditions	BIOPAC EOG 100B; (BIOPAC Systems, Santa Barbara, CA) - QED	-EEG and EMG activities -Performance	-Experts had longer QED and greater cortical activation in the right-central region compared with non-experts. - Association between cortical activation and QE duration.
Moore (2013)	Golf (Putting)	30 novice participants	Random assignment to: -QE training group -Control group (technical training) Baseline, training, retention, and pressure putts	ASL Mobile Eye II (ASL,Waltham, MA) - QED	-Anxiety (MRF-3) - Cognitive Appraisal - Performance errors	The quiet eye trained group performed more accurately, displayed more effective gaze control (longer QED) and appraised the pressure test more favorably.
Moore (2012)	Golf (Putting)	127 novice golfers	Randomly assignment to 2 instruction groups: - Challenge group - Threat group	Mobile Eye tracker (ASL; Bedford, MA). - QED	- Cognitive Appraisal -Immediate Anxiety Measurement Scale - Performance Errors - Cardiac and EMG activity -Putting Kinematics	The challenge group performed more accurately, reported more favorable emotions, and displayed more effective gaze (longer QED), putting kinematics and muscle activity than the threat group.
Moore (2012)	Golf (Putting)	40 novice golfers	Random assignment to: -QE training group -Control group Pre-training, practice, training, follow up retention task, and pressure test	Mobile Eye Tracker (ASL; Bedford, MA) - QED	- anxiety (MRF-3) -Performance - Cardiac and EMG activity - Putting kinematics	The quiet eye trained group performed more accurately, displayed more effective gaze control (longer QED) and appraised the pressure test more favorably.
Panchuk (2014)	Golf (Putting)	29 amateur golfers	3 intervention groups: -Marker under the ball -Hole-focus instruction -Novel putting device (PBoS). - Control group Pre / post-test.	Mobile Eye tracker (ASL; Bedford, MA). - QED -QE dwell time	-Putting accuracy	- Longer QED on hits than on misses - The control and PBoS groups did not change the QED while the hole-focus group had a decrease, and the marker group an increase in QED. - QE dwell time increased only for the marker group.
Panchuk (2006)	Ice-Hockey	8 elite goaltenders	2 experimental conditions: -5 meters shots -10 meters shots	501 Eye Tracker (ASL) -QED, QEO, and QE Offset		- Longer QED and earlier QEO for saves compared to goals - QE offset occurred later in 5 m trials compared to 10 m trials

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First author	Sport	Sample	Experimental Conditions and Design	ET used and QE parameters measured	Other measures	Main results related to QE
Panchuk (2009)	Ice-Hockey	8 experienced goaltenders 9 experienced shooters	4 occlusion conditions: -head and upper body -lower body, -puck/stick, -all but puck flight	Mobile eye-tracking system (ASL) -QED, QEO, QE offset	-Performance (save percentage)	- QEO earlier on saves than goals - Relative QED longer on saves than goals
Piras (2011)	Soccer (penalty kick)	7 intermediate level goalkeeper	2 different types of kicks: -instep kick -inside kick	Mobile ET system (ASL MA, USA) - QED		- Participants had longer QED for saves compared to goals
Rienhoff (2012)	Dart	13 skilled 16 less skilled players	3 different viewing conditions: - Baseline - Central - Peripheral	Head-mounted eye-tracking system was used (Eyelink II, SR Research) - QED	- Performance	- For Baseline condition, significant correlations between QED and both throwing accuracy and consistency for the less skilled players -QED and throwing accuracy in central vision conditions were significantly positively correlated for less skilled players
Rienhoff (2015)	Basket (free throws)	9 expert, 9 advanced 9 novice players	3 manipulations of attention focus: - on the ball (external) - on their hands (internal) - no instruction (control)	Light-weight, head-mounted, ET (Arrington Research BS007, Scottsdale, AZ) - QEO and QED	- Shooting performance	-External focus of attention lead to a decrease in performance and reduction QED. -Better performance was associated with longer QED across all skill levels.
Vickers (2007)	Biathlon	10 elite biathlon shooters	2 different pressure conditions: -low pressure (LP) -high pressure (HP)	Model 501 mobile eye tracker (ASL; Bedford, MA) -QED	-Cognitive Anxiety (CSAI-2) -Physiological arousal (RPE and HR) -Performance accuracy -Monark cycle ergometer power output	-QED longer on hit than misses -In 100% Power Output condition, QED decreased -Increasing QED on the highest workload prevent choking during HP condition -In lower workload conditions, QED could be shorter with no effects on performance
Vine (2010)	Golf (Putting)	14 novice players	Random assignment to: -QE training group -Control group Pre-test, acquisition phase, retention-transfer (pressure)-retention test putts	ASL Mobile Eye II (ASL, Waltham, MA) - QED	- Cognitive state anxiety -Performance errors	- The QE-trained group maintained more effective attentional control and performed better in the pressure test -Longer QED was associated with better performance across all test putts

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First author	Sport	Sample	Experimental Conditions and Design	ET used and QE parameters measured	Other measures	Main results related to QE
Vine (2011)	Golf (Putting)	22 elite golfers	Assignment to: -QE training group -Control group Pre-training, practice, training, follow up retention task, and pressure test	ASL Mobile Eye II (ASL,Waltham, MA) - QED	- Cognitive state anxiety - Competitive and experimental Performance	-QED predicted 43% of the variance in putting performance. - The QE-trained group maintained their optimal QE under pressure conditions and had better performance.
Vine (2011)	Basket (free throws)	20 novice athletes	Assignment to 2 groups: -QE Training group -Control group Pre-test, retention test 1, pressure test, retention test 2	Mobile ET ASL (ASL; Bedford, MA) -QED	- Anxiety (MRF-3) - Performance	-QE trained group had significantly longer QE periods and better performance under heightened levels of cognitive anxiety.
Vine (2017, In press)	Golf (Putting)	27 skilled golfers	3 conditions of vision occlusion: -early (prior to backswing), -late (during putter stroke), - no (control)	Mobile ET(ASL; Bedford, MA). - QED	-Performance -Putting Kinematics	-No significant differences in QED across conditions, -Performance decrease in late occlusion condition and not change in early occlusion condition
Vine (2013)	Golf (Putting)	45 novice golfers	Assignment to 3 instruction groups: -QE -Analogy -Explicit Baseline-Retention-Pressure-Retention putts	ASL Mobile ET (ASL,Waltham, MA) - QED	-Anxiety (MRF-3) -Movement Specific Reinvestment Scale (MSRS) - Performance errors	- All the groups increased QED following training -QE-trained group outperformed the Analogy group in the Retention tests and both other groups in the Pressure test, underpinned by superior visual attentional control (longer QED).
Vine (2013)	Golf (Putting)	50 expert golfers	Participants performed putts under pressure until they missed (''shootout'').	ASL Mobile ET (ASL,Waltham, MA) - Total QED - QED-pre and QED-online - QED- Dwell	-Anxiety (MRF-3) - Movement phase durations.	-Total QED was shorter for the final (missed) putt compared with the first and penultimate (successful) putts. -QED-pre was similar across the three putts, while QED-online and QED-dwell were shorter on the missed putt.
Wilson (2009)	Basket (free throws)	10 experienced players	2 counterbalanced conditions: -low anxiety condition -high anxiety condition	Mobile ET (ASL; Bedford, MA). - QED e QEO	-Anxiety (MRF-L) - Performance	- Participants had longer QED and earlier QEO for successful shots (hits) compared with misses- - High anxiety resulted in significant reductions in QED and free throw success rate.

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First author	Sport	Sample	Experimental Conditions and Design	ET used and QE parameters measured	Other measures	Main results related to QE
Wilson (2009)	Golf (Putting)	6 university team golfers	Players performed 25 putts in a randomized order; five on each slope of flat, - .9° left-to-right and right-to-left -1.8° left-to-right and right-to-left	ASL Mobil Eye gaze-registration system (Bedford, Massachusetts) - number of fixations - QED	-Performance(holed or missed and error)	Shorter QED on missed than on holed putts
Wood (2010)	Soccer (penalty kick)	18 experienced footballer	2 counterbalanced conditions: -threat (low vs. high) -goalkeeper movements (stationary vs. waving arms)	Mobile ET (ASL; Bedford, MA) - QED	-The anxiety thermometer - Performance	No significant main effects were found for threat or goalkeeper movement on QED
Wood (2011)	Soccer (penalty kick)	20 university-level soccer players	Randomly assignment to 2 groups: -QE training group - Control group Baseline, retention test, pressure test (penalty shootouts)	Mobile Eye gaze registration System (ASL; Bedford, MA) -QED aiming phase (A-QE) -QED execution phase (B-QE)	- Anxiety (MRF-3) - Performance	-The QE training group showed longer A-QED and B-QED with respect to the control group, - No differences in performance were registered between the two groups
Wood (2012)	Soccer (penalty kick)	20 experienced footballer	Randomly assignment to 2 groups: -QE training program -Practice program Baseline, retention, transfer (penalty shootouts)	Mobile Eye tracker (ASL; Bedford, MA, USA) - QED	- Anxiety (MRF-3) - Control beliefs - Performance	-The QE training group showed longer QED and better performance in all the conditions and increased their perceptions of shooting ability (competence) and ability to score and cope with the pressure (control)
Ziv (2015)	Golf (Putting)	72 novice players	Assignment to 3 groups: -Internal focus group (24) - External focus group (24) - Control group (24) 2 experimental conditions: -Non Distraction - Distraction/Non distraction	Mobile Eye tetherless ET system (ASL, Bedford, MA, USA). - QED	- Performance Errors	-Under non-distracted conditions, QED was longer in the EXT participants than other groups while their performance did not improve. -Under distracting conditions, higher performance was observed in both the INT and EXT attentional focus participants than in the Controls.

Note. QED = quiet eye duration; QEO = quiet eye onset; MRF-3 = Mental Readiness Form-3; EEG = Electroencephalography; EMG = electromyography; CSAI-2 = Competitive State Anxiety Inventory-2; RPE = rating of perceived exertion; HR = hear-rate; HP = High Pressure; MRF-L = Mental Readiness Form-Likert.

2.4 Results

The studies extracted and reviewed focused on different sports such as golf/putting (n = 13), basket/free throws (n = 4), shooting (n = 3), Soccer/penalty kick (n = 4), Ice-Hockey (n = 2), bowling (n = 1), dart (n = 2) and biathlon (n = 1). Overall, the studies reported in Table 1 evidenced some crucial research issues that will be briefly summarized below. It is important to note that many studies focused on more than one research issue at the same time.

2.4.1 The Effects of Expertise on QE

The first research issue is the link between the QE and the expertise of the athletes. Overall, 7 studies (Causer et al., 2010; Chia et al., 2017; Fischer et al., 2015; Klostermann, Kredel & Hossner, 2014; Mann et al., 2011; Rienhoff et al., 2012, 2015) compared the QE of experts with one of the no-expert athletes, across different sports, training or experimental conditions (e.g., difficulty, pressure). The results of five (Causer et al., 2010; Chia et al., 2017; Klostermann, Kredel & Hossner, 2014; Mann et al., 2011; Rienhoff et al., 2015) of these studies confirmed the evidence of pioneering studies (Vickers, 1996; Williams, Singer & Frehlich, 2002), showing that experts have longer quiet eye durations (QED), early quiet eye onset (QEO), and/or later QE offset. Furthermore, some studies (e.g., Causer et al., 2010; Rienhoff et al., 2015) showed a positive correlation between QED and or QEO and performance. Only two studies did not register differences in QE parameters (Fischer et al., 2015; Rienhoff et al., 2012).

2.4.2 The Effect of Task Difficulty on QE

A second issue is the analysis of the link between the difficulty of the sporting task and the QE. Few studies focused on this issue, and many of them did not confirm the past results (Vickers, 1996) showing that QED increases with task difficulty (Chia et al., 2017; Vine et al., 2017; Wood & Wilson, 2010). However, a study focused on dart players (Horn et al., 2012) showed that QED increases with task difficulty.

2.4.3 The Effect of Focus of Attention

A third issue is the relation between the focus of attention during the sporting task and the QE. Studies on this topic emerged recently in the literature, focusing on the effects of different attentional focus on QE and performance (Klostermann, Kredel & Hossner, 2014). It seems that an external focus provides better performance and a longer QED (Ziv & Lidor, 2015) and that a different focus location in an external condition of attention brings a variation on QE parameters as the QE offset (Klostermann, Kredel & Hossner, 2014). However, another study provided opposite effects (Rienhoff et al., 2015) especially related to QED and performance when external attentional focus occurred.

2.4.4 Competitive Anxiety and QE

Six studies deal specifically with the issue of the relationship between athletes' competitive anxiety/pressure and the QED. Four studies (Causer et al., 2011; Moore, Vine, Wilson & Freeman, 2012; Vine et al., 2013; Wilson, Vine & Wood, 2009) showed that the athletes that perform under high anxiety conditions in different sports (shotgun, basket, and golf) have a shorter QED along with a decreased performance. Only one study focused on soccer (Wood & Wilson 2011) didn't find any relation between "high threat" condition and QED, while a relevant study focused on biathlon (Vickers & Williams, 2007) stressed that an increase of QED prevents choking during high-pressure conditions.

2.4.5 QE Training

A final issue is the possibility to improve QED and consequently the performance through specific training. Overall, seven studies (Moore, Vine, Cooke, Ring & Wilson, 2012; Vine & Wilson, 2010; Vine, Moore & Wilson, 2011; Vine & Wilson, 2011; Vine et al., 2013; Wood & Wilson, 2011, 2012) analyzed the effect of specific QE training protocols on the QE parameters during the performance. The results showed that training focused on QE was efficacious in different sports (golf putting, basket free throw, soccer penalty kick): the athletes significantly increased their QED and recorded higher performance. Moreover, these studies showed that the athletes trained with specific QE protocols were able to maintain a longer QED and provide better performance (with the exception of Wood & Wilson, 2011) than the other athletes under high anxiety conditions.

2.3 Discussion

The present studies identified 30 original studies that in the last decade used the ET systems to study the Quiet Eye in different sport settings. Overall, from the data extracted by these studies emerged that ET was a useful instrument to address different research issues within sports domains. However, some inconsistencies in results were emerged across the different issues, reflecting mainly differences in data analysis as well as in definition and operationalization of task difficulty and task-specific skills. Consequently, new studies using comparable methodologies need to confirm the results that emerged in this mini-review in other/ new sports specialties (e.g., combined event in modern pentathlon).

Furthermore, according to some studies included in this review (Mann et al., 2011; Moore, Vine, Wilson & Freeman, 2012; Moore, Vine, Cooke, Ring & Wilson, 2012), additional future studies need to combine ET with other instruments (e.g., EEG, EMG) in order to jointly analyze the different processes involved in the athletes' best performance.

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Chapter 3: Study 2 - A study of quiet eye's phenomenon in the shooting section of "laser run" of modern pentathlon

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A study of quiet eye's phenomenon in the shooting section of "laser run" of modern pentathlon

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3.1 Abstract

The aim of the study was to evaluate the effects of the quiet eye (QE) phenomenon on performances during the shooting section of "Laser Run" of Modern Pentathlon in two samples of athletes (novices and experts). The "Laser Run" consists of running and shooting activities. The study involved 18 experienced athletes of the Italian National Team of Modern Pentathlon (i.e., "elite" group) and 18 young and nonexpert athletes of a local Pentathlon club (i.e., "novice" group). Participants performed, in ecological conditions, five trials of four series of shootings (as it occurs in the real competitions), for a total of 20 series. During the shooting trials, athletes wore a mobile Eye Tracking System to record eye movements (saccades, blinks, and fixations). Key measures of the study were QE parameters (QE Duration [QED], Relative QED [RQED], and QE Onset), as well as the performance (accuracy and time to perform the event). The results revealed that both groups of athletes had a longer QED, RQED, and an earlier onset during their best shots than during the worse ones. Furthermore, differences between the groups showed that elite athletes had an earlier onset and a shorter QED than the novice group of athletes. These results provide insightful information about different cognitive and perceptual processes involved in Modern Pentathlon's athletes' performances at both the elite and non-elite levels.

Keywords

Expertise, Pentathlon, Quiet eye (QE), Target shooting, Visual behavior

3.2 Introduction

The sporting arena provides an excellent "in vivo" lab in which to test theoretical assumptions related to motor performances. In an aiming sport, the ability to coordinate and program precise aiming movements and attention are crucial (Vickers, 1996a, 1996b). In these sports, the processing of critical visual information and the ability to self-regulate cognitive and emotional activity are keys to the successful execution of self-paced movement skills. (Tosi, et al., 2019; Williams, Singer, & Frehlich, 2002).

Between the variables related to sports performances, gaze behavior, in particular the "quiet eye" (QE) phenomenon, was defined in 1996 by Vickers in a study on aiming task sports (Vickers, 1996a, 1996b). This phenomenon has been defined by the author as "the final fixation or tracking gaze that is located on a specific location or object (a relevant target) in the task environment within 3° of the visual angle or less for a minimum of 100 ms, before the execution of the critical phase of the movement." Characteristics of the QE are: a specific location of the fixation; the start of the fixation, namely the onset, that occurs before the critical final phase of the movement; its duration; and the end of the fixation, namely offset, that occurs when the gaze deviates off the location or object by more than 3° for more than 100 ms (Vickers, 1996a, 1996b). In a study by Causer, Bennett, Holmes, Janelle, and Williams (2010), the authors compared QE in different specialties of clay target shooting with different timing. The duration of the QE has been parameterized as relative to the time spent by the athletes, labeled as Relative QE Duration (RQED). RQED was the duration of the phenomenon divided by the time used to perform the action. This represents the percentage of the time that the athlete is engaged in the QE relative to the duration of the execution of the entire skill (Lebeau et al., 2016).

Over the past 20 years, several studies have shown that QE has a significant relationship with the athlete's sports performance. Specifically, these studies took into account some features of this phenomenon provided in different sports disciplines, that is golf (Vickers, 1992), basket (De Oliveira, Huys, Oudejans, Van De Langenberg, & Beek, 2007; Oudejans, Koedijker, Bleijendaal, & Bakker, 2005; Vickers, 1996a, 1996b), billiard (Williams et al., 2002), rifle shooting (Janelle et al., 2000), clay target shooting (Causer et al., 2010; Causer, Holmes, & Williams, 2011; Causer, Holmes, Smith, & Williams, 2011), and biathlon (Vickers & Williams, 2007). As evidenced by these studies and by several reviews on this topic, an earlier QE onset and a longer Quiet Eye Duration (QED) and RQED correlated with higher performance and/or a higher level of the athletes' expertise (Fegatelli, Giancamilli, Mallia, Chirico, & Lucidi, 2016; Lebeau et al., 2016; Rienhoff, Tirp, Strau, Baker, & Schorer, 2016).

Despite the robustness of the empirically identified phenomenon and progress over the recent years (for an overview, see Gonzalez et al., 2015), the mechanisms underlying the QE effect are still not well understood. From a theoretical point of view, different hypotheses have been proposed to explain the relationship between QE and performance. One of the predominant hypotheses is "the programming hypothesis" (Horn, Alexander, Gardin, Sylvester, & Okumura, 2012; Mann, Coombes, Mousseau, & Janelle, 2011; Williams et al., 2002). In line with this hypothesis, the QE facilitates information processing, and its duration seems to reflect the time needed to program the motor behavior and to accurately tune the response. Thus, longer QEDs are thought to extend this critical motor preparation period, enhancing performance (Mann et al., 2011; Vickers, 2011). Williams et al. (2002), in a study on billiard players, reported longer QEDs with increased levels of task complexity, and therefore a reduction of QED when the time available for the task was experimentally reduced. Their findings support the programming hypothesis in that longer QED corresponds to greater information processing demands for complex tasks, requiring longer programming times. Furthermore, according to the affordance hypothesis, different authors, manipulating the availability of visual information, demonstrated that QE has not only the function to preprogram the motor behavior (offline control) but also to act as a behavioral control (online control; De Oliveira et al., 2007; Oudejans, Van De Langenberg, & Hutter, 2002). Vine, Lee, Walters-Symons, and Wilson (2015), in their study, were able to also calculate the proportion between the two different QE functions (offline vs. online control). From a neuro-behavioral perspective, some authors found that a QE duration might reflect two different purposes relative to internal movement plans (Corbetta, Patel, & Shulman, 2008; Vine et al., 2015). These different purposes have been linked to a delicate trade-off between two different streams of bio-visual information processing: top-down (dorsal attentional network [DAN]) and bottom-up (ventral attentional network [VAN]) control networks (Corbetta et al., 2008), both involved in target selection and computations for movement parameterization during the QE (Gonzalez et al., 2015). According to Corbetta, the first (DAN) is a goal-directed attentional system centered on the dorsal posterior parietal and frontal cortex and allows one to link relevant stimuli to response planning, whereas the second (VAN) is a stimulus-driven attentional system centered on the temporoparietal and ventral frontal cortex that intrudes with the previous during the detection of salient stimuli. Whereas the amygdala (involved in emotional regulation) and hippocampus (involved in recording memories) are enclosed in the VAN system, Vickers (2012) suggests that "when a long duration QE is maintained on an optimal location a mental buffer or barrier is created that prevents intruding thoughts or bad experiences arising in the hippocampus and amygdala from distracting attention and leading to higher levels of anxiety;" this can improve the performance. However, this explanation does not fully describe the positive facilitator effects of the QE or define the actual information that is being processed (Gonzalez et al., 2015). Furthermore, the notion that experts have longer QEDs reflecting prolonged attention and motor preparation time questions whether only open-loop programming mechanisms are active during this extended time (Vine, Lee, Moore, & Wilson, 2013), which coherently would need a major online control. The findings of a longer duration of the QE in expert athletes have led some scientists to investigate it, in particular, labeling it as the "efficiency paradox" (Mann, Wright, & Janelle, 2016). The paradox lays on the "controlled versus automatic" processes mainstream (e.g., Fitts & Posner, 1967); consistent with this theory, the motor expertise is generally characterized by the automatization of the process underlying the motor performance, reported in the literature as a decrease in reaction times, processing demands, and also in aiming task experiment (Lucidi, Grano, Barbaranelli, & Violani, 2006; Maslovat, Hodges, Chua, & Franks, 2011; McMorris & Graydon, 2000), contrasting, then, with the "programming hypothesis." Consequently, Klostermann, Kredel, and Hossner (2014) proposed the inhibition hypothesis, with reference to Neumann and Deschepper (1992), an alternative explanation of the QE phenomenon that is still rooted in the cognitive domain relying on the selection-for-action mechanism (Allport, 1987; Cisek & Kalaska, 2010; Neumann, 1996), suggesting the QE as a "shielding mechanism" to inhibit nonoptimal task solutions selecting the optimal movement to execute. In this sense, it can be hypothesized that the increasing number of alternative task solutions gathered over years of practice comes with increasing shielding demands that, in turn, leads to the prediction of longer QE durations for experts than for novices or near-experts (Klostermann & Hossner, 2018).

Most of the studies evaluating QE were related to far aiming tasks in self-paced sports. In these sports, the time used to perform does not affect performance (i.e., archery, basketball free throw, golf putting, pistol and rifle shooting, and soccer penalty kicks). The athletes, in these tasks, can perform without time constraints. The best performance corresponds to the best score. A few studies investigated the QE phenomenon in shooting aiming tasks where there is a limited time to hit a target.

For example, Causer et al. (2010), in their studies, evaluated QE parameters in different specialties of clay target pigeon (trap, double trap, and skeet). In these specialties, time constraint depends on the speed of the target (the plate) established by the rules of the sport for each specialty. Temporal constraint depends on external factors and is common to all athletes. In their studies, Causer, Holmes, Smith et al. (2011) showed how QE characteristics were different depending on the expertise of the group (elite athletes showed an earlier onset QE and a longer RQED compared with novice athletes) and anxiety conditions (high-anxiety conditions could lead to later onset and a shorter QED than in low-anxiety ones). In these studies, the authors found the same patterns of differences in QE parameters in relation to the accuracy: best shots were characterized by an earlier QE onset and a longer QED. Furthermore, in another study, a QE training procedure was evaluated for skeet specialty. Results showed an earlier QE onset, a longer QE, and a reduction of the velocity (peak velocity) in a group of athletes who received training compared to their colleagues in the control group.

Another example has been provided by a study by Vickers and Williams (2007) that evaluated the differences in QE parameters and accuracy at different pressure conditions (low-pressure vs. high pressure) and power output (percentage of maximum oxygen uptake) in a sample of 10 National Biathlon athletes. In this sport, time becomes a significant element in the performance; in fact, the athletes try to hit the targets as quickly as possible, so they can start skiing to reach the finish line. The biathlon rules state that each missed shot at the range generally involves a penalty lap of 150 m, stressing the importance of being accurate rather than fast during the execution of the task. Results from this study relating to the differences between QE parameters and performance showed that best shots were characterized by an earlier QE onset and a longer QED.

The aim of the current study is to investigate the QE phenomenon in two samples of athletes of different expertise (novices vs. experts) in a timed targeting sport: the shooting section of the "Laser Run."

"Laser Run" is the final trial of Modern Pentathlon; it consists of running and shooting activities. The goal of this sport is to reach the finish line before the other athletes. The shooting involves four series of 10 m pistol shootings in a range equipped with targets. Each of the four series of shootings is followed by running for 800 m. Each series consists of hitting five targets with an unlimited number of shots in a maximum time of 50 s on a target with a valid zone of dimension 59.5 mm (score $\geq$7.3). Thus, the athletes start to run immediately after the target has been hit correctly five times. The time taken during the shooting range is detected electronically: the time starts when the first shot hits the target (irrespective of whether it is higher or lower than a 7.3 score) and stops when the correct fifth shot (score $\geq$7.3) hits the target. Scores range from 0 to 10.9; the latter corresponds to the perfect center of the target.

Thus, during "Laser Run," the best athlete will be the one who runs and shoots fastest. Paradoxically, during a competition, an athlete could miss the target several times; however, he could finish the shooting task first due to his rapidity of execution rather than his accuracy in shooting the target because there are no penalties for missed shots. In this sport, the athlete's performance depends on two different parameters:

accuracy (score equal to or more than 7.3) and speed (time taken to complete the task). The performer can control the time at which the skill (shooting) is executed (self-paced skill), but he should try to be as fast as possible in the execution to exit the shooting range.

To date, there have been no attempts to examine visual search in such targeting tasks where time is a crucial part of the performance, and no studies have looked at how these factors interact with the shots' accuracy and the expertise of the athletes.

The hypothesis of this study is that given the specific nature of the aiming task in the "Laser Run," the QE phenomenon will emerge as in literature in relation to shots' accuracy. With respect to the expertise group differences, there are no other studies evaluating these differences in this specific timed sport.

We expect that:

- Best shots will be related to longer QE and earlier onset than worse shots both in expert and novice athletes.
- Expert athletes, given the specificity of this sport, will be able to have a better performance using less time than their novice colleagues.
- Therefore, given the specificity of the sport and in line with the above-mentioned literature (Williams et al., 2002), we expect that the elite athletes will be able to activate QE earlier (QE onset) than novice athletes; then they would significantly reduce the time of execution and consequently the QE duration.

3.3 Materials and method

3.3.1 Participants

The study involved 36 athletes of the Italian Federation of Modern Pentathlon (FIPM) from two different agonistic levels. The first group was composed of 18 experienced athletes of the Italian National Team of Modern Pentathlon (i.e., "elite" group; 9 male; 9 female). These athletes were aged between 17 and 30 years (mean age = 24.3; standard deviation [SD] = 4.76). The second group was composed of 18 nonexperts athletes of a local Pentathlon club (i.e., "novice" group; 10 male; 8 female). These athletes were aged between 14 and 19 years (mean age = 15.3 years, SD = 1.84). All athletes had normal or corrected-to-normal visual acuity. The athletes had a different dominant shooting eye: 31 athletes shot with only the right eye opened, 3 athletes shot with only the left eye opened, and 2 athletes shot with both eyes opened.

3.3.2 Gaze behavior measurement device

Gaze was recorded using the SensoMotoric Instruments Eye Tracking Glasses (SMI Eye Tracking Glasses 2.0, SensoMotoric Instruments GmbH, Teltow, Germany), a noninvasive video-based glasses-type eye tracker, and the SMI software "iView" (www.smivision.com). Gaze data were analyzed using an SMI-ETG laptop (Lenovo-X230) with the SMI software "BeGaze" (SMI; BeGaze, 3.3). The Eye Tracking Glasses and the SMI-ETG laptop were linked by a USB cable, properly set to allow participants to shoot freely. In particular, the apparatus consisting of a pair of glasses equipped with an external camera to record the athlete's visual field and two internal cameras to record eye movements (saccades, blinks, and fixations). The portable computer was connected to the ETG through which it is possible to observe live what the eyewear was recording and then analyze the record and the data.

3.3.3 Procedures

All participants were informed about the general purpose of our study, the eye tracker device was shown to each participant before the experiment, and he or she was then given the opportunity to ask questions regarding testing procedures. All participants provided written informed consent before taking part in the study.

The study was performed at the shooting range of the Italian National Olympic Committee in Rome, as ecological conditions.

Participants used their own personal laser handguns. All participants were required to follow the rules of the "combined event" discipline during the experiment, as agreed by the Union International of Modern Pentathlon: specifically, we asked the participants to perform five trials of four series of shootings for a total of 20 series.

Before starting the experiment, each participant was asked to warm up for at least 10 min without ETG. After the warm-up phase, the athletes were asked to wear the ETG with the aid of the experimenter.

Given that the SMI ETG records the subject's gaze behavior of both eyes to enable monocular vision, we occluded the lens corresponding to the eye ordinarily kept closed by the athlete during the performance. This procedure does not hinder the data reporting by the instrument.

The calibration of the Eye Tracking Glasses was conducted using one reference point while participants were in their comfortable shooting stance. The accuracy of the calibration was checked periodically at the beginning of each shoot trial.

Participants were asked to perform a second warm-up phase with the ETG to familiarize themselves with the procedure and the apparatus. The experiment started when each athlete was confident with the eye tracker glasses and the procedure.

3.3.4 Measures

The study relied on the following key variables:

Action Time. The time, in milliseconds, occurring between a shot and the previous one. This index is not available for the first shot of each series.

Accuracy. The score of the shot was recorded as an accuracy performance outcome; it ranges from “0” corresponding to a shot off of the target and 10.9 corresponding to the center of the target.

QED. It corresponds to the time (ms) between the start of the QE (QE onset) and its end.

RQED. According to the literature on self-paced shooting aim sport, the RQED corresponds to the QE duration divided by the “Action Time.” This represents the percentage of the time that the athlete is engaged in the quiet eye mechanism relative to the duration of execution of the entire skill (Lebeau et al., 2016).

Onset. The time from the start of the action (previous shot) and the start of the QE mechanism.

3.3.5 Statistical analysis

According to procedures used in literature (e.g., Causer et al., 2010), we selected the 25 “best” shots and the 25 “worst” shots for each athlete, considering the shots' accuracy (score). The key variables of the current study were calculated as the mean of those best and worst shots.

A series of 2 × 2 mixed analyses of variance (ANOVA) was performed on the following measures: the Action Time, the score, and the QE parameters (QED, RQED, QE onset) using SPSS (version 25.0 SPSS Inc.). ANOVAs considered as independent variables: a “within-subject” factor SCORE (“best vs. worst”), and a “between-subjects” factor EXPERTISE (“elite” vs. “novice” athletes).

3.4 Results

3.4.1 Athletes' action time

As reported in Table 1, significant differences emerged overall between the two groups ($F(1,34) = 73.57$; $p < .001$; partial eta squared = .684); overall, “elite” athletes performed their shots faster (mean = 2.84) than the novice athletes (mean = 4.388). No significant differences emerged, instead, between best and worst shots (F(1,34) = .31; p = .582; partial eta squared = .009) and for the interaction between the factors considered in the analysis (F(1,34) = .27; p = .609; partial eta squared = .008).

Table 1

Action Time across the Expertise of the Athletes and Shots Accuracy

Dependent variable	Independent variables		Average time (ms)	SD
	Expertise	Shots accuracy		
Action time	Elite	Best	2.840	.240
		Worst	2.838	.259
	Novice	Best	4.723	.951
		Worst	4.678	.852

Note. SD: standard deviation.

3.4.2 Athletes' performance

As reported in Table 2, overall, elite athletes showed significantly ($F_{(1,34)} = 47.376$; $p < .001$; partial eta squared = .582) better performances (mean score = 8.43) than their novice colleagues (mean score = 7.24). Independently of their expertise, the athletes reported a significantly better score in their best shots than in worst ones ($F_{(1,34)} = 658.229$, $p < .001$; partial eta squared = .951). Furthermore, the results showed a significant interaction effect comparing the two groups of athletes in their performance across best and worst shots ($F = 48.156$, $p < .001$; partial eta squared = .582). Overall, the elite athletes showed an accuracy rate of 76% (only 24% of all shots were lower than 7.3), whereas novice athletes had an accuracy rate of 52% (48% of all shots were lower than 7.3; Table 3).

Table 2

Performance across the Level of the Athletes and Shot Accuracy

Dependent variable	Independent variables		Mean score	SD
	Expertise	Shots accuracy		
Performance	Elite	Best	9.835	.146
		Worst	7.033	.558
	Novice	Best	9.676	.156
		Worst	4.796	1.241

Note. SD: standard deviation.

Table 3

Quiet Eye Parameters across the Level of the Athletes and Shots Accuracy

Dependent variable	Independent variables		Mean	SD
	Expertise	Shots accuracy		
QE duration	Elite	Best	856.197 ms	334.894
		Worst	799.453 ms	302.324
	Novice	Best	1696.079 ms	1098.432
		Worst	1615.722 ms	1101.452
Relative QE duration	Elite	Best	.300	.121
		Worst	.282	.112
	Novice	Best	.377	.237
		Worst	.358	.237
QE onset	Elite	Best	2174.844 ms	376.356
		Worst	2190.006 ms	360.711
	Novice	Best	3256.859 ms	1135.787
		Worst	3397.521 ms	1241.288

Note. QE: quiet eye; SD: standard deviation.

3.4.3 QE parameters

With respect to QE duration, overall elite athletes showed a significant ($F(1,34) = 9.542$; $p = .004$; partial eta squared = .219) shorter duration of their QE (mean time = 827.825 ms) than novice athletes (mean time = 1655.901).

Furthermore, independently of their expertise, the athletes showed significantly longer QED ($F(1,34) = 4.670$; $p = .038$; partial eta squared = .121) in their best shots (mean = 1276.138 ms) than in their worst shots (mean = 1207.588 ms). No significant effect, instead, emerged for the interaction between the two factors considered ($F(1,34) = .139$; $p = .712$; partial eta squared = .004).

With respect to the relative QED, the two groups showed no significant differences ($F(1,34) = 1.545$; $p = .222$; partial eta squared = .043). However, the result showed that, overall, the athletes had significantly ($F(1,34) = 4.738$; $p = .037$; partial eta squared = .122) longer relative QED in their best shots (mean = .339) than in their worst shots (mean = .320). Even for this variable, no significant effect for interaction emerged ($F(1,34) = .002$; $p = .962$; partial eta squared = .000)

Finally, with respect to QE onset, the elite athletes, overall, reported a significantly ($F(1,34) = 15.470$; $p < .000$; partial eta squared = .313) earlier onset (mean = 2182.425) than novice athletes (mean = 3327.190). Furthermore, overall, athletes, independent of their expertise, reported a significantly ($F(1,34) = 4.121$; $p = .050$; partial eta squared = .108) earlier onset in their best shots (mean = 2715.851 ms) than in their worst shots (mean = 2793.763 ms). No significant effect for interaction, instead, emerged ($F(1,34) = 2.673$; $p = .111$; partial eta squared = .073).

3.5 Discussion

The purpose of this study was to investigate the QE phenomenon during the "Laser Run" in two samples of athletes with different levels of expertise (novice and elite). The study can be considered the first in the literature that evaluates the QE phenomenon in a sport in which the athlete has to find an optimum trade-off between accuracy and time of execution to reach the best performance. In fact, during the "Laser Run" competition, the best athletes will be the ones who run and shoot faster. For this reason, unlike other targeting sports, the goal of the shooting task is to be sufficiently accurate in hitting the target five times with a minimum score of 7.3 in the fastest time possible. So, apart from being able to accurately shots five times the target with a score higher than 7.3, it is advantageous for one to minimize the time spent for the execution of the action. Paradoxically during a competition, an athlete could miss the target several times; however, he could finish the shooting task before an athlete who decides to shoot only five perfect shots without missing.

Overall, the data resulted from the evaluation of how QE parameters are related to the performance (best vs. worst), regardless of the expertise levels, found the same QE pattern of the existing literature, confirming a significant relationship between the QE parameters (QED, RQED, and QE onset) and accuracy (Fegatelli et al., 2016; Gonzalez et al., 2015; Lebeau et al., 2016). Specifically, the data show that best shots are characterized by a longer QED, RQED, and an earlier QE onset than the worst shots.

As hypothesized, significant differences emerged by comparing the two samples in terms of the time of execution and accuracy. Elite athletes, in fact, performed their tasks better than their novice colleagues. Specifically, differences in terms of the time of execution showed that the elite athletes performed their task with a mean time approximately 40% lower than the novice athletes. Furthermore, in terms of accuracy, the elite athletes showed better accuracy than the novice ones. Elite athletes showed a mean score of 8.4 (SD .33) compared with the 7.2 (SD .65) scored by novice athletes, suggesting that task difficulty for an elite athlete is quite low.

The two samples were then compared, taking into account their level of expertise (elite vs. novice) and their level performances (best shots vs. worst shots) on the QE parameters (QED, RQED, and QE onset) to evaluate how the QE parameters will differentiate the athletes. Results showed a main effect of the expertise on the QED and QE onset variables. Overall, the elite athletes showed a shorter QED (mean time = 827.825 ms) than the novice athletes (mean time = 1655.901 ms), but at the same time, as expected, they started their quiet eye significantly earlier (mean = 2182.425) than the novice sample (mean = 3327.190). Nonsignificant differences emerged between the two groups considering RQED ($F(1,34) = 1.545$; $p = .222$; partial eta squared = .043).

To date, there have been no studies that examined visual search in such targeting tasks and evaluating how these factors interact with expertise and performance. Interesting data from our study showed elite athletes having a significantly shorter QED than the novice group; this result could be inferentially deducted from two orders of reasons. First, the differences between the two groups of athletes in terms of time spent in performing the action are relevant and could also account for the differences in their QED. In our study, the time constraints are subjective and related to the expertise of the athletes who, during the years, trained their motor behavior in function of the specific task that involves time and accuracy together, with a specific emphasis on the time, and a task demand that was simple in terms of accuracy (not the best accuracy ever). This result is in line with the literature (e.g., Williams et al., 2002), in which results showed that reducing the availability of time to perform an aiming task, consequently, a reduction of the QED emerges.

Second, comparing the two groups in terms of performances, it is interesting to underline that elite athletes' mean score (8.4) is quite higher than the demands of the task (7.3) compared with novice ones, performing instead, on average less than the minimum task required (7.2). Therefore, to account for this difference, an overall analysis of all the shots of the two groups of athletes showed that the elite athletes have an accuracy rate of 85% (only 15% of all shots were lower than 7.3), whereas novice athletes had an accuracy rate of 60% (40% of all shots were lower than 7.3). This finding indicates that given the trade-off needed for this sport, balancing accuracy and action time, the novice athletes set their priority towards accuracy to reach a complex shooting task, which was not difficult for the expert group of athletes. This result, therefore, could support the "programming hypothesis," in that longer QEDs correspond to greater information processing demands for complex tasks, requiring longer programming times, given the time availability. Williams et al. (2002) found shorter QE duration in billiard players who dealt with lower task demands than a higher difficulty task.

Fitts' law (Fitts, 1954) can provide useful information about the cognitive mechanism that could explain the trade-off between the time of execution (speed) and accuracy during this shooting task: this law, indeed, connotes an inverse relationship between the accuracy of a movement and the speed with which it can be performed. So, the elite athletes who showed a higher degree of accuracy compared with novice athletes might decide to be less accurate, increasing the speed of movement to improve their performance in the task. Thus, the expertise of the athlete could allow more experienced athletes to execute the movement faster but still maintaining an adequate level of accuracy for this task, thus reducing the QE period enough to reach the minimum score (minimum 7.3). Hence, it is reasonable that athletes with more expertise in a motor task where the time of execution is part of the performance will be more efficacious in balancing the trade-off between speed of movement and accuracy in the most functional way to obtain their best performance, thus reducing the time of execution and consequently the QED, anticipating their QE onset.

The study is the first to evaluate the "Laser Run" specialty; it, however, has some limitations. The results seem to provide coherent support to the statement "the quiet eye of elite performers is of an optimal duration, being neither too long nor too short, but ideal given the constraints of the task being performed" by Vickers (2009) and could provide important information about some cognitive and perceptual processes involved in Modern Pentathlon athletes' performances at both the elite and non-elite level.

Clearly, other studies need to confirm the inferences made in this study to confirm these results. Manipulations of the task difficulty and time available are needed to confirm the hypothesis related to the different duration of the QE between the two groups of athletes; subsequently, a bigger sample can be very useful to confirm the trends that did not reach statistical significance.

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Chapter 4: Study 3 - When the Going Gets Tough, What Happens to Quiet Eye? The Role of Time Pressure and Performance Pressure during Basketball Free-Throws

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When the going gets tough, what happens to quiet eye? The role of time pressure and performance pressure during basketball free throws

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4.1 Abstract

In aiming sport contexts, the quiet eye (QE) - the final ocular fixation before movement initiation - is a crucial perceptual-cognitive skill. Indeed, an extended QE permits athletes to achieve high performances, aiding optimal attentional control, particularly in situations in which athletes are "under pressure." Such situations are common in sport, especially when time runs out, and even just a few points can mean the difference between victory and defeat. Although QE has been widely investigated across several sports and tasks, no previous studies have considered both the role of time pressure and performance pressure on QE. The current study aimed to comprehend the effect of tough sport situations on QE characteristics. Accordingly, we tested basketball players (competitive-élites and semi-élites) in free throw trials, manipulating both the time available to perform the task and the relevance of the performance. The results showed that time pressure and performance pressure impaired QE characteristics, regardless of expertise levels. Also, time pressure led to a decrease in free throw accuracy. Interestingly, the match between task demands and the ability to cope seemed to play a role on QE, especially in the competitive-élite players, with negative QE characteristics (short and late) when task demands exceeded the ability to cope. These findings suggest that QE research and QE training protocols should account for time pressure, performance pressure, and the players' perceived ability to cope with the requested task.

Keywords

Quiet eye, Free throw, Gaze behavior, Perception-action, Eye tracking, Demand and resource evaluations

4.1 Introduction

One of the main factors that permit athletes to produce high performance levels is to focus their gaze on relevant information while ignoring the irrelevant one (Janelle et al., 2020; Williams & Jackson, 2019). Such increase in attentional focus mainly occurs at the moment immediately preceding the motor action (Janelle et al., 2020) through the "quiet eye" (QE), a phenomenon defined as "a fixation or tracking gaze that is located on a specific location […] 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; the QE offset occurs when the gaze moves off the location […]" (Vickers & Williams, 2007). An early QE onset and a long QE duration correlate with higher athletes' expertise and best performances in a wide range of sports that require aiming tasks (Fegatelli et al., 2016; Lebeau et al., 2016; Mann et al., 2007; Moran et al., 2019; Rienhoff et al., 2016). Moreover, the QE training is beneficial to the aiming performances (cf. Lebeau et al., 2016). The reasons for the beneficial effects of an extended QE duration should be conducted to the possibility of employing much time as possible to program movement parameters (Gonzalez et al., 2017; Vickers, 1996; Walters-Symons et al., 2017), fulfilling at the same time also a "shielding function" from irrelevant information, which could penalize the motor action's performing (Vickers, 2016). Such QE functions could be explained by Corbetta & Shulman's (2002) theoretical attentional framework. Following the authors, people elaborate visual information through two attentional networks continuously interacting. The first, the goal-directed attentional system, facilitates identifying environmental cues related to the internal plans. The second, the stimulus-driven attentional system, responding to relevant and unattended stimuli through the so-called "attention-grabbing effect" (Corbetta & Shulman, 2002). The QE should aid the goal-directed network, permitting athletes to focus on relevant cues while suppressing potential distractions (Gonzalez et al., 2017). About the role of distractions in sport, the Attentional Control Theory (ACT; Eysenck & Wilson, 2016) states that athletes' susceptibility to distractions characterizes stressful sport situations, like the ones characterized by performance pressure (i.e., high relevance of performing well; Baumeister, 1984). In line with the role of QE on attentional networks, the literature showed that, during performance pressure conditions, a short QE duration was associated with poor sports performances, whereas maintaining a long QE duration seems a strategy to avoid performances failures (Causer et al., 2011; Vine, Lee, et al., 2013; Vine et al., 2014; Vine & Wilson, 2011; Wilson et al., 2009). Nevertheless, studies showed that when athletes evaluated a stressful situation as "threatening," they were more likely to exhibit a short QE, whereas a "challenging" situation was related to a long QE duration (Brimmell et al., 2019; Moore et al., 2013). Such evaluations depend on the balance between perceived task demands and the perceived resources to perform the task. In detail, a lower level of perceived resources than the perceived task demands could lead to a threatening evaluation. Instead, a match of perceived resources and perceived task demand would lead to a challenging task evaluation (cf. the biopsychosocial model (BPSM) of challenge and threat; Blascovich & Tomaka, 1996; Seery, 2013).

In the QE literature, a well-known sporting task is the basketball free throw (cf. Marques et al., 2018). Generally, successful free throws had a more extended and earlier QE than misses (Rienhoff et al., 2015, 2013; Wilson et al., 2009). Moreover, only expert players showed a more prolonged and earlier QE in their hits than their misses (Vickers, 1996). The interest in understanding the perceptive-cognitive performance predictors of free throw could be traced back to its role in determining a match's outcome, particularly in the last quarter of games with close score differences, in which only a few points could determine the victory (or the defeat) of a team (Gómez Ruano et al., 2016; Kozar et al., 1994; Malarranha et al., 2013). Such situations are characterized both by time pressure and elevated levels of performance pressure. Wilson et al. (2009) showed that basketball players reduced their QE duration during free throws in conditions with performance pressure. Interestingly, to our knowledge, QE basketball free throw studies neither employed time pressure nor considered the evaluations of situational demands and personal coping resources. Nevertheless, Kozar et al. (1994) recommended implementing basketball training situations likely the last moments of a closed match, permitting athletes to be prepared for such match situations. Therefore, the simultaneous manipulation of time pressure and performance pressure in QE basketball studies could outline new insights about the role of this fixation in comfortable and harsh match situations, potentially supporting the framing of new QE training protocols in more realistic game situations. Such insights could also be extended to other self-paced tasks (e.g., soccer penalty kicks: Piras & Vickers, 2011; Wood & Wilson, 2011, 2012; the final round of 10m air-pistol: Shah et al., 2020; golf-putting: Harris et al., 2019, 2020; Walters-Symons et al., 2017). Since no studies at our knowledge previously assessed the role of time pressure and performance pressure simultaneously on QE characteristics, our study aimed to evaluate the variation of the QE in basketball free throws, performed by participants with different expertise, manipulating the time available to perform the motor action and the relevance of performing well. Consequently, we assessed the QE duration, the QE onset, and the demand and resource evaluation of players conducting free throws in randomized trials, different from each other, according to time pressure and performance pressure manipulations.

As the primary goal, we aimed to explore the effect of the game situations we employed, considering all the combinations of performance pressure and time pressure manipulations (Table 1) on QE characteristics. Given the role that the coping evaluation related to the task have on attentional and visuomotor control, we assumed that trials perceived as challenging would be characterized by QE characteristics deemed as beneficial for the performance (i.e., a relatively long and early QE) than trials perceived as not challenging (e.g., threatening). As a secondary goal, we aimed to explore the effect of the manipulations on our sample's expertise. Given the effectiveness of the goal-directed attentional network of the highest levels of expertise, we expected that the most expert athletes would perform their hits exhibiting longer and earlier QE compared to their misses across all trials.

Table 1

Summary of Trials' Design with Instructions

Trial	Time Pressure	Performance Pressure	Trial's instructions
NOTP/NOPP	Absent	Absent	"Perform ten free throws."
NOTP/PP	Absent	Present	"Perform ten free throws. It is very important to score as many points as you can because your score will be recorded to establish a ranking with your teammates."
TP/NOPP	Present	Absent	"Perform ten free throws, as fast as possible."
TP/PP	Present	Present	"Perform ten free throws, as fast as possible. It is very important to score as many points as you can because your score will be recorded to establish a ranking with your teammates."

Note. NOTP = no time pressure; NOPP = no performance pressure; PP = performance pressure; TP = time pressure.

4.2 Materials and methods

4.2.1 Participants

We recruited a total of 37 male basketball players. We categorized the expertise of each athlete according to the classification system proposed by Swann et al. (2015). Correspondingly, we split the sample into two groups, classifying the first as “competitive-élite” and the second as “semi-élite.” We also removed from the analysis three participants who score below 30% during the pretest phase (cf. "Task and Protocol” section), given that such threshold is used previously in literature as a criterion to define novice players (cf. Ryu et al., 2016; Vickers et al., 2017; Vine & Wilson, 2011). Table 2 reported the accuracy percentage of each participant during the pretest. The final sample was composed of 18 competitive-élite players and 16 semi-élite players. Competitive-élite participants played from the 1st to 3rd National Italian Basketball division (Italian series B, A2, and A), with a mean age of 16.61 (SD = 1.88) and an average of 8.33 years of playing experience (SD = 3.69). They trained with an average of 6.39 days per week (SD = 1.05). Semi-élite participants played from Regional divisions to the 4th National Italian Amateur division (from Regional divisions to Italian Serie C Gold), with a mean age of 14.44 (SD = 1.31) and an average of 5.41 years of playing experience (SD = 2.37). Semi-élite players trained with an average of 5.47 days per week (SD = 1.65). The Ethical Committee of the Department of Social and Developmental Psychology (Sapienza University of Rome) approved the present study before participant recruitment. Written informed consent was obtained from all participants, and in the case of minors, the informed consent was obtained by parents or legal guardians.

Table 2

Free Throws's Percent Accuracy for each Participant in the Pretest and the Four Experimental Trials

Expertise	Participant	Trials				
		Pretest	NOTP/NOPP	NOTP/PP	TP/NOPP	TP/PP
Competitive-élite	P1	78%	80%	80%	30%	50%
	P2	56%	90%	80%	50%	50%
	P3	67%	70%	90%	30%	50%
	P4	74%	30%	70%	50%	90%
	P5	71%	60%	90%	70%	90%
	P6	73%	70%	60%	80%	40%
	P7	79%	80%	70%	40%	70%
	P8	68%	70%	100%	30%	70%
	P9	83%	80%	70%	80%	70%
	P10	79%	80%	40%	50%	50%
	P11	93%	80%	90%	90%	80%
	P12	74%	80%	40%	40%	70%
	P13	67%	70%	90%	90%	60%
	P14	68%	70%	30%	90%	50%
	P15	60%	50%	60%	40%	40%
	P16	78%	60%	70%	30%	50%
	P17	87%	80%	90%	60%	80%
	P18	78%	80%	70%	70%	40%
	Average	69.47% [a]	71.11%	71.67%	56.67%	61.11%
	SD	11.88% [a]	14.10%	19.78%	22.49%	16.76%

(continued)

(continued)

Expertise	Participant	Trials				
		Pretest	NOTP/NOPP	NOTP/PP	TP/NOPP	TP/PP
Semi-élite	P19	54%	80%	80%	80%	40%
	P20	45%	60%	70%	20%	50%
	P21	67%	80%	30%	30%	30%
	P22	57%	80%	70%	60%	70%
	P23	57%	90%	80%	50%	40%
	P24	80%	80%	90%	40%	90%
	P25	74%	80%	80%	40%	100%
	P26	68%	60%	30%	70%	40%
	P27	60%	40%	70%	40%	30%
	P28	50%	30%	30%	40%	20%
	P29	79%	70%	70%	60%	60%
	P30	67%	80%	60%	70%	70%
	P31	63%	80%	70%	80%	80%
	P32	63%	60%	70%	30%	30%
	P33	40%	30%	80%	30%	30%
	P34	40%	50%	60%	50%	60%
	Average	64.18% [a]	65.63%	65.00%	49.38%	52.50%
	SD	11.90% [a]	19.31%	18.97%	18.79%	24.08%
Total Sample	Average	67.68% [a]	68.53%	68.53%	53.24%	57.06%
	SD	12.82% [a]	16.72%	19.41%	20.85%	20.67%

Note. NOTP = no time pressure; NOPP = no performance pressure; PP = performance pressure; TP = time pressure; SD = standard deviation. The findings of a z-test for two means showed that the difference in percent accuracy between competitive-élites and semi-élites in the pretest trial was significant (z = 5.919, $p < .001$). The findings regarding a two-way mixed ANOVA (between-subject factor:

expertise; within-subject factor: experimental trial) exhibited that the percent accuracy between the four experimental trials was significantly different ($F_{(3, 96)} = 7.044$, $p < .001$, $\eta^2_p = .180$). In detail, the percent accuracy between NOTP/NOPP and NOTP/PP trials was similar, as well as between TP/NOPP and TP/PP trials (all the *p-values* of the pairwise comparisons >.05). Instead, the percent accuracy of NOTP/NOPP and NOTP/PP trials was significantly different from the one of TP/NOPP and TP/PP trials, with higher percent accuracy in the trials without time pressure than the ones with time pressure (all the p-values of the pairwise comparisons <.05). [a] Given the unequal number of throws performed by each participant in the pretest trial, we computed weighted averages and weighted standard deviations to report the descriptive statistics of the pretest trial.

4.2.2 Equipment

We recorded the gaze behavior using a SensoMotoric Instruments (SMI) Eye Tracking Glasses 2 system (SMI ETG 2, SensoMotoric Instruments GmbH, Teltow, Germany) with a sampling rate of 60 Hz. The SMI ETG 2 is a light head-mounted mobile binocular eye tracker (68g) with a gaze tracking accuracy of 0.5° of visual angle. The SMI ETG 2 incorporates an HD scene camera to record the environment, set for the data collection with a resolution of 960x720p @ 30fps. We linked the SMI ETG 2 via USB to a recording unit (Galaxy Note 4 smartphone, Samsung) to improve the participants' comfort. The smartphone was placed in a small waist bag attached to the lower backs of participants and remotely controlled by a laptop (Lenovo Thinkpad X230; Lenovo). In this way, we can both calibrate and see the participants' gaze behavior using the iViewETG software (iViewETG SMI; version 2.7.0). The SMI ETG 2 required a mandatory calibration before recording gaze movements. Accordingly, we calibrated the eye-tracker using one reference point, asking athletes to focus their gaze on a basketball backboard's specific point (i.e., a corner). The participants' movement was recorded using a camcorder (HDR-PJ410, Sony, Japan) located to see the participants' sagittal plane during the task.

4.2.3 Measures

4.2.3.1. Action time

The free throw movement has been coded in three phases (cf. Wilson et al., 2018) using the camcorder. The first, the "lift phase," has its onset from the ball's first upward movement; the second, the "flexion phase," started from the first frame where the elbow flexes; the third and last, the "extension phase," initiated from the first frame when the angle between the upper and the lower arm starts to increase, as the participant moved the ball toward the basket (extension of the elbow). The extension phase ended with the final extension of the shooting arm, as soon as the ball leaved the fingertips. Therefore, for the present study, the action time is the difference between the onset of the lift phase and the end of the extension phase (in milliseconds). The action time was calculated as a manipulation check for the time pressure.

4.2.3.2. Demand and resource evaluation score (DRES) and trait anxiety (STAI-Y2)

We provided two specific items to measure the perceived task demand and perceived resource to perform each trial, in a similar way to previous studies (Brimmell et al., 2019; Chia et al., 2017; Vine, Freeman, et al., 2013). We assessed perceived task demand by asking, "How difficult do you consider the next trial?". We recorded the responses using a 10-point Likert scale (1 = not at all; 10 = extremely). Instead, we provided the perceived resource item drawing from the Mental Readiness Form-Likert (MRF-L; Krane, 1994), which provided an item to measure self-confidence. The MRF-L self-confidence item is composed of a bipolar 11-point Likert scale (confident/not confident) in which participants report how they feel "right now." For the study purpose, we transformed the 11-point Likert scale to a 10-point one. Then, we reversed the new item (i.e., from "confident/not confident" to "not confident/confident"). Lastly, we computed the DRES by subtracting perceived task demands from perceived resources, and we standardized the DRES in Z scores to better comprehend the results. Accordingly, a zero or slightly positive DRES should reflect a challenge state, corresponding to the perceived resources that match or marginally exceed the perceived task demands. Note that a large excess of perceived resources than the perceived demands should correspond to a disengagement state from the task. Instead, a negative score should represent a threat state (i.e., the perceived task demands exceed the perceived resources). Brimmell et al. (2019) outlined that although the lack of psychometric testing of the DRES, such a measure has been implemented in previous QE research (Chia et al., 2017; Vine, Freeman, et al., 2013) and is related to performance across several tasks (cf. Hase et al., 2019). Moreover, given the potential interaction (Endler & Kocovski, 2001) between trait anxiety, referred to the stability of an individual in anticipating the anxious response during a situation perceived as threatening, and the response of an individual dealing with a potentially threatening or dangerous situation (i.e., state anxiety), we administered the State Trait Anxiety Inventory-Y (STAI-Y; Spielberger & Vagg, 1984) to control for the effect of trait anxiety on DRES score. Indeed, people with higher trait anxiety could tend to perceive situations as more threatening than people with low trait anxiety (e.g., Horikawa & Yagi, 2012; Man et al., 2005). We used the STAI-Y2 form, a self-administer questionnaire consisting of 20 items that assess anxiety levels generally felt by the person. Higher scores represent higher levels of trait anxiety.

4.2.3.3. QE onset

The QE onset begins before the critical movement is performed (Vickers and Williams, 2007). In the case of the free throw, such critical movement has been defined as the extension of the arm before the release of the ball (i.e., the onset of the extension phase; Harle & Vickers, 2001; Rienhoff et al., 2015; Vine & Wilson, 2011; Wilson et al., 2009, 2018). Accordingly, for the present study, the QE onset is computed as the interval, in milliseconds, between the onset of the extension phase and the QE initiation. A negative value represents a QE onset that occurred before the critical movement.

4.2.3.4. QE duration

To be considered a QE, the final fixation had to last at least 100 ms, within 3° of visual angle and directed at the rim, the backboard, or the net (Wilson et al., 2018). The end of the QE (QE offset) occurred when the gaze moves off the location by 3° of visual angle for more than 100 ms. Accordingly, the QE can extend through the extension phase (Causer et al., 2017; Wilson et al., 2018). For the present study, the QE duration was calculated as the difference between the end of the QE and the initiation of the QE.

4.2.4. Task and Protocol

The data collection was conducted in a basketball field compliant with the Italian Basketball Federation (FIP) rules. Before taking part in the data collection, we informed all the participants about the current study's general purpose and the relative procedure. After, we administered the STAI-Y2. Then, we showed all the equipment employed for the experiment, allowing participants to ask questions about the protocol. Following, each participant was asked to warm up for at least 10 min without wearing the SMI ETG 2, conducting basketball free throws and their usual warm-up routines. At the end of this warm-up phase, athletes wore the SMI ETG 2 with the researchers' support to conduct a pretest phase. In this phase, we requested each participant to perform not less than ten free throws to permit athletes to get used to the instrumentation and to verify the proper functioning of the SMI ETG 2 during the motor action. The participants could continue to perform free throws at their leisure as soon as they feel confident with the equipment. Once players familiarized themselves with the procedure and the equipment, we started the data collection. We asked participants to carry out ten free throws in each of the four randomized trials (no time pressure and no performance pressure: NOTP/NOPP; performance pressure without time pressure: NOTP/PP; time pressure without performance pressure: TP/NOPP; time pressure and performance pressure: TP/PP), for a total of 40 throws per participant. All throws were taken from behind the free throw line (distance from the center of the basket = 4.23 m). Before each trial, we gave participants the trial instructions (Table 1). After provided the instructions, we administered the measures needed to compute the DRES. Then, we calibrated the SMI ETG 2 and checked the calibration in real-time during data collection until the trial's end to ensure its stability. To prevent possible issues related to fatigue, we provide participants 5 min pause between trials. The total procedure took approximately 60 min.

4.3 Data analysis

Two video files were created for each participant, one by the SMI ETG 2 and the other by the camcorder. The video files were manually synced using a frame-by-frame method, utilizing a specific event observable in both the video files (e.g., the ball touching the ground or the rim; cf. Klostermann et al., 2018). The SMI BeGaze software (version 3.7.60) was used for gaze behavior and the VideoPad software (NCH Software, version 7.36) for the participant's movement video. The throws coded for the analysis were 1240 of the maximum 1360 possible, performed by 18 competitive-élites and 16 semi-élites (for details, see Supplementary Material – Table A1).

Recently, in eye tracking research, linear mixed-effects ANOVA models are gain interest in data analysis, given the advantages in terms of unbalanced data sets, missing data, and the possibility of taking into consideration the variability of the participants' performances in research involving repeated measures (Baayen et al., 2008; Bagiella et al., 2000; Dixon, 2008; for an application on QE basketball research, cf.; Vickers et al., 2019). Accordingly, the dependent measures of the current study were analyzed employing several linear mixed-effects ANOVA models. Fixed effects were the expertise participants (competitive-élite; semi-élite), the time pressure (NOTP = no time pressure; TP = time pressure), the performance pressure (NOPP = no performance pressure; PP = performance pressure), and the throw outcome (hit; miss); random effects were participants ($n = 34$). About the DRES score, we added the STAI-Y2 score as a covariate for the analysis, and we removed the "throw outcome" as a fixed effect since we administered DRES-related measures before each trial. Moreover, given the role of challenge and threat state on attentional mechanisms (Vine et al., 2016), we ran separate linear mixed-effects ANOVA on the QE onset and the QE duration, employing the Z scores of DRES to categorize the engagement state on the task (threatening state: Z score DRES < -1; challenging state: $1 <$ Z score DRES <1; disengaged state: Z score DRES >1). Accordingly, we considered as fixed effects the expertise participants (competitive-élite; semi-élite), the throw outcome (hit; miss), and the engagement state on the task (threatening; challenging; disengaged); random effects were participants ($n = 34$). In the presence of significant interaction effects, post hoc pairwise comparisons were employed using the Bonferroni correction to determine interaction effects. Data were analyzed using IBM SPSS version 25 (IBM Corp, 2017). The significance level was set at $\alpha = .05$; meanwhile, α levels between .05 and .10 are considered marginally significant. At last, the effect size was calculated using partial eta squared ($\eta 2p$) through the calculator provided by Lakens (2013).

4.4 Results

Due to the high number of analyzed effects through the linear mixed-effects ANOVA, the non-significant effects of the model "expertise * time pressure * performance pressure * throw outcome" (Analysis 1) are shown in Supplementary Material – Table A2, while all the effects concerning the model "expertise * engagement state on the task * throw outcome" (Analysis 2) are shown in Supplementary Material – Table A3.

4.4.1. Action time

The time pressure significantly reduced the action time ($F(1, 1211.598) = 116.739$, $p < .001$, $\eta 2p = .088$; NOTP: M = 721.692 ms, SE = 36.107 ms; TP: M = 514.909 ms, SE = 35.787 ms) meanwhile performance pressure significantly increased it ($F(1, 1210.740) = 14.204$, $p < .001$, $\eta 2p = .012$; NOPP: M = 582.320 ms, SE = 35.907 ms; PP: M = 654.282 ms, SE = 35.976 ms). Findings regards the interaction of time pressure * performance pressure ($F(1, 1216.087) = 8.548$, $p < .01$, $\eta 2p = .007$) exhibited that time pressure significantly reduced action time both in trials without performance pressure ($p < .001$, $\eta 2p = .025$; NOTP/NOPP: M = 657.485 ms, SE = 38.660 ms; TP/NOPP: M = 507.155 ms, SE = 38.123 ms) and with performance pressure ($p < .001$, $\eta 2p = .072$; NOTP/PP: M = 785.900 ms, SE = 38.686 ms; TP/PP: M = 522.663 ms, SE = 38.232 ms). Instead, performance pressure significantly increased action time only in the trials without time pressure ($p < .001$, $\eta 2p = .017$; NOTP/NOPP: M = 657.485 ms, SE = 38.660 ms; NOTP/PP: M = 785.900 ms, SE = 38.686 ms). Regarding the interaction of expertise * performance pressure, the findings showed a significant effect ($F(1, 1210.740) = 4.527$, $p < .05$, $\eta 2p = .004$). In detail, only semi-élites significantly increased the action time during trials with performance pressure, compared to trials without this manipulation ($p < .001$, $\eta 2p = .014$; NOPP: M = 524.820 ms, SE = 51.999 ms; PP: M = 637.407 ms, SE = 51.962 ms). Finally, a significant three-way interaction emerged, expertise * time pressure * performance pressure ($F(1, 1216.087) = 5.037$, $p < .05$, $\eta 2p = .004$). Findings exhibited a significant longer action time for competitive-élites, compared to semi-élites, only in the NOTP/NOPP trial ($p < .05$, $\eta 2p = .080$; competitive-élites in NOTP/NOPP: M = 740.849 ms, SE = 54.305 ms; semi-élites in NOTP/NOPP: M = 574.121 ms, SE = 55.041 ms). Furthermore, performance pressure led to an increment of the duration of action time only for semi-élite athletes during throws without time pressure ($p < .001$, $\eta 2p = .025$; semi-élite in NOTP/NOPP: M = 574.121 ms, SE = 55.041 ms; semi-élite in NOTP/PP: M = 786.497 ms, SE = 55.791 ms). Finally, the time pressure significantly reduced action time, both for semi-élites during trials without performance pressure ($p < .05$, $\eta 2p = .005$; NOTP/NOPP: M = 574.121 ms, SE = 55.041 ms; TP/NOPP: M = 475.518 ms, SE = 55.722 ms) and with performance pressure ($p < .001$, η2p = .048; NOTP/PP: M = 786.497 ms, SE = 55.791 ms; TP/PP: M = 488.317 ms, SE = 54.903 ms), and for competitive-élites during trials without performance pressure ($p < .001$, η2p = .022; NOTP/NOPP: M = 740.849 ms, SE = 54.305 ms; TP/NOPP: M = 538.792 ms, SE = 52.045 ms) and with performance pressure ($p < .001$, η2p = .028; NOTP/PP: M = 785.303 ms, SE = 53.607 ms; TP/PP: M = 557.009 ms, SE = 53.221 ms).

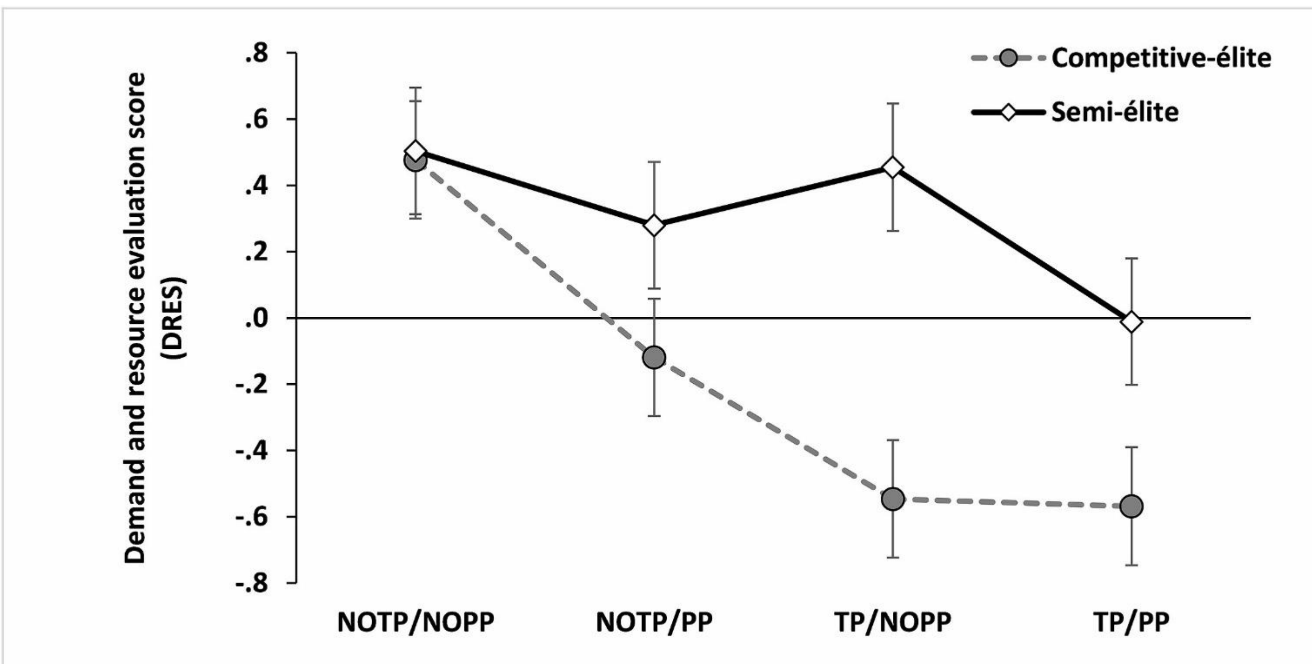
4.4.2. Demand and resource evaluation score (DRES)

The time pressure significantly reduced the DRES (F(1, 1208.488) = 231.763, $p < .001$, η2p = .161; NOTP: M = .285, SE= .119; TP: M = -.167, SE = .119), as well as performance pressure (F(1, 1208.613) = 120.921, $p < .001$, η2p = .091; NOPP: M = .223, SE = .119; PP: M = -.105, SE = .119). To note that results showed a marginal significant difference between expertise levels on DRES (F(1, 33.858) = 3.295, p = .078, η2p = .089; competitive-élites: M = -.189, SE = .173; semi-élites: M = .307, SE = .187). Findings regards the interaction of expertise * time pressure (F(1, 1208.509) = 90.350, $p < .001$, η2p = .070) showed that there were no differences in DRES between competitive-élites and semi-élites considering the trials without time pressure (competitive-élites in NOTP: M = .179, SE = .175; semi-élites in NOTP: M = .392, SE = .188;, η2p = .017). Instead, competitive-élites showed lower DRES than semi-élites considering the trials with time pressure ($p < .01$, η2p = .188; competitive-élites in TP: M = -.557, SE = .175; semi-élites in TP: M = .222, SE = .189). The time pressure significantly reduced the DRES both for semi-élites ($p < .001$, η2p = .013; NOTP: M = .392, SE = .188; TP: M = .222, SE = .189) and competitive-élites ($p < .001$, η2p = .206; NOTP: M = .179, SE = .175; TP: M = -.557, SE = .175)

About the time pressure * performance pressure findings (F(1, 1209.661) = 7.673, $p < .01$, η2p = .006), pairwise comparisons exhibited a significant decrease of DRES comparing the absence of time pressure with the presence of such manipulation, both in the trials without performance pressure ($p < .001$, η2p = .117; NOTP/NOPP: M = .491, SE = .121; TP/NOPP: M = -.045, SE = .121) and with performance pressure ($p < .001$, η2p = .060; NOTP/PP: M = .080, SE = .121; TP/PP: M = -.290 SE = .121). Moreover, performance pressure significantly reduced DRES, both in trials without time pressure ($p < .001$, η2p = .076; NOTP/NOPP: M = .491, SE = . 121; NOTP/PP: M = .080, SE = .121) and with time pressure ($p < .001$, η2p = .026; TP/NOPP: M = -.045, SE = .121; TP/PP: M = -.290, SE = .121). Finally, the expertise * time pressure * performance pressure findings (F(1, 1209.688) = 46.140, $p < .001$, η2p = .037) showed that both time and performance pressure significantly reduced DRES, even considering the expertise levels, with few exceptions (Figure 1). Indeed, performance pressure reduce the DRES (all pairwise comparisons were $p < .001$), except for competitive-élites engaged in trials with time pressure (p = .711, η2p = .000; TP/NOPP: M = -.546, SE =.177; TP/PP: M = -.568, SE = .178). About the effect of time pressure, such manipulation reduced the DRES (all pairwise comparisons were $p < .001$) except for semi-élites that perform free throws during trials without performance pressure (p = .419, η2p = .001; NOTP/NOPP: M = 504., SE = .191; TP/NOPP: M = .455, SE = .192). For what concern the difference on DRES between competitive-élites and semi-élites, findings showed that there was a significant difference in the TP/NOPP trial ($p < .001$, η2p = .262; competitive-élites: M = -.546, SE = .177; semi-élites: M = .455, SE = .192) and a marginal significant difference in the TP/PP trial (p = .053, η2p = .099; competitive-élites: M = -.568, SE = .178; semi-élites: M = -.011, SE = .191).

Figure 1

Average Values of Demand and Resource Evaluation Score (DRES) of each Trial according to Expertise Levels



Note. NOTP = no time pressure; NOPP = no performance pressure; TP = time pressure; PP = performance pressure.

4.4.3. QE duration

4.4.3.1 Analysis 1

Competitive-élite athletes performed significantly longer QE duration than semi-élite athletes ($F_{(1, 34.660)} = 8.384$, $p < .01$, $\eta^2_p = .195$; competitive-élites: M = 1080.918 ms, SE = 104.973 ms; semi-élites: M = 639.376 ms, SE = 110.613 ms). Moreover, hits are characterized by significant longer QE duration ($F_{(1, 1215.364)} = 5.146$, $p < .05$, $\eta^2_p = .004$; M = 903.565 ms, SE = 77.290 ms) than misses (M = 816.729 ms, SE = 79.914 ms) and time pressure significantly reduced the QE duration of athletes ($F_{(1, 1210.699)} = 108.744$, $p < .001$, $\eta^2_p = .082$; NOTP: M = 1055.143 ms, SE = 78.788 ms; TP: M = 665.151 ms, SE = 78.224 ms). Interactions' findings exhibited significant effects regards expertise * time pressure ($F_{(1, 1210.699)} = 27.286$, $p < .001$, $\eta^2_p = .022$) and time pressure * performance pressure * throw outcome ($F_{(1, 1210.335)} = 10.002$, $p < .01$, $\eta^2_p = .008$). Competitive-élite athletes performed significant longer QE duration than semi-élites only during the absence of time pressure ($p < .001$, $\eta^2_p = .293$; competitive-élites in NOTP: M = 1373.592 ms, SE = 109.059 ms; semi-élites in NOTP: M = 736.694 ms, SE = 113.737 ms). Furthermore, time pressure significantly reduced QE duration both for competitive-élite athletes ($p < .001$, $\eta^2_p = .090$; NOTP: M = 1373.592 ms, SE = 109.059 ms; TP: M = 788.245 ms, SE = 107.580 ms) and semi-élites ($p < .001$, $\eta^2_p = .011$; NOTP: M = 736.694 ms, SE = 113.737 ms; TP: M = 542.057 ms, SE = 113.590 ms; see Figure 2A). Regardless of expertise, athletes performed a significant longer QE duration during hits than misses only in the NOTP/PP trial ($p < .001$, $\eta^2_p = .010$; hits in NOTP/PPP: M = 1182.908 ms, SE = 84.841 ms; misses in NOTP/PP: M = 906.262 ms, SE = 98.406 ms). Moreover, performance pressure significantly increased QE duration of the hit throws performed without time pressure ($p < .05$, $\eta^2_p = .005$; NOTP/NOPP: M = 1039.018 ms, SE = 84.838 ms; NOTP/PP: M = 1182.908 ms, SE = 84.841 ms) and reduced the QE duration of the missed throws performed without time pressure ($p < .05$, $\eta^2_p = .003$; NOTP/NOPP: M = 1092.385 ms, SE = 98.221 ms; NOTP/PP: M = 906.262 ms, SE = 98.406 ms). Finally, time pressure significantly reduced QE duration, regardless of the presence of performance pressure, both for hits and misses (Figure 2B and 2C, respectively).

The four-way interaction between expertise * performance pressure * time pressure * throw outcome was not significant. Nevertheless, the pairwise comparisons showed statistically significant differences (Table 3 reported the means and the standard errors). Indeed, competitive-élites performed a significantly longer QE duration during their hits than misses in the TP/NOPP trial ($p < .05$, $\eta^2_p = .004$) and in the NOTP/PP trial ($p < .01$, $\eta^2_p = .006$). Semi-élites too performed significantly longer QE duration in their hits than misses, but only in the NOTP/PP trial ($p < .05$, $\eta^2_p = .005$). Furthermore, performance pressure led to an increment of QE duration, but only for hit throws performed by competitive-élites in the NOTP/PP trial ($p < .05$, $\eta^2_p = .005$). Time pressure significantly reduced the QE duration, regardless of expertise, performance pressure, and throw outcome (all pairwise comparisons were $p < .05$). The only exception consisted in the misses performed by semi-élites with performance pressure: in this case, time pressure did not reduce the QE duration in a significant way ($p = .981$, $\eta^2_p = .000$). Finally, competitive-élites showed a significantly longer QE duration than semi-élites across all trials and levels of throw outcome (all pairwise comparisons were $p < .01$), except for four comparisons. The first regard the comparison between competitive-élites and semi-élites in the misses performed in the TP/NOPP trial ($p = .306$, $\eta^2_p = .014$); the second was about the comparison between competitive-élites and semi-élites in the misses performed in the TP/PP trial ($p = .383$, $\eta^2_p = .010$). The third concerned the difference in QE duration between competitive-élites and semi-élites in hits performed in the TP/NOPP trial ($p = .058$, $\eta^2_p = .056$). The fourth and last regards the comparison in QE duration between competitive-élites and semi-élites in hits performed in the TP/PP trial ($p = .104$, $\eta^2_p = .042$).

Table 3

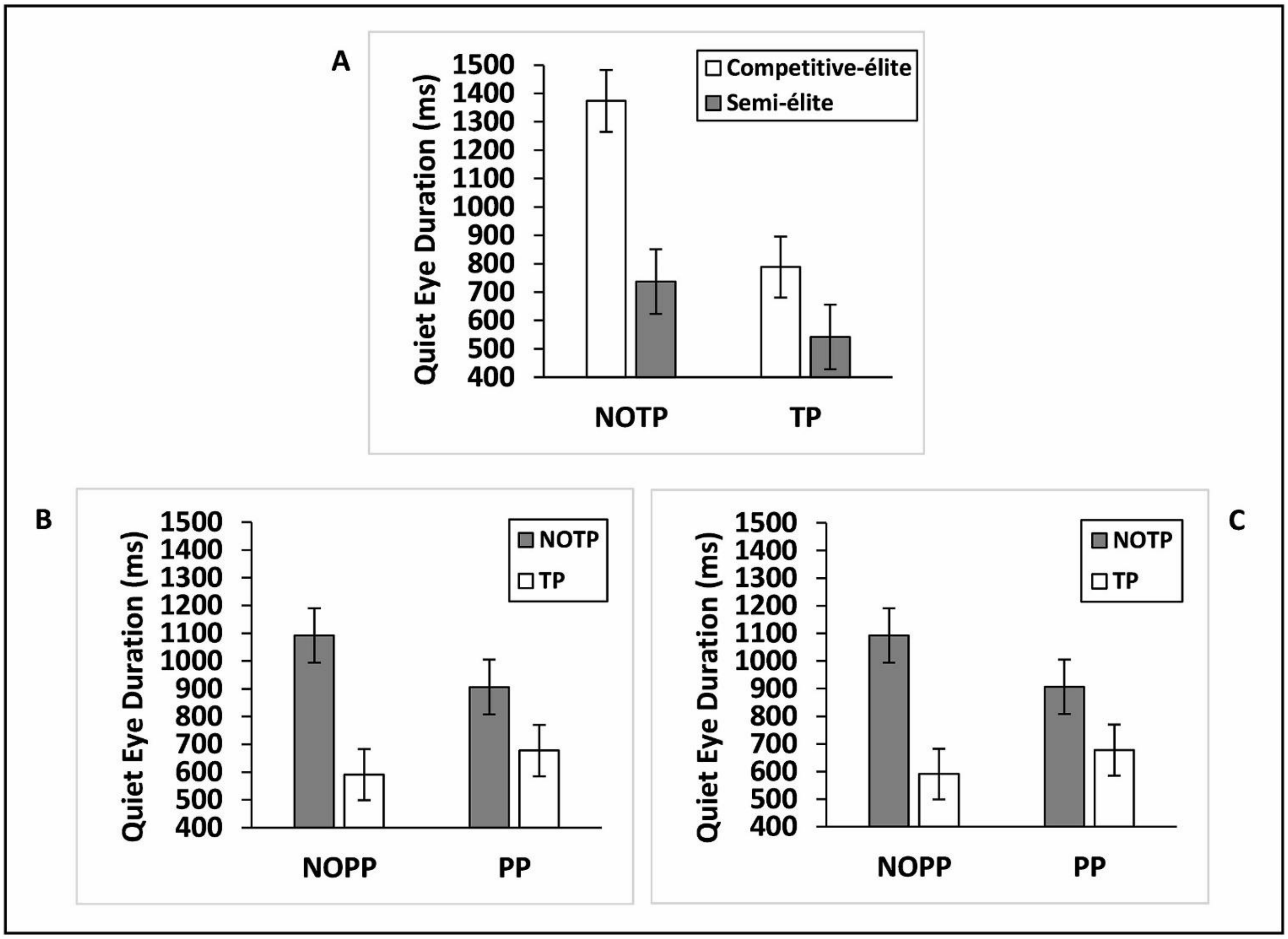
Averages and Standard Errors of QE Duration for each Trial across Expertise and Throw Outcome Levels

Throw outcome	Expertise	Trial			
		NOTP/NOPP	TP/NOPP	NOTP/PP	TP/PP
Hit	Competitive-élite	1319.189 (116.603)	895.847 (119.503)	1515.541 (115.747)	813.31 (121.14)
	Semi-élite	758.847 (123.262)	553.988 (130.747)	850.274 (124.076)	521.523 (129.014)
Miss	Competitive-élite	1440.778 (141.341)	685.415 (126.753)	1218.859 (138.691)	758.408 (130.881)
	Semi-élite	743.991 (136.427)	496.314 (132.793)	593.664 (139.642)	596.405 (130.143)

Note. The unity of measures of QE duration is in milliseconds. Standard errors are presented in parentheses. NOTP = no time pressure; NOPP = no performance pressure; TP = time pressure; PP = performance pressure.

Figure 2

Mean Quiet Eye Duration by (A) Expertise and Time Pressure, and by Time Pressure and Performance Pressure across Hits (B) and Misses (C)



Note. NOTP = no time pressure; TP = time pressure; NOPP = no performance pressure; PP = performance pressure.

4.4.3.2 Analysis 2

Results showed a significant interaction effect of expertise * engagement state on the task * throw outcome ($F_{(4,\ 1230.429)} = 3.991$, $p < .01$, $\eta^2_p = .013$). The pairwise comparisons (cf. Table 4) findings exhibited that competitive-élites both during their hits and misses had significant lower QE duration in threatening state than challenging state and disengagement state, while there were no significant differences on the QE duration comparing the challenging state with the disengagement state. Instead, results about semi-élites (cf. Table 4) did not show significant differences on QE duration comparing threatening, challenging and disengagement state, both for hits and misses. Moreover, competitive-élites showed longer QE duration in hits than misses during threatening state ($p < .05$, $\eta^2_p = .004$; hits: M = 859.535 ms, SE = 132.021 ms; misses: M = 636.437 ms, SE = 142.496 ms) and challenging state ($p < .05$, $\eta^2_p = .004$; hits: M = 1258.951 ms, SE = 120.023 ms; misses: M = 1088.738 ms, SE = 128.120 ms), while there was no significant difference between hits and misses during disengagement state ($p = .187$, $\eta^2_p = .001$). At the end, competitive-élites exhibited significant longer QE duration than semi-élites during challenging state, both for hits ($p < .01$, $\eta^2_p = .236$; competitive-élites: M = 1258.951 ms, SE = 120.023 ms; semi-élites: M = 663.918 ms, SE = 125.647 ms) and misses ($p < .01$, $\eta^2_p = .150$; competitive-élites: M = 1088.738 ms, SE = 128.120 ms; semi-élites: M = 576.343 ms, SE = 128.703 ms), and during disengagement state, both for hits ($p < .01$, $\eta^2_p = .066$; competitive-élites: M = 1433.286 ms, SE = 152.996 ms; semi-élites: M = 811.986 ms, SE = 168.986 ms) and misses ($p < .05$, $\eta^2_p = .023$; competitive-élites: M = 1192.980 ms, SE = 198.962 ms; semi-élites: M = 654.486 ms, SE = 171.551 ms). There was no difference on QE duration between competitive-élites and semi-élites in the hits ($p = .865$, $\eta^2_p = .000$) and misses ($p = .396$, $\eta^2_p = .004$) performed in threatening state.

Table 4.

Averages and Standard Errors of QE Duration for each Engagement State on the Task across Expertise and Throw Outcome Levels, with Pairwise Comparisons (p-values)

Expertise	Throw outcome	Engagement state on the task	M	SE	1	2	3
Competitive-élite	Hit	1. Low	859.535	132.021	--		
		2. Medium	1258.951	120.023	< .001	--	
		3. High	1433.286	152.996	< .001	.365	--
	Miss	1. Low	636.437	142.496	--		
		2. Medium	1088.738	128.120	< .001	--	
		3. High	1192.980	198.962	< .05	1.000	--
Semi-élite	Hit	1. Low	904.289	226.480	--		
		2. Medium	663.918	125.647	.700	--	
		3. High	811.986	168.986	1.000	.800	--
	Miss	1. Low	864.203	226.836	--		
		2. Medium	576.343	128.703	.469	--	
		3. High	654.486	171.551	.985	1.000	--

Note. The unity of measures of QE duration is in milliseconds. M = mean; SE = standard error.

4.4.4. QE onset

4.4.4.1. Analysis 1

Competitive-élite athletes had a significant earlier QE onset compared to semi-élites ($F(1, 34.968) = 6.561$, $p < .05$, $\eta 2p = .158$; competitive-élites: M = −872.369 ms, SE = 80.872 ms; semi-élites: M = −571.923 ms, SE = 84.962 ms). Time pressure findings exhibited a significant delay of the QE onset ($F(1, 1212.621) = 60.707$, $p < .001$, $\eta 2p = .048$) during throws performed in trials with time pressure (M = −584.652 ms, SE = 60.929 ms) compared to trials without time pressure (M = −859.640 ms, SE = 61.562 ms). Interactions' findings exhibited significant effects regards expertise * time pressure ($F(1, 1212.621) = 24.389$, $p < .001$, $\eta 2p = .020$) and time pressure * performance pressure * throw outcome ($F(1, 1212.261) = 14.991$, $p < .001$, $\eta 2p = .012$). Competitive-élite athletes had a significant earlier QE onset than semi-élites in trials without time pressure ($p < .001$, $\eta 2p = .260$; competitive-élites in NOTP: M = −1097.012 ms, SE = 85.535 ms; semi-élites in NOTP: M = −622.268 ms, SE = 88.563 ms) meanwhile there was no statistically significant difference in trials with time pressure ($p = .307$, $\eta 2p = .026$; competitive-élites in TP: M = −647.726 ms, SE = 83.882 ms;

semi-élites in TP: M = −521.578 ms, SE = 88.392 ms). Time pressure significantly delayed the QE onset, both for competitive-élites ($p < .001$, η2p = .061; NOTP: M = −1097.012 ms, SE = 85.535 ms; TP: M = −647.726 ms, SE = 83.882 ms) and semi-élites ($p < .05$, η2p = .003; NOTP: M = −622.268 ms, SE = 88.563 ms; TP: M = −521.578 ms, SE = 88.392 ms; see Figure 3A). Regardless expertise, hits had a significant earlier QE onset than misses ($p < .001$, η2p = .010; hits: M = −1006.051 ms, SE = 68.352 ms; misses: M = −753.490 ms, SE = 82.979 ms), only when throws are performed in the NOTP/PP trial. Moreover, performance pressure significantly anticipated QE onset in the hit throws performed without time pressure ($p < .001$, η2p = .012; NOTP/NOPP: M = −793.363 ms, SE = 68.352 ms; NOTP/PP: M = −1006.051 ms, SE = 68.352 ms) and in the miss throws performed with time pressure ($p < .05$, η2p = .004; TP/NOPP: M = −499.053 ms, SE = 75.925 ms; TP/PP: M = −663.414 ms, SE = 76.457 ms). The time pressure delayed the QE onset in a statistically significant way for hits (see Figure 3B) performed both in trials with performance pressure ($p < .001$, η2p = .042; NOTP/PP M = −1006.051 ms, SE = 68.352 ms; TP/PP: M = −568.822 ms, SE = 72.347 ms) and in trials without performance pressure ($p < .01$, η2p = .008; NOTP/NOPP: M = −793.363 ms, SE = 68.352 ms; TP/NOPP: M = −607.320 ms, SE = 72.439 ms). Regarding misses (see Figure 3C), time pressure significantly delayed the QE onset only for throws performed without performance pressure ($p < .001$, η2p = .019; NOTP/NOPP: M = - 885.657 ms, SE = 82.792 ms; TP/NOPP: M = - 499.053 ms, SE = 75.925 ms), meanwhile QE onset of misses throws performed with performance pressure were not significantly delayed by time pressure ($p = .262$, η2p = .001; NOTP/PP: M = −753.490 ms, SE = 82.979 ms; TP/PP: M = −663.414 ms, SE = 76.457 ms). The four-way interaction between expertise * performance pressure * time pressure * throw outcome was not significant. Nevertheless, the pairwise comparisons showed statistically significant differences (Table 5 reported the means and the standard errors). Indeed, the hit throws performed by semi-élites in the NOTP/PP trial had an earlier QE onset than misses performed in the same trial ($p < .05$, η2p = .004). About the comparison of the QE onset between hit and misses performed by competitive-élites, findings showed that in the NOTP/PP trial, the competitive-élites had a significant earlier QE onset during their hits than misses ($p < .01$, η2p = .006), while in the TP/PP trial the competitive-élites had a significant later QE onset during their hits than misses ($p < .05$, η2p = .003). Performance pressure led to an anticipation of the QE onset, but only in the throws performed by competitive-élites. In detail, competitive élites showed an earlier QE onset in their hits performed during the NOTP/PP trial than the NOTP/NOPP trial ($p < .001$, η2p = .010). Note that also semi-élites exhibited an earlier QE onset during their hits in the NOTP/PP trial than in the TP/PP trial. However, this effect is very near the significance level ($p = .051$, η2p = .003). The time pressure delayed in a significant way the QE onset across all trials and expertise levels, except for a few comparisons. Both competitive-élites and semi-élites delayed the QE onset in the hits performed in the TP/PP trial than the NOTP/PP trial (competitive-élites: $p < .001$, $\eta 2p = .053$; semi-élites: $p < .05$, $\eta 2p = .005$). Instead, only competitive-élites delayed the QE onset of their hits in the TP/NOPP trial comparing the NOTP/NOPP trial ($p < .001$, $\eta 2p = .014$). Also, only competitive-élites delayed the QE onset of misses performed in the TP/NOPP trial than the NOTP/NOPP trial ($p < .001$, $\eta 2p = .021$). At last, competitive-élites showed an earlier QE onset than semi-élites across all trials and throw outcomes not characterized by the time pressure. Indeed, competitive-élites exhibited an earlier QE onset than semi-élites in the hits performed in the NOTP/NOPP trial ($p < .01$, $\eta 2p = .123$) and in the NOTP/PP trial ($p < .001$, $\eta 2p = .182$). Regarding misses, competitive-élites showed an earlier QE onset than semi-élites in the misses performed in the NOTP/NOPP trial ($p < .01$, $\eta 2p = .065$) and in the NOTP/PP trial ($p < .01$, $\eta 2p = .056$).

Table 5

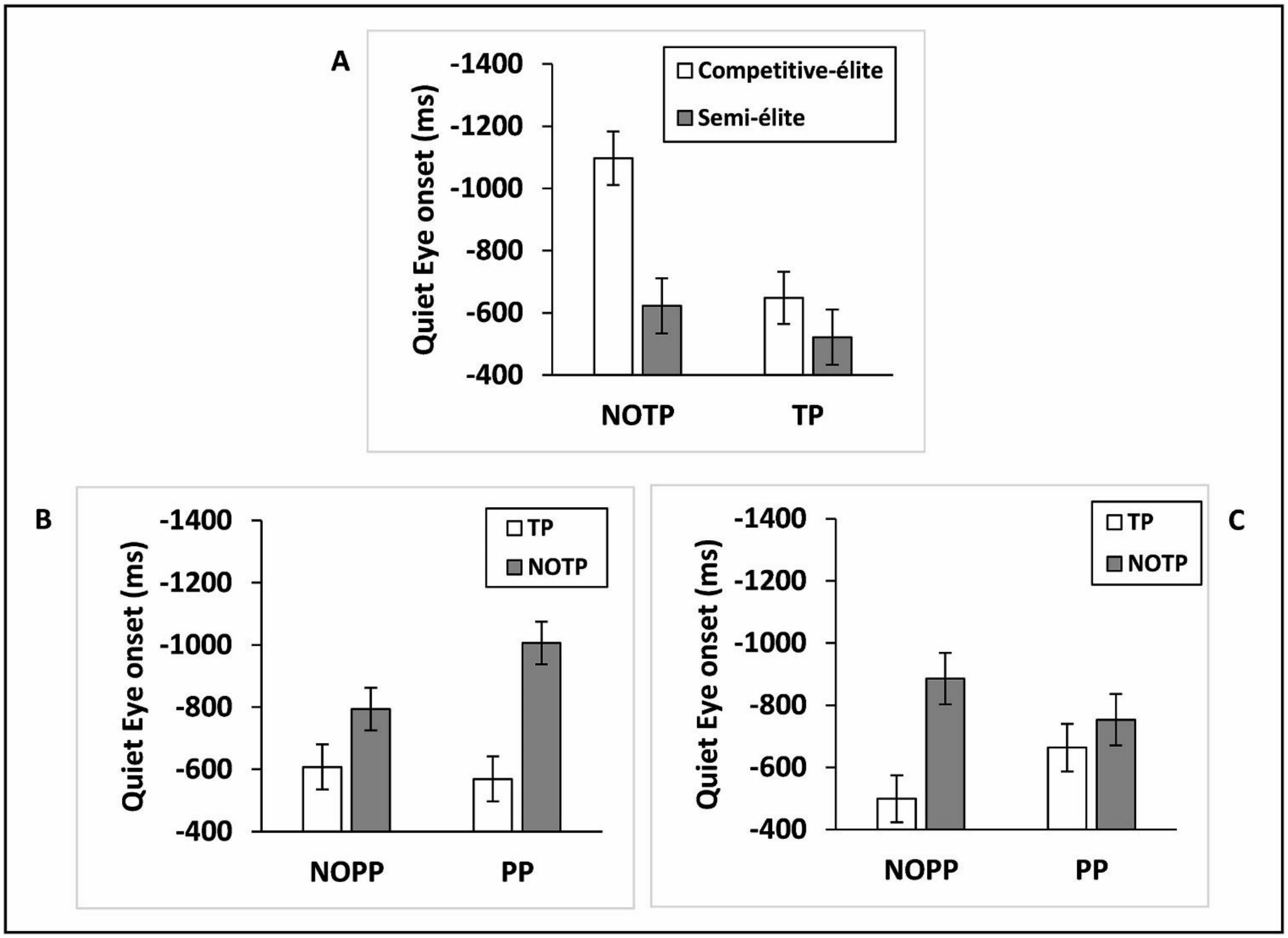
Averages and Standard Errors of QE Onset for each Trial across Expertise and Throw Outcome Levels

Throw outcome	Expertise	Trial			
		NOTP/NOPP	TP/NOPP	NOTP/PP	TP/PP
Hit	Competitive-élite	-998.190 (93.982)	-657.79 (97.189)	-1263.832 (93.038)	-600.818 (98.949)
	Semi-élite	-588.537 (99.274)	-556.85 (107.444)	-748.269 (100.16)	-536.826 (105.571)
Miss	Competitive-élite	-1138.053 (120.494)	-535.545 (105.047)	-987.975 (117.701)	-796.751 (109.441)
	Semi-élite	-633.261 (113.575)	-462.561 (109.653)	-519.006 (116.998)	-530.076 (106.794)

Note. The unity of measures of QE onset is in milliseconds. Standard errors are presented in parentheses. A negative value represents a QE onset before the critical movement (i.e., a higher value corresponds to an earlier quiet eye onset). NOTP = no time pressure; NOPP = no performance pressure; TP = time pressure; PP = performance pressure.

Figure 3

Mean Quiet Eye Onset by (A) Expertise and Time Pressure, and by Time Pressure and Performance Pressure across Hits (B) and Misses (C)



Note. NOTP = no time pressure; TP = time pressure; NOPP = no performance pressure; PP = performance pressure. A negative value represents a quiet eye onset before the critical movement (i.e., longer bar – earlier quiet eye onset).

4.4.4.2 Analysis 2

The results showed a significant interaction effect of expertise * engagement state on the task * throw outcome ($F_{(4,\ 1229.184)} = 5.537$, $p < .001$, $\eta^2_p = .018$). The pairwise comparisons (cf. Table 6) findings exhibited that competitive-élites during their hits and misses had significantly later QE onset in threatening state than challenging state and disengagement state. At the same time, there were no significant differences in the QE onset comparing the challenging state with the disengagement state. Instead, results about semi-élites (cf. Table 6) did not show significant differences on QE onset comparing threatening, challenging, and disengagement states, both for hits and misses. Moreover, competitive-élites and near-élites did not show differences in QE onset between hits and misses performed during threatening, challenging state, or disengagement states (all the pairwise comparisons were $p > .05$). At the end, competitive-élites exhibited significant earlier QE onset than semi-élites during challenging state, both for hits ($p < .05$, $\eta^2_p = .158$; competitive-élites: M = −995.853 ms, SE = 98.850 ms; semi-élites: M = −611.527 ms, SE = 103.108 ms) and misses ($p < .01$, $\eta^2_p = .158$; competitive-élites: M = −967.467 ms, SE = 107.211 ms; semi-élites: M = −513.897 ms, SE = 106.303 ms), and during disengagement state, both for hits ($p < .01$, $\eta^2_p = .070$; competitive-élites: M = −1189.389 ms, SE = 132.162 ms; semi-élites: M = −578.764 ms, SE = 146.634 ms) and misses ($p < .05$, $\eta^2_p = .019$; competitive-élites: M = −1028.509 ms, SE = 177.220 ms; semi-élites: M = −539.867 ms, SE = 149.305 ms). There was no difference in QE onset between competitive-élites and semi-élites in the hits ($p = .350$, $\eta^2_p = .004$) and misses ($p = .156$, $\eta^2_p = .008$) performed in the threatening state.

Table 6

Averages and Standard Errors of QE Onset for each Engagement State on the Task across Expertise and Throw Outcome levels, with Pairwise Comparisons (p-values)

Expertise	Throw outcome	Engagement state on the task	M	SE	1	2	3
Competitive-élite	Hit	1. Low	-600.849	111.063	--		
		2. Medium	-995.853	98.850	< .001	--	
		3. High	-1189.389	132.162	< .001	.190	--
	Miss	1. Low	-461.694	121.695	--		
		2. Medium	-967.467	107.211	< .001	--	
		3. High	-1028.509	177.220	< .01	1.000	--
Semi-élite	Hit	1. Low	-816.902	202.400	--		
		2. Medium	-611.527	103.108	.812	--	
		3. High	-578.764	146.634	.745	1.000	--
	Miss	1. Low	-798.313	202.937	--		
		2. Medium	-513.897	106.303	.390	--	
		3. High	-539.867	149.305	.581	1.000	--

Note. The unity of measures of QE onset is in milliseconds. M = mean; SE = standard error. A negative value represents a QE onset before the critical movement (i.e., a higher value corresponds to an earlier quiet eye onset).

4.5 Discussion

To the best of our knowledge, the current study is the first that assessed the QE behavior of competitive-élite and semi-élite basketball players, manipulating simultaneously the time provided to athletes (i.e., time pressure) and the relevance of the performance (i.e., performance pressure), also considering the perceived task demands and resources. We measured free throw outcomes (i.e., hits and misses) across four different free throw trials in an ecological setting.

Our principal interest was to comprehend the effect of time pressure and performance pressure on free throw QE characteristics, since the relevance of this task in the latest match minutes, during which the end of the game is very close, and the performance pressure could be very high (Gómez Ruano et al., 2016; Kozar et al., 1994; Malarranha et al., 2013). Accordingly, we analyzed the effect of time pressure and performance pressure on free throw QE characteristics. The findings showed that players shortened their QE duration (see Figure 2A, 2B, and 2C) and delayed the QE onset during trials with the time pressure (Figure 3A, 3B, and 3C). Findings of the interaction between expertise and time pressure exhibited that competitive-élite players had longer and earlier QE than semi-élites, but only during trials without time pressure (Figure 2A and Figure 3A). We can explain such effects if we consider that free throw is a self-paced task (i.e., in which the athlete decides the onset of his/her action; Kent, 2007) since studies that evaluated time pressure in such tasks showed that this manipulation negatively affects the QE duration (e.g., Williams et al., 2002). On the other hand, concerning the QE onset findings, we can speculate that basketball players engaged in time-pressured free throws cannot adapt their QE through its anticipation. Such QE anticipation strategy is commonly implemented in external-paced tasks (i.e., tasks influenced by factors that are not under the control of the athlete, requiring an adaptation of motor actions; Kent, 2007), assuming significant advantages in terms of sports performances (cf. Causer et al., 2011; Chirico et al., 2019). Interestingly, the presence of time pressure decreased the free throw accuracy (cf. Table 2), which is in line with the effect of time pressure on self-paced task performances (cf. Williams et al., 2002). The difficulty in adapting the QE characteristics to a familiar but novel task (i.e., free throw in time-pressured trials) could be explained by our interaction findings between expertise and time pressure. Indeed, competitive-élites did not seem to transfer the QE duration and QE onset from trials in which they are experts to ones in which they have no previous experience (cf. Flindall et al., 2020; Rienhoff et al., 2013). Following our results, we advocate the recommendations of Kozar and colleagues to develop practice situations "as close as possible" to the ones players could face during a match (Kozar et al., 1994; cf.; Gómez Ruano et al., 2016; Malarranha et al., 2013), also implementing time-pressured conditions in the already established QE free throw training protocols (Harle & Vickers, 2001; Vine & Wilson, 2011), emphasizing the anticipation of the QE onset. As a manipulation check, it is relevant to outline that the action time was negatively affected by the time pressure, exhibiting that we successfully manipulated the time available for the athletes to perform the research tasks.

Regarding the effect of performance pressure on QE characteristics, it is necessary to note that this factor might lead either to an extension or a reduction of the QE duration, increasing or decreasing, respectively, the sport performance (Brimmell et al., 2019; Moore et al., 2013; Wilson et al., 2009). These opposite effects of performance pressure on QE and performance outcome could be explained by considering the athletes' evaluation to cope with task demands (e.g., Blascovich & Tomaka, 1996; Seery, 2013). In detail, a task in which performance is particularly relevant could be seen either as challenging, potentially leading to an extension of the QE duration, or as threatening, with a QE duration reduction (Brimmell et al., 2019; Moore et al., 2013). Our QE results showed that successful throws (i.e., hits) are characterized by a more prolonged and earlier QE than unsuccessful ones (i.e., misses) in the trial with performance pressure but without time pressure. In this regard, the current DRES score findings showed that the coping resources nearly match the perceived task demands in this trial. Such results underlined that athletes could consider this trial as challenging, showing a better attentional control than other trials, results in line with the theoretical framework of BPSM (cf. Brimmell et al., 2019). Interestingly, also the PP/TP trial was evaluated by semi-élites as challenging (cf. Figure 1). However, these athletes did not show a more prolonged and earlier QE in their hits than misses. To better comprehend such results, it could be important to consider what happened to the QE characteristics according to DRES levels and the participants' expertise (i.e., Analysis 2). Results showed that, during a challenging state, competitive-élites performed earlier and longer QE during hits than misses. Instead, semi-élites did not show such a pattern. Moreover, findings of semi-élites did not show any differences across challenging, threatening, and disengagement state on QE characteristics. At the same time, competitive-élites exhibited different QE characteristics according to DRES levels (in particular, longer and earlier QE in challenging and threatening states than in the disengagement state). In light of this, it could be discussed the appropriateness of the DRES on semi-élite athletes. It is not straightforward to verify such an argument for two main reasons. The first was that there was no psychometric testing of the DRES in the literature (cf. Brimmell et al., 2019) that could explain the measurement invariance of this tool between different levels of expertise. The second was that, to our knowledge, the present study is the first within the QE literature that employs the expertise classification system of Swann et al. (2015), making comparisons with previous studies complex since they used different expertise classification systems. Our findings would seem to suggest that future works should focus on the psychometric testing of the DRES, also considering the sport expertise of the athletes.

To summarize, it seems that the performance pressure led to the extension and the anticipation of the QE, but only when time pressure did not occur. Indeed, the simultaneous presence of performance and time pressure seems to have a detrimental effect on attentional mechanisms, and so on the QE, with also a decrease in throw performances. Interestingly, the trials in which the players scored poorly were those with time pressure (cf. Table 2). The coping evaluation related to the task seemed to have a role on QE, and so performances, but only considering competitive-élites.

Lastly, we assumed that only the most experienced athletes would have the ability to adapt the QE characteristics, across all trials, in their best performance, following ACT (Eysenck & Wilson, 2016). Findings showed that competitive-élites exhibited a more prolonged and earlier QE than semi-élites only in the trials without time pressure. Moreover, competitive-élites did not exhibit superior attentional control across all trials. They exhibited higher QE duration and earlier QE onset for hits than misses only in the NOPP/TP and PP/NOTP trials. To speculate, since competitive-élites cannot adapt their QE duration, especially in tough trials (e.g., PP/TP trial), we could state that such results highlight the relevance of promoting QE training not only to less experienced athletes (e.g., novices, near experts, semi-élites) but also to the most experienced athletes. However, it is essential to note that competitive-élites performed better than semi-élites across all trials (Table 2). It is possible to speculate that, in the toughest trials (i.e., TP/NOPP and TP/PP trials), competitive-élites successfully compensated for the negative effect of the threatening state on their attentional processing efficiency showing better performances than semi-élites, in line with ACT predictions.

In a nutshell, considering all the above results, it seems relevant to implement conditions with time and performance pressure in QE training protocols (cf. Harle & Vickers, 2001; Vine & Wilson, 2011), given the effects of these two factors on QE and, consequently, on accuracy. Such training could aid both the most experienced and the least experienced players to improve their perceptual-cognitive skills and performances, especially in conditions characterized by little time available and performance pressure (cf. Kinrade et al., 2015) that could reduce the coping evaluation related to the task, as might happen in the last quarter of a basketball match (Gómez Ruano et al., 2016; Kozar et al., 1994; Malarranha et al., 2013).

Our work has some limitations. One of the first refers to the manipulation of the time available to perform free throws. Such tasks, as a rule, are not characterized by time pressure. Nevertheless, we used this type of task given the well-known relationships between QE, throwing outcome, and expertise in free throws, which allowed us to better control the effect of our experimental manipulations.

Still, regarding time pressure, we did not implement a strict time limit during which athletes had to perform the free throw (e.g., time constraint), but we requested athletes to throw as quickly as possible (cf. Table 1). In our opinion, the implementation of such instruction permitted a high ecological validity of the present investigation, resembling those conditions highlighted by Gómez Ruano et al. (2016; cf. Kozar et al., 1994 and Malarranha et al., 2013), characterized by time pressure. However, we think also that the employment of time constraints could be important for future research.

About the sample, we did not collect an equal number of hits and misses from our sample (Supplementary materials – Table A1). The reason was to prevent any possible fatigue effect on athletes. Indeed, considering the number of trials in our study and our sample's relatively high expertise level, it could have been very exhausting for the players to perform an equal number of hits and misses for each trial (cf. the first Vickers's study on free throw of experts and near-experts (1996), in which a participant performed 108 free throws before achieving the minimum goal of ten misses).

Still, about the number of throws, we could not code 8.82% of the throws (Supplementary materials – Table A1) due to technical issues. However, it should be noted that the numbers of throws analyzed are definitely numerous, even compared to previous QE studies on basketball free throw.

Furthermore, although the eye-tracker utilized in the current study is a well-established instrument employed in many ecological QE and eye tracking research regarding basketball studies (cf. Marques et al., 2018), it is a tool that athletes are not used to. Accordingly, the eye-tracker could have created some annoyance.

Lastly, the research design we employed did not permit us to test some QE underlying functions hypothesis, as Klostermann's inhibition hypothesis, which seems to well-apply to free throws (Klostermann, 2019; Klostermann, 2020). However, the current study's main aim was not to understand which underlying cognitive mechanism QE responds to but the effect of game factors that could affect the QE of self-paced tasks.

Despite these limitations, we believe our research could be helpful to basketball players, trainers, and sports psychologists since it could give some suggestions to previous QE training protocol on basketball free throws (e.g., Vickers, 2016; Vine & Wilson, 2011). Indeed, considering our results, it could be relevant to implement conditions with the time and performance pressure, regardless of the athlete’s expertise. In our view, given the similarity of QE features across a wide range of self-paced tasks, our study could represent a base for testing the effects of factors usually manipulated individually on QE research (i.e., time pressure; performance pressure) on other self-paced tasks, to give more insights in how to improve the transfer effect of the current QE training protocols in the harshest game situations.

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Supplementary Material – Appendix A

Table A.1 - *Throws' Numbers and Outcome*

Sample	Trial	Throws' coding			Throws' outcome		
		Coded	Not coded	Total	Hit	Miss	Total
Competitive-élite	NOTP/NOPP	159 (88.33%)	21 (11.67%)	180	119 (74.84%)	40 (25.16%)	159
	NOTP/PP	170 (94.44%)	10 (5.56%)	180	126 (74.12%)	44 (25.88%)	170
	TP/NOPP	166 (92.22%)	14 (7.78%)	180	98 (59.04%)	68 (40.96%)	166
	TP/PP	149 (82.78%)	31 (17.22%)	180	91 (61.07%)	58 (38.93%)	149
	Total	644 (89.44%)	76 (10.56%)	720	434 (67.39%)	210 (32.61%)	644
Semi-élite	NOTP/NOPP	160 (100.00%)	0 (0.00%)	160	105 (65.63%)	55 (34.38%)	160
	NOTP/PP	150 (93.75%)	10 (6.25%)	160	101 (67.33%)	49 (32.67%)	150
	TP/NOPP	136 (85.00%)	24 (15.00%)	160	71 (52.21%)	65 (47.79%)	136
	TP/PP	150 (93.75%)	10 (6.25%)	160	77 (51.33%)	73 (48.67%)	150
	Total	596 (93.13%)	44 (6.88%)	640	354 (59.40%)	242 (40.60%)	596
Total sample	NOTP/NOPP	319 (93.82%)	21 (6.18%)	340	224 (70.22%)	95 (29.78%)	319
	NOTP/PP	320 (94.12%)	20 (5.88%)	340	227 (70.94%)	93 (29.06%)	320
	TP/NOPP	302 (88.82%)	38 (11.18%)	340	169 (55.96%)	133 (44.04%)	302
	TP/PP	299 (87.94%)	41 (12.06%)	340	168 (56.19%)	131 (43.81%)	299
	Total	1240 (91.18%)	120[a] (8.82%)	1360	788 (63.55%)	452 (36.45%)	1240

Note. Throws percentage are in parentheses. NOTP = no time pressure; NOPP = no performance pressure; PP = performance pressure; TP = time pressure. [a] Throws not included in the analysis due to technical issues (e.g., technical errors and/or low-quality recordings).

Table A.2 - *Statistical Outputs of Non-Significant Effects of the Linear Mixed-Effects ANOVA Models of Analysis 1 (Expertise * Time pressure * Performance pressure * Throw Outcome)*

Results	df, df error	F	p - value	Partial η²
Action Time				
EXP	1, 34.641	1.152	.29	.032
TO	1, 1217.470	1.266	.26	.001
EXP * TP	1, 1211.598	.192	.66	.000
EXP * TO	1, 1217.470	.347	.56	.000
TP * TO	1, 1211.544	.229	.63	.000
PP * TO	1, 1213.870	.603	.44	.000
EXP * TP * TO	1, 1211.544	.004	.95	.000
TP * PP * TO	1, 1211.222	.034	.85	.000
EXP * PP * TO	1, 1213.870	.269	.60	.000
EXP * TP * PP * TO	1, 1211.222	.599	.44	.000
DRES				
EXP * PP	1, 1208.599	.37	.54	.000
QED				
PP	1, 1210.018	.008	.93	.000
EXP * PP	1, 1210.018	.022	.88	.000
EXP * TO	1, 1215.364	.37	.54	.000
TP * PP	1, 1214.376	.223	.64	.000
TP * TO	1, 1210.602	.438	.51	.000
PP * TO	1, 1212.465	1.516	.22	.001
EXP * TP * PP	1, 1214.376	.134	.71	.000
EXP * TP * TO	1, 1210.602	1.596	.21	.001
EXP * PP * TO	1, 1212.465	.258	.61	.000
EXP * TP * PP * TO	1, 1210.335	.443	.51	.000
QE Onset				
PP	1, 1211.618	2.147	.14	.002
TO	1, 1219.467	1.451	.23	.001
EXP * PP	1, 1211.618	.648	.42	.001
EXP * TO	1, 1219.467	.598	.44	.000
TP * PP	1, 1217.726	.101	.75	.000
TP * TO	1, 1212.623	1.073	.3	.001
PP * TO	1, 1215.320	.993	.32	.001
EXP * TP * PP	1, 1217.726	.093	.76	.000
EXP * TP * TO	1, 1212.623	.199	.66	.000
EXP * PP * TO	1, 1215.320	.097	.75	.000
EXP * TP * PP * TO	1, 1212.261	1.732	.19	.001

Note. EXP = expertise; TO = throw outcome; TP = time pressure; PP = performance pressure; DRES = demand and resource evaluation score; QED = quiet eye duration; QE = quiet eye.

Table A.3 - *Statistical Outputs of Non-Significant Effects of the Linear Mixed-Effects ANOVA Models of Analysis 2 (Expertise * Engagement State on the Task * Throw Outcome)*

Results	df, df error	F	p - value	Partial η²
QED				
EXP	1, 42.283	3.451	.07	.075
EST	2, 1233.908	2.172	.11	.004
TO	1, 1209.842	6.394	.01	.005
EST * TO	2, 1210.873	.153	.86	.000
EXP * TO	1, 1209.842	.920	.34	.001
EXP * EST * TO	4, 1230.429	3.991	<.01	.013
QE Onset				
EXP	1, 43.962	2.426	.13	.052
EST	2, 1220.603	1.449	.23	.002
TO	1, 1210.620	2.058	.15	.002
EST * TO	2, 1211.918	.053	.95	.000
EXP * TO	1, 1210.620	.264	.61	.000
EXP * EST * TO	4, 1229.184	5.537	<.001	.018

Note. QED = quiet eye duration; EXP = expertise; EST = engagement state on the task; TO = throw outcome; QE = quiet eye.

Chapter 5: Study 4 - High-Pressure Game Conditions affect Quiet Eye depending on the Player's Expertise: Evidence from the Basketball Three-Point Shot

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Article

High-Pressure Game Conditions affect Quiet Eye depending on the Player's Expertise: Evidence from the Basketball Three-Point Shot

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5.1 Abstract

Research on attention in sport contexts using eye-tracking methodology has highlighted that the highest levels of expertise and performances are characterized by a specific gaze behavior consisting of a perception-action variable named quiet eye. The present study aimed to understand the role of the quiet eye during a relevant task in basketball games, the three-point shot, especially in game conditions in which even a single point may determine the victory or the defeat. Twenty-one basketball players (twelve competitive-elites and nine semi-elites) with a high-shooting style performed three-point shots in four game scenarios different from each other for the time available (time pressure) and the relevance of the score (performance pressure). The results showed that competitive-elites performed, at the same time, a longer quiet eye online duration and a shorter QE preprogramming duration than semi-elites, especially in the highest-pressure condition. On the one hand, these results suggest that the quiet eye during three-point shots could fulfill an online control function. On the other hand, the findings stressed the importance of implementing experimental conditions that can resemble as closely as possible those of an actual sport situation. Finally, we suggest to coaches and sports psychologists interested in administering to athletes a quiet eye training protocol with the aim of improving three-point shot performances to consider the shooting style of the players.

Keywords

Quiet eye, Gaze behavior, Basketball, Three-point shot, Eye-tracking, Sport, Attention, Perception-action

5.2 Introduction

In 1996, Vickers found that elite basketball players lengthened their last eye fixation before the extension of the arm during successful than unsuccessful shots (Vickers, 1996). Vickers named this fixation "quiet eye" (QE), defining it as "the final fixation or tracking gaze that is located on a specific location or object in the task environment within 3° of visual angle (or less) for a minimum of 100 ms" (cf. Vickers, 2016a). In a subsequent work in 2001, Harle and Vickers taught university basketball players how to extend this final fixation. The players who received the training protocol improved their free throw shooting accuracy more than those who did not receive it (Harle & Vickers, 2001). A few years later, Vine and Wilson proposed the same training protocol also to novice basketball players. Their results showed that the prolongation of the QE led not only to the increase of successful free throws but permitted players also to resist the adverse effects of anxiety on free throw performances (Vine & Wilson, 2011). The results described so far have been replicated throughout the last 25 years in a wide range of sports (e.g., archery, billiards, golf, soccer, hockey, shotgun) and motor tasks (e.g., targeting, interceptive timing, tactical, cf. Vickers, 2016b). Generally, the literature reports that experts showed earlier and longer QE than near or non-experts, as well as successful performances compared to unsuccessful ones (Fegatelli et al., 2016; Klostermann & Moeinirad, 2020; Lebeau et al., 2016; Mann et al., 2007; Moran et al., 2019; Rienhoff et al., 2016). Moreover, the QE training protocols positively affect aiming performances (cf. Harle & Vickers, 2001; Vickers et al., 2017; Vine et al., 2011; Vine & Wilson, 2011). Given the relevance of the QE in defining the highest levels of expertise and performances (Vickers, 2007), various authors focused on understanding the underlying mechanisms of this fixation. To date, there is no unanimous agreement in the literature on the prevalent one since the QE seems to fulfill more than one function related to expertise and performance (Gonzalez et al., 2017; Helsen et al., 2016; Klostermann & Hossner, 2018; Wilson et al., 2016). However, several findings suggest that the QE could represent a measure of attentional control (Gonzalez et al., 2017; Vine, Lee, et al., 2013). Following the Attentional Control Theory (ACT; Eysenck et al., 2007; cf. also Vine et al., 2016), an extended QE permits athletes to inhibit all the irrelevant information, allowing athletes to keep focused on their task without being distracted from internal (e.g., negative self-talk or emotions) or external (e.g., the noise of the crowd in the stands) distractions (Brams et al., 2019; Corbetta & Shulman, 2002; Haider & Frensch, 1999; Vickers, 2016a). Accordingly, the QE is related to the preservation of the attentional state of the athletes (Corbetta & Shulman, 2002; Harris et al., 2021; Vickers, 2009). Following Gonzalez et al. (2017) review, an extended QE allows athletes to extract useful environmental information for the task. This information is necessary to plan the movement parameters (i.e., a preprogramming function) and potentially adjust the action taking place (i.e., an online control function; cf. Vine, Lee, et al., 2013; Vine et al., 2017). The type of task the athlete is performing seems to influence the gaze behavior (e.g., Chirico et al., 2019; Klostermann et al., 2018; Klostermann, 2020; Rienhoff et al., 2013; Vickers, 2009) and, accordingly, the specific function that the QE could fulfill in that task. Several authors proposed that it is possible to comprehend and analyze the QE functions referring to the QE timing (when the QE begins and ends with respect to the critical movement; cf. Causer et al., 2017; Vine, Lee, et al., 2013; Vine et al., 2017; Walters-Symons et al., 2018). Accordingly, a preprogramming function is related to the QE occurring before the critical movement. An online function is associated with the QE that occurs during the ongoing action (Causer et al., 2017; Vine et al., 2017).

An important example is basketball, a sport that has always been of particular interest in QE literature. Indeed, the type of shot seems to influence the timing of the QE (Oudejans et al., 2002). At present, the two most studied basketball shots are the set and the jump shots (cf. Marques et al., 2018). From a kinematic point of view, the difference between these two shots relies on the moment the player shoots the ball. Indeed, in the set shot, the players throw the ball with their feet on the ground. In the jump shot, athletes released the ball during jumping (Okubo & Hubbard, 2018). Studies on the gaze behavior on the set shots showed that the QE begins in the phase immediately preceding the extension of the arms towards the basket, ending just before their full extension (Vickers, 1996). A long duration of the QE characterizes the successful throws and the experts (Czyz et al., 2019; Fischer et al., 2015; Harle & Vickers, 2001; Klostermann, 2019; Rienhoff et al., 2013, 2015; Vine & Wilson, 2011; Wilson et al., 2009, 2018; Zwierko et al., 2018). According to several authors, the QE in the set shots, given its early timing, plays a relevant role in pre-planning the movement parameters before the critical phase of the movement (Gonzalez et al., 2017; Vine et al., 2014).

The jump shots are characterized by a similar timing to set shots for what concerns the QE onset. However, unlike set shots, the QE could extend throughout and beyond the extension of the arms, especially for the high-style shooters (i.e., players who extend their arms when the ball is above the head) rather than low-style shooters (i.e., players who extend their arms when the ball is in front of the face). Indeed, the high-style shot permits players to look at the basket also during the final moments of the shot (De Oliveira, 2016; De Oliveira et al., 2006, 2007, 2008; Klostermann et al., 2018; Oudejans et al., 2012; Oudejans et al., 2002). Accordingly, the QE characteristics of the jump shots of high-style shooters could represent the acquisition of visual information to control the ongoing action (De Oliveira, 2016; De

Oliveira et al., 2006, 2007, 2008; Klostermann et al., 2018; Oudejans et al., 2012; Oudejans et al., 2002; Zwierko et al., 2016).

The jump shot is considered a relevant skill in the basketball game, given the advantages of overcoming the opponent's defense and throwing the ball from various distances (Okazaki et al., 2015). In this regard, it is interesting to note that almost all the research on QE focused on the jump shots performed inside the three-point line (i.e., field goals). The only exception was the work of Vickers et al. (2019), who found that elite basketball players with a low-style shooting improved their accuracy during the three-point shot in the case of a long QE duration (QED), with a limited vision of the hoop during the last phases of the action (Vickers et al., 2019).

Despite the significance of the three-point shot in basketball games, it is curious to note that only the study of Vickers et al. (2019) evaluated the QE characteristics of elite low-shooting style players engaged in this task. In addition to being the shot that provides the most points during a match, the three-point shots play a critical role in establishing the outcome of a game, especially in the fourth game quarter with narrow score differentials (Gómez Ruano et al., 2016). In such a situation, players are subjected to high levels of time and performance pressure. Indeed, the fourth game quarter determines the last opportunity to make throws, in which even a single additional point might determine the outcome of the entire game. The literature on QE assessed the role of time pressure and performance pressure on QE characteristics (e.g., Williams et al., 2002; Wilson et al., 2009), showing that time pressure shortened the QED, negatively influencing performances (Williams et al., 2002), and that performance pressure could have positive or negative effects on the QE characteristics and performances according to the match between task demands and the ability to cope of the players (cf. the biopsychosocial model (BPSM) of challenge and threat; Blascovich & Tomaka, 1996; Brimmell et al., 2019; Moore et al., 2013; Seery, 2013). More specifically, when task demands largely exceed the ability to cope of the players, athletes experience a "threatening state," which negatively affects the goal-directed attentional control. In line with ACT and the QE role on attentional control, in such a state, athletes reduced the QED, increasing the proneness to distractions, with an impairment on the processing efficiency and potential repercussions on performance effectiveness (Eysenck & Wilson, 2016; Vine et al., 2016). Although time and performance pressure are factors that can characterize the shots that occur during the last quarter of a closed-score game, as far as we know, only one QE previous study evaluated the effect of the interaction between time and performance pressure on QE characteristics on set shots (in detail, on the free throws, cf. Giancamilli et al., 2022). The findings showed that the interaction effect of time and performance pressure led players to experience a "threatening state," with impairment on attentional control, as indicated by the reduction of the QED and the delay of the QE onset. It is interesting to note that several findings suggest a change in the gaze behavior when task demands are similar to those that athletes can experience during actual game situations (Dicks et al., 2010; Klostermann et al., 2018; Vickers et al., 2019), but to our knowledge, no previous QE research on three-point jump shots assessed the stress evaluation process and its effect on attentional control. Indeed, only Vickers et al. (2019) and Steciuk & Zwierko (2015) investigated the QE during this type of shot. Still, none of these authors assessed any variables that could relate to the stress evaluation process.

Summarizing all the above, experts and high sports performances are generally characterized by a high level of attentional control (Eysenck & Wilson, 2016). According to several authors, a gaze behavior strictly connected to attentional control is the QE (Gonzalez et al., 2017; Vickers, 2016b). It has been suggested that this fixation is related to attentional control through the extraction of environmental information (Gonzalez et al., 2017). Such a process can occur to plan the movement parameters, fulfill a preprogramming function, or monitor the ongoing action, in the case of an online control function (Horn & Marchetto, 2020; Klostermann et al., 2018; Vine, Lee, et al., 2013; Walters-Symons et al., 2018). Evidence from the literature suggested that the type of task could determine the specific function fulfilled by the QE (Chirico et al., 2019; Klostermann et al., 2018; Klostermann, 2020; Rienhoff et al., 2013; Vickers, 2009). In particular, the QE seems to fulfill an online control function in the motor actions in which the movement permits the observation of the ongoing action (cf. De Oliveira, 2016). Several authors suggested that the basketball jump shots relied on this QE function (e.g., De Oliveira et al., 2007). Given the shortage of QE studies on three-point shots, a relevant jump shot in basketball, we aimed to assess the effect of high-pressure conditions, as the ones that could occur in the last quarter of a basketball game with narrow score differentials (Gómez Ruano et al., 2016). Such situations are characterized by high levels of time and performance pressure. Accordingly, building on the QE literature which assessed the effect of high-pressure conditions (e.g., Vickers & Williams, 2007; Vine et al., 2013; Williams et al., 2002; Wilson et al., 2009), and the one that suggested a change in the QE characteristics when task demands are similar to actual game situations (Dicks et al., 2010; Klostermann et al., 2018; Vickers et al., 2019) we explored the effect of time and performance pressure on QE characteristics (cf. Giancamilli et al., 2022) during three-point shots performed using a high-shooting style technique.

Consequently, we assessed the QE characteristics (duration and timing), the performance accuracy, and the match between task demands and the ability to cope of players with different expertise levels, who conducted three-point shots in randomized trials, different from each other according to time pressure and performance pressure manipulations. The primary purpose was to investigate the impact of the manipulations we implemented (i.e., time and performance pressure) on QE characteristics, considering all their possible combinations (Table 1). We assumed that time and performance pressure would lead players to experience a threatening state (i.e., the task demands exceed the ability to cope with them; cf. Vine et al., 2016), impairing the QE characteristics and shot accuracy (Giancamilli et al., 2022; Williams et al., 2002; Wilson et al., 2009). Given the literature on the gaze behavior of high-style shooters (e.g., De Oliveira et al., 2008), we expected that the impairment on the QE characteristics could affect especially the QE late components (i.e., QE offset and QE online duration; cf. Vine, Lee, et al., 2013). In the second place, we aimed to explore the effect of time and performance pressure according to the expertise level of the players. Accordingly, we expected that the time and performance pressure would have a greater impact on the minor expert players' accuracy and QE. In contrast, the most expert athletes would exhibit higher accuracy and superior attentional control, regardless of the manipulations (cf. Eysenck & Wilson, 2016).

5.3 Materials and Methods

5.3.1 Participants

We used convenience sampling for the current study. Indeed, we contacted a local basketball team that had already collaborated with us in our previous work (Giancamilli et al., 2022). We asked coaches about athletes' reachability, and we successfully recruited 21 male basketball players. To note that all the players were the same who participated in the data collection of our previous work already mentioned (cf. Giancamilli et al., 2022), except for the participant "P20" (Table 2). However, it is essential to note that the data collection reported in the present work and the task requested to the athletes were different from those of Giancamilli et al. (2022).

The expertise of each player was categorized according to the equation and classification system of Swann et al. (2015), which used: (A) the athlete's highest standard of performance, (B) the success at the athlete's highest level, (C) the experience at the athlete's highest level, (D) the competitiveness of sport in athlete's highest level and (E) the global competitiveness of sport. Accordingly, our sample is composed of nine semi-elite and twelve competitive-elite players. All players used the high-style shooting technique and self-reported normal vision.

From a descriptive point-of-view, the so-called “semi-elite” participants played from Regional divisions to the 4th National Italian Amateur division (from Regional divisions to Italian Serie C Gold). The mean age of the semi-elite group was of 13.78 years (SD = 1.56). They had an average of 4.06 years of playing experience (SD = 2.19), and they trained with an average of 4.22 days per week (SD = 1.56).

For what concern the group of so-called “competitive-elite” participants, it is composed of athletes who played from the 1st to 3rd National Italian Basketball division (Italian series B, A2, and A). The mean age of the competitive-elite group was of 16.92 years (SD = 1.78). They had an average of 9.33 years of playing experience (SD = 3.52), and they trained with an average of 6.25 days per week (SD = 1.23). The Ethical Committee of the Department of Psychology of Development and Socialization Processes (“Sapienza” University of Rome) approved the present study before participant recruitment. We collected written informed consent from all participants. In the case of minors, we collected informed consent from parents or legal guardians.

5.3.2 Equipment

All the shots were recorded using a digital high-definition camera (HDR-PJ410, Sony, Japan) located orthogonal to the shooting trajectory to determine each phase of the shooting movement. The gaze behavior was recorded using a SensoMotoric Instruments (SMI) light head-mounted mobile binocular eye tracker with automatic parallax compensation. The specific model used for the present study was the Eye Tracking Glasses 2 (SMI ETG 2, SensoMotoric Instruments GmbH, Teltow, Germany) with a sampling rate of 60 Hz. The SMI ETG 2 weighs approximately 68 grams. It is composed of goggles with two infrared cameras to record eye movement, with a gaze tracking accuracy of 0.5° of visual angle. A third high-definition camera is in the central part of the goggles, above the nose pad, to record the visual scene. The SMI ETG 2 implemented a proprietary algorithm (i.e., “SMI Event Detection algorithm”) based on a velocity-based algorithm (SensoMotoric Instrument, 2018, pp. 306-319) to detect the initiation and the end of each fixation. For the present data collection, the resolution of the visual scene camera was set at 960x720p @ 30fps. An external recording unit (Galaxy Note 4 smartphone, Samsung) was placed in a small waist bag attached to the lower backs of participants and linked via USB to the SMI ETG 2 to improve the players' comfort. The external recording unit was remotely controlled through a laptop (Lenovo Thinkpad X230; Lenovo), used for calibrating and monitoring the participants' gaze behavior. The calibration and the real-time monitoring of the gaze behavior were performed using the iViewETG software (iViewETG SMI; version 2.7.0). We calibrated the eye-tracker by asking players to look on a specific corner on the basketball backboard. The calibration was mandatory since the SMI ETG

2 requested a reference point before recording gaze movements. After the data collection, we extracted the gaze behavior data from the recordings using the SMI BeGaze software (version 3.7.60).

5.3.3 Measures

5.3.3.1 Shot Accuracy

The performance was scored using a 4-point scale used in previous QE basketball studies (e.g., Rienhoff et al., 2013). A hit without rim contact is coded as 4 points, while with board or rim contact is 3 points; a shot that fails, missing the board or the rim is 2 points, and an airball is 1 point. Accordingly, all the shots coded as 4 and 3 points are labeled as "successful shots," while all the shots with a score of 2 and 1 points as "unsuccessful shots".

5.3.3.2 Action Time

We used the video file from the camcorder to code each shot in three phases (cf. Klostermann et al., 2018; Oudejans et al., 2012; Vickers et al., 2019). The "jump phase" started with the frame of the ball's first upward movement. The "flexion phase" began with the first frame where the elbow flexes, until the maximum flexion of the elbow, with the ball raised above the head. The "extension phase" initiated from the initial extension of the elbow, as the participant moved the ball toward the basket, ending with the final extension of the shooting arm, with the ball leaving the fingertips. The action time was computed in milliseconds as the difference between the jump phase's onset and the extension phase's end.

5.3.3.3 Demand and Resource Evaluation Score (DRES) and Trait Anxiety (STAI-Y2)

We measured the perceived task demand and perceived resource to perform the task in a modality in line with previous studies (Brimmell et al., 2019; Chia et al., 2017; Vine et al., 2013). The perceived task demands were assessed by asking, "How difficult do you consider the next trial?". The rating scale was a 10-point Likert scale (1 = not at all; 10 = extremely). The item to assess the perceived resource to perform the task has been drawn from the Mental Readiness Form-Likert (MRF-L; Krane, 1994). In detail, we employed the MRF-L self-confidence item, which is composed of a bipolar 11-point Likert scale (confident / not confident) in which participants report how they feel "right now". Before computing the DRES, we transformed the 11-point Likert scale to a 10-point one, and we reversed the new item (i.e., from "confident/not confident" to "not confident/confident"). The DRES was calculated by subtracting perceived task demands from perceived resources, and the results were normalized in Z scores to make the findings easier to understand. A DRES equal to or close to zero should reflect a challenge state, indicating perceived resources that equal or are very near to perceived task demands. It is worth noting that a large overflow of perceived resources compared to perceived demands should signify disengagement from the activity. On the other hand, a negative score should indicate a threat state (i.e., the perceived task demands exceed the perceived resources). Although the absence of psychometric testing of the DRES, Brimmell and colleagues (2019) observed that this measure had been used in prior QE research (Chia et al., 2017; Vine et al., 2013) and is connected to performance across many tasks (cf. Hase et al., 2019).

Given that people with higher trait anxiety could tend to perceive situations as more threatening than people with low trait anxiety (e.g., Endler & Kocovski, 2001; Horikawa & Yagi, 2012; Man et al., 2005), we also used the STAI-Y2 form of the State Trait Anxiety Inventory-Y (Pedrabissi & Santinello, 1989; Spielberger, 1983; Spielberger & Vagg, 1984). The STAI-Y2 is a self-administered questionnaire with 20 questions that measure the person's overall anxiety levels. Higher scores indicate higher levels of trait anxiety. The STAI-Y2 score has been used in the analysis to control for the effect of trait anxiety on the DRES score.

5.3.3.4 QE Onset

The initiation of the QE is called "QE onset," and it occurs before performing the critical movement. The extension of the arm before the release of the ball has been defined as the critical movement in basketball throws (i.e., the onset of the extension phase; Harle & Vickers, 2001; Rienhoff et al., 2015; Vine & Wilson, 2011; Wilson et al., 2018; Wilson et al., 2009). Therefore, we calculated the QE onset as the interval in milliseconds between the onset of the extension phase and the QE initiation. A negative value indicates that the QE began before the critical movement.

5.3.3.5 QE Duration

To be considered a QE, a fixation had to last at least 100 milliseconds, within 3° of visual angle, and being the last fixation directed at the rim, the backboard, or the net (Klostermann et al., 2018; Wilson et al., 2018). For the present study, the QE duration was calculated as the difference between the end of the QE and the initiation of the QE.

5.3.3.6 QE Offset

The end of the QE is called "QE offset". It occurs when the gaze deviates off the location for a minimum of 100 ms (Vickers, 2007). We calculated this variable as the interval, in milliseconds, between the onset of the extension phase and the end of the QE. A positive value represents that the QE ends after the critical movement.

5.3.3.7 QE Preprogramming and Online Duration

Similar to Causer et al. (2017) and Vine, Lee, et al. (2013), the contribution of the QE for preprogramming or online purposes has investigated computing two specific QE components. The QE preprogramming duration is defined as the interval, in milliseconds, starting at the QE onset and ending at the initiation of the action (i.e., the onset of the jump phase). The QE online duration is defined as the interval, in milliseconds, starting at the initiation of the action and ending at the QE offset.

5.3.4 Task and Protocol

The protocol adopted was the same as employed in our previous work (Giancamilli et al., 2022). We collected the data in a basketball court compliant with the Italian Basketball Federation (FIP) normative. Each participant was informed through a written informed consent regarding the present study in terms of the general aim and the procedure adopted before taking part in the data collection. The STAI-Y2 was then administered. After completing the STAI-Y2, we showed the equipment used, permitting participants to ask any questions. Once completed this briefing phase, we initiated the warm-up phase, which consisted of 10 minutes during which each participant conducted his usual warm-up routines and basketball three-point shots. At the end of the 10 minutes, the researchers' aided the athletes to wear the SMI ETG 2, requesting each participant to perform not less than ten three-point shots. In doing so, we permitted athletes to get used to the instrumentation, and we verified the proper functioning of the SMI ETG 2 before the collection of gaze behavior data. The participants could continue to conduct shots at their leisure as soon as they feel confident with the equipment. We began collecting data when the participants had become comfortable with the method and equipment. The participants' task consisted in performing ten three-point shots in each of the four randomized trials (without time pressure and performance pressure: NOTP/NOPP; with performance pressure and without time pressure: NOTP/PP; with time pressure and without performance pressure: TP/NOPP; with time pressure and performance pressure: TP/PP), for a total of 40 shots per participant.

Before each trial, one of the scholars had the role of giving participants the trial instructions (Table 1) and administering the measures required to compute the DRES. The same scholar made the players believe that he scored only the shots during the trials with performance pressure (NOTP/PP and TP/PP ones) to build the public ranking. After providing the trial’s related instructions and administering the questionnaire, we placed a bucket containing not less than ten basketball balls close to the participants. Another scholar involved in the data collection had the role to remain near the participant to pass the ball. Note that the researcher did not enter the visual field of the athlete engaged in the trial, but he was sufficiently near to grab the ball from the bucket and pass it to the player. Such task of the scholar was particularly relevant during trials with time pressure (TP/NOPP and TP/PP ones). In these trials, the researcher has been instructed to pass the ball using a rhythmic and fast pace to the participant involved in the trials with time pressure. All shots were taken from behind the three-point shot line (distance from the center of the basket = 6.75 meters), in the position straight in front of the basket. Another researcher, different from the other two, calibrated the SMI ETG 2 and continuously verified the calibration quality in real-time during data collection until the trial's completion to guarantee its stability. A fourth scholar had the role of starting the camcorder and checking the proper functioning of the instrument. We gave participants a 5-minute break between trials to avoid fatigue issues. The total procedure took approximately 60 minutes.

Table 1

Summary of Designs of Trials with Instructions

Trial	Time Pressure	Performance Pressure	Trial's instructions
NOTP/NOPP	Absent	Absent	"Perform ten three-point shots."
NOTP/PP	Absent	Present	"Perform ten three-point shots. It is very important to score as many points as you can because your score will be recorded to establish a ranking with your teammates."
TP/NOPP	Present	Absent	"Perform ten three-point shots as fast as possible."
TP/PP	Present	Present	"Perform ten three-point shots as fast as possible. It is very important to score as many points as you can because your score will be recorded to establish a ranking with your teammates."

5.3.5 Data Analysis

The video data produced by the SMI-ETG 2 and the digital camera were manually synced frame-by-frame by identifying a specific event observable in both the video files (e.g., the ball touching the ground or the rim; cf. Klostermann et al., 2018) using the SMI BeGaze software for the gaze behavior video and the VideoPad software (NCH Software, version 10.36) for the participant's movement video. The video files synchronization and the coding of each action phase were performed by two coders working together. Each stage of these procedures ended only after a unanimous agreement between the coders. The gaze behavior data were then extracted from the selected areas of interest (AOIs), which were the rim, the backboard, and the net (cf. Klostermann et al., 2018; Wilson et al., 2018) using the “AOI editor” and “Export Metrics” functions provided by the BeGaze. The shots coded for the analysis were 840, performed by twelve competitive-elites and nine semi-elites (Supplementary Material – Table 1).

The dependent measures of the current study were analyzed employing several mixed-models ANOVA with fixed and random effects. In such ANOVA, the fixed effects are the levels of factors representing levels of experimental manipulations or levels of a between-groups characteristic. Instead, the random effect generally represents a random sample from a population (Sahai & Ageel, 2000). Accordingly, we considered as fixed effects the expertise participants (competitive-elite; semi-elite), the time pressure (NOTP = without time pressure; TP = with time pressure), the performance pressure (NOPP = without performance pressure; PP = with performance pressure), and the throw outcome (hit; miss); the random effect of the models were participants (considered as random intercept; $n = 21$). Analyzing the DRES, we employed the STAI-Y2 score as a covariate, also removing the fixed effect "throw outcome" given that DRES was a trial-related variable. For what concerns the analysis on shot accuracy, we removed the fixed effect "throw outcome". In the presence of significant interaction effects, post hoc pairwise comparisons were employed using the Bonferroni correction to determine interaction effects. Data were analyzed using IBM SPSS version 27 (IBM Corp, 2020). The software automatically employed the Satterthwaite approximation to calculate the degrees of freedom. The significance level was set at $\alpha = .05$; meanwhile, α levels between .05 and .10 are considered marginally significant. At last, the effect size of each ANOVA effect was calculated using partial eta squared ($\eta 2p$) through the calculator provided by Lakens (2013). The effect size was interpreted according to Cohen’s criteria (1969; cf. Richardson, 2011), with .0099 considered a low effect, .0588 a medium effect, and .1379 a large effect.

5.4 Results

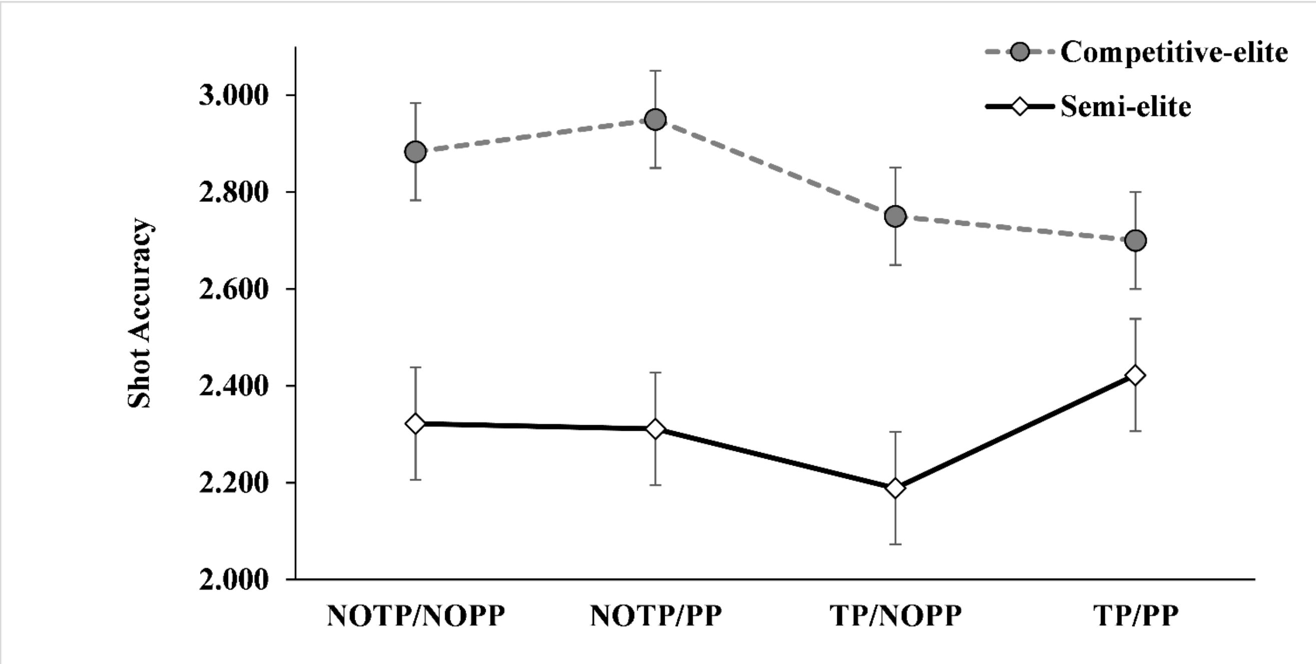
Due to the high number of analyzed effects, the non-statistically significant effects and the statistics not reported on the "Results" section are shown in the Supplementary Material (Tables 2-9). Also, we reported the post hoc pairwise comparisons only for the highest order significant interaction effects. However, we reported the complete descriptive statistics of mixed-models ANOVA with fixed and random effects for each dependent variable in the Supplementary Material (Tables 10-15).

5.4.1 Shot Accuracy

ANOVA results showed a significant difference for expertise ($F(1, 21) = 22.562$, $p < .001$, $\eta 2p = .518$). Regardless of the manipulations implemented, competitive-elites had a higher shot accuracy than semi-elites (competitive-elites: M = 2.821, SE = .070; semi-elites: M = 2.311, SE = .081). The results did not show other significant effects. The average values of shot accuracy of each trial according to expertise levels are shown in Figure 1.

Figure 1

Average Values of Shot Accuracy for each Trial according to Expertise Levels



Note. NOTP = no time pressure; NOPP = no performance pressure; TP = time pressure; PP = performance pressure.

Table 2

Percent Accuracy of Participants for each Trial

Expertise	Participant	Trials			
		NOTP/NOPP	NOTP/PP	TP/NOPP	TP/PP
Competitive-elite	P1	60%	50%	70%	50%
	P2	40%	70%	20%	30%
	P3	50%	60%	30%	10%
	P4	40%	30%	40%	40%
	P5	40%	50%	70%	10%
	P6	50%	50%	20%	40%
	P7	70%	70%	70%	80%
	P8	50%	60%	50%	70%
	P9	40%	40%	50%	30%
	P10	50%	30%	30%	30%
	P11	40%	70%	20%	30%
	P12	70%	60%	20%	40%
	Average	50.00%	53.33%	40.83%	38.33%
	SD	11.28%	14.35%	20.65%	20.82%
Semi-elite	P13	10%	10%	20%	10%
	P14	20%	0%	20%	10%
	P15	60%	30%	20%	20%
	P16	20%	10%	10%	50%
	P17	50%	10%	0%	40%
	P18	20%	30%	30%	60%
	P19	30%	40%	30%	20%
	P20	20%	20%	20%	30%
	P21	30%	50%	40%	20%
	Average	28.89%	22.22%	21.11%	28.89%
	SD	16.16%	16.41%	11.67%	17.64%
Total Sample	Average	40.95%	40.00%	32.38%	34.29%
	SD	17.00%	21.68%	19.72%	19.64%

Note. NOTP = no time pressure; NOPP = no performance pressure; PP = performance pressure; TP = time pressure; SD = standard deviation.

5.4.2 Action Time

Findings exhibited a significant effect for performance pressure ($F(1, 819.070) = 9.426$, $p < .01$, $\eta 2p = .011$) and significant interaction effects about expertise x time pressure ($F(1, 819.123) = 11.728$, $p < .01$, $\eta 2p = .014$), expertise x performance pressure ($F(1, 819.070) = 8.571$, $p < .01$, $\eta 2p = .010$), time pressure x performance pressure ($F(1, 819.275) = 7.387$, $p < .01$, $\eta 2p = .009$), expertise x time pressure x performance pressure ($F(1, 819.275) = 13.651$, $p < .001$, $\eta 2p = .016$), expertise x performance pressure x throw outcome ($F(1, 819.601) = 4.240$, $p < .05$, $\eta 2p = .015$). Pairwise comparisons of expertise x time pressure x performance pressure interaction exhibited that time pressure shortened the action time of semi-elites when performance pressure occurred ($p < .05$, NOTP/PP: M = 436.566 ms, SE = 36.374 ms; TP/PP: M = 395.683 ms, SE = 36.027 ms) and of competitive-elites during trials without performance pressure ($p < .05$, NOTP/NOPP: M = 480.661 ms, SE = 30.915 ms; TP/NOPP: M = 450.270 ms, SE = 30.961 ms). Instead, time constraint extended the action time of competitive-elites during trials with performance pressure ($p < .001$, NOTP/PP: M = 477.433 ms, SE = 30.921 ms; TP/PP: M = 543.160 ms, SE = 30.992 ms). About the TP/PP trial, the competitive-elites performed a longer action time than semi-elites in this trial ($p < .01$, competitive-elites: M = 543.160 ms, SE = 30.992 ms; semi-elites: M = 395.683 ms, SE = 36.027 ms). Moreover, performance pressure extended the action time of competitive-elites during trials with time pressure ($p < .001$, TP/NOPP: M = 450.270 ms, SE = 30.961 ms; TP/PP: 543.160 ms, SE = 30.992 ms). Pairwise comparisons of expertise x performance pressure x throw outcome interaction showed that performance pressure significantly increased the action time of competitive-elites, during hits ($p < .001$, NOPP: M = 455.237 ms, SE = 31.084 ms; PP: M = 519.540 ms, SE = 31.102 ms) and misses ($p < .05$, NOPP: M = 475.694 ms, SE = 30.831 ms; PP: M = 501.053 ms, SE = 30.859 ms). Finally, competitive-elites performed a significant longer action time than near-elites in the hits during performance pressure ($p < .05$, competitive-elites: M = 519.540 ms, SE = 31.102 ms; semi-elites: M = 408.304 ms, SE = 37.207 ms).

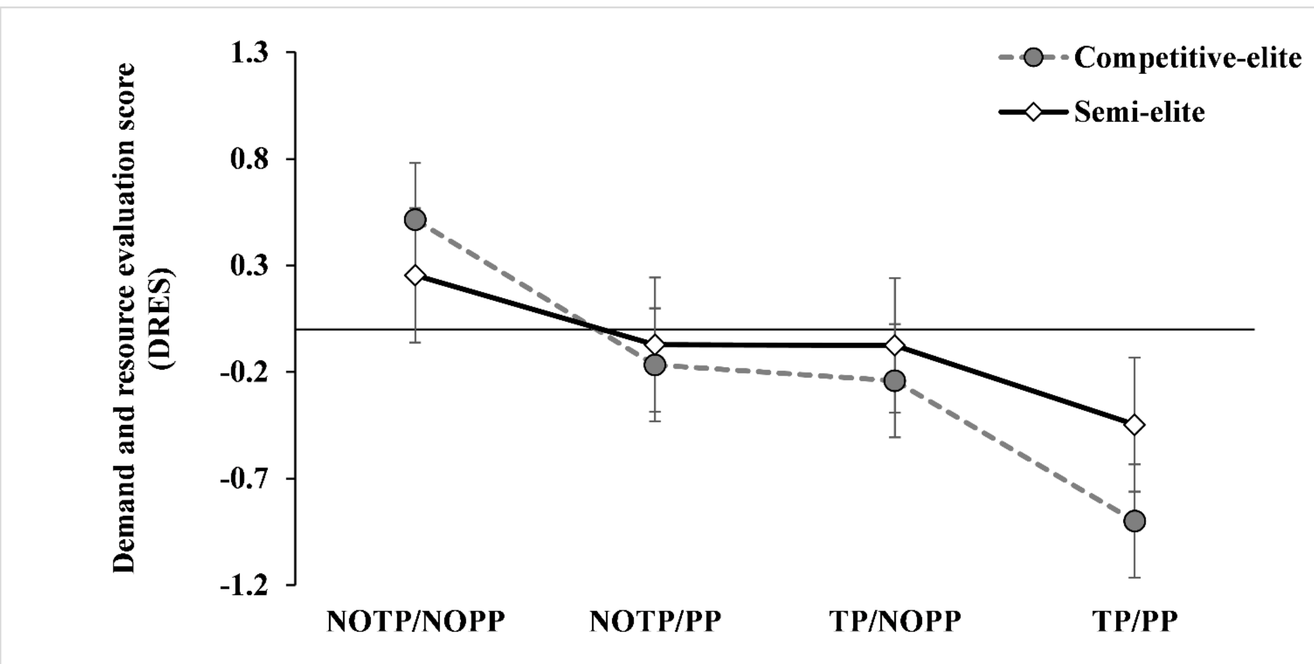
5.4.3 Demand and Resource Evaluation Score (DRES)

Results showed a significant effect for time pressure ($F(1, 819) = 334.860$, $p < .001$, $\eta 2p = .290$), performance pressure ($F(1, 819) = 289.369$, $p < .001$, $\eta 2p = .261$), and significant interaction effects about expertise x time pressure ($F(1, 819) = 42.794$, $p < .001$, $\eta 2p = .050$), and expertise x performance pressure ($F(1, 819) = 28.659$, $p < .001$, $\eta 2p = .034$). Pairwise comparisons of expertise x time pressure interaction exhibited that time pressure decreased the DRES of the competitive-elites ($p < .001$, NOTP: M = .174, SE = .245; TP: M = -.570, SE = .245) and of the semi-elites ($p < .001$, NOTP: M = .091, SE =

.290; TP: M = -.261, SE = .290). Also, pairwise comparisons of expertise x performance pressure interaction showed that performance pressure lowered the DRES of the competitive-elites (p < .001, NOPP: M = .136, SE = .245; PP: M = -.533, SE = .245) and of the semi-elites (p < .001, NOPP: M = .090, SE = .290; PP: M = -.259, SE = .290). Moreover, regardless of the expertise, participants showed significant highest DRES in the NOTP/NOPP trial, while the lowest DRES in the TP/PP trial (all p < .001). No significant differences are found comparing the DRES of the NOTP/PP trial to the TP/NOPP one (all p > .05) or comparing the DRES of competitive-elites and near-elites for each trial (all p > .05; Figure 2).

Figure 2

Mean DRES of each Trial according to Expertise Levels



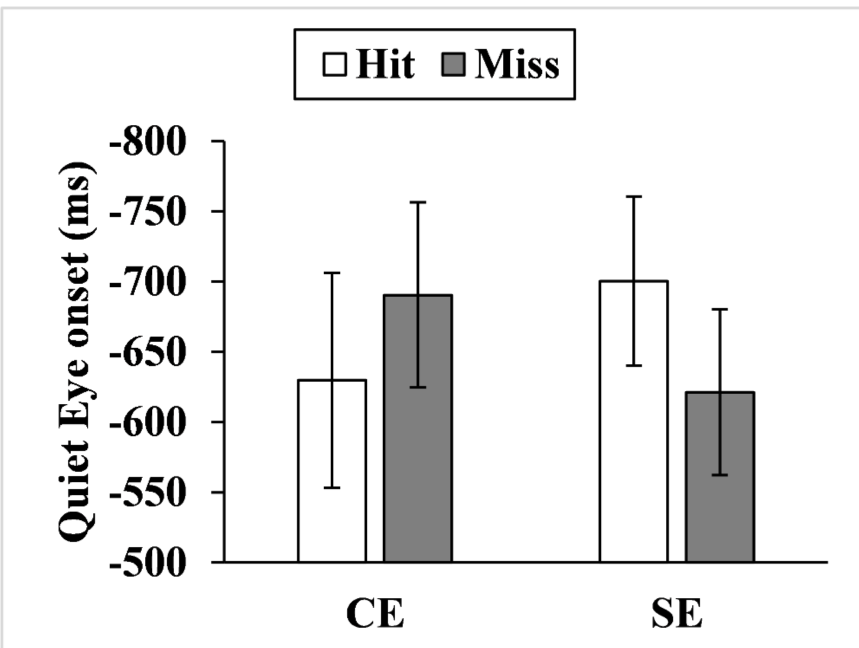
Note. NOTP = no time pressure; NOPP = no performance pressure; TP = time pressure; PP = performance pressure.

5.4.4 QE Onset

Findings showed a significant effect for time pressure (F(1, 819.662) = 10.088, p < .01, η2p = .012) and a significant interaction effect about expertise x throw outcome (F(1, 827.054) = 4.202, p < .05, η2p = .005) and a marginally significant interaction effect about expertise x time pressure x performance pressure (F(1, 820.517) = 3.797, p = .052, η2p = .005). Pairwise comparisons of expertise x throw outcome did not exhibit significant differences of the QE onset between competitive-elites and semi-elites across throw outcome levels, nor between hits and misses across expertise levels. In a purely descriptive way, Figure 3 showed that competitive-elites had a later QE onset in their hits than their misses ($p = .141$, misses: $M = -690.527$ ms, $SE = 58.973$ ms; hits: $M = -629.764$ ms, $SE = 60.290$ ms), whereas semi-elites exhibited the opposite pattern ($p = .146$, misses: $M = -621.234$ ms, $SE = 65.938$ ms; hits: $M = -700.305$ ms, $SE = 76.346$ ms). Pairwise comparisons of expertise x time pressure x performance pressure (Figure 4) exhibited that the time pressure delayed the QE onset of competitive-elites during performance pressure trials ($p < .001$, NOTP/PP: $M = -754.327$ ms, $SE = 65.740$ ms; TP/PP: $M = -545.856$ ms, $SE = 66.405$ ms).

Figure 3

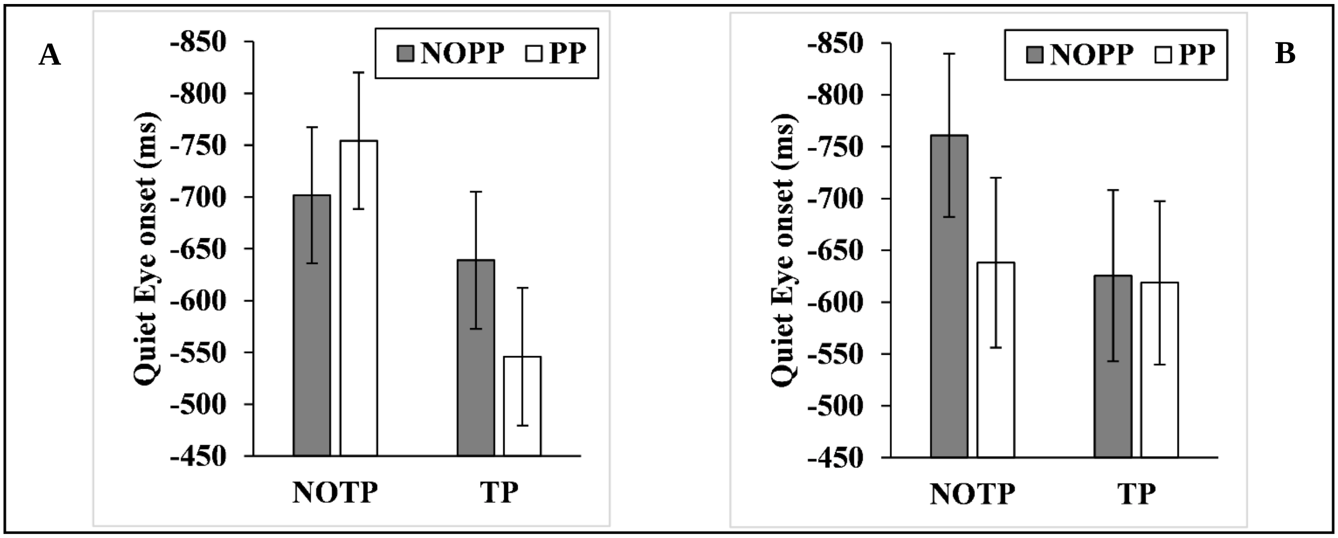
Mean Quiet Eye Onset during Hits And Misses across Expertise Levels



Note. Quiet eye onset is reported in milliseconds. A negative value represents a quiet eye onset before the critical movement (i.e., longer bar - earlier quiet eye onset); CE = competitive-elite; SE = semi-elite.

Figure 4

Mean Quiet Eye Onset across Time and Performance Pressure Levels by (A) Competitive-Elite and (B) Semi-Elite Players. A Negative Value represents a Quiet Eye Onset before the Critical Movement (i.e., longer bar – earlier Quiet Eye Onset)



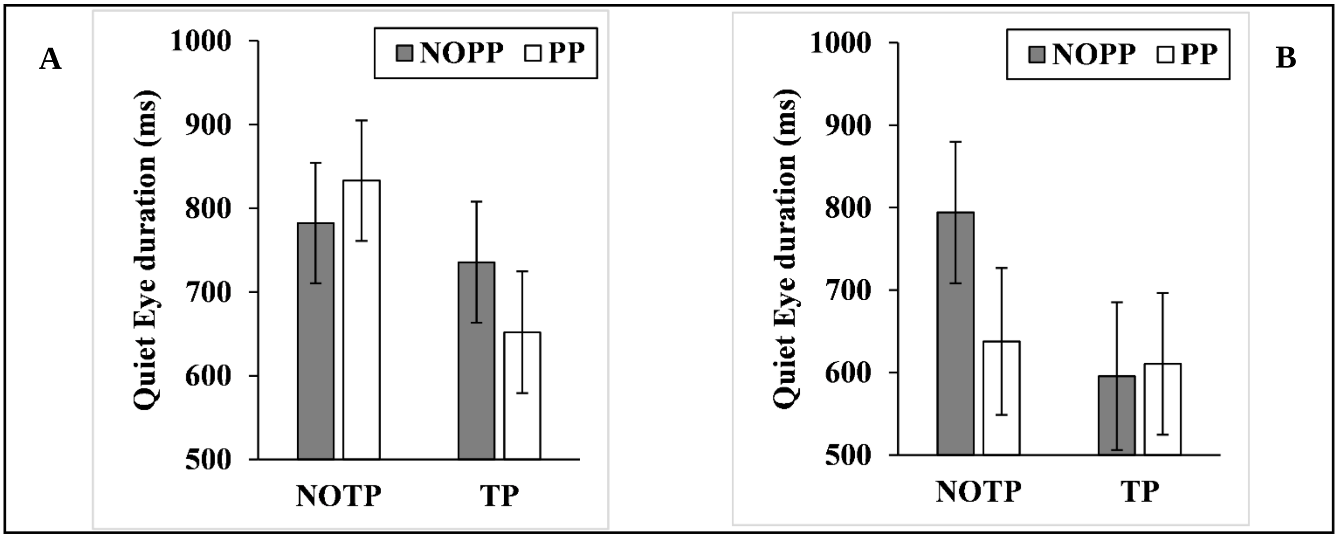
Note. NOTP = no time pressure; NOPP = no performance pressure; TP = time pressure; PP = performance pressure.

5.4.5 QE Duration

Results showed a significant effect for time pressure ($F(1, 819.557) = 10.969$, $p < .01$, $\eta 2p = .013$) and a significant interaction effect about expertise x time pressure x performance pressure ($F(1, 820.268) = 4.969$, $p < .05$, $\eta 2p = .006$). Pairwise comparisons of expertise x time pressure x performance pressure interaction (Figure 5) exhibited that performance pressure shortened the QED of semi-elites during trials without time pressure ($p < .05$, NOTP/NOPP: M = 794.233 ms, SE = 85.994 ms; NOTP/PP: M = 637.707 ms, SE = 89.008 ms). Time pressure reduced the QED of semi-elites during trials without performance pressure ($p < .05$, NOTP/NOPP: M = 794.233 ms, SE = 85.994 ms; TP/NOPP: M = 595.657 ms, SE = 89.611 ms) and the QED of competitive-elites during trials with performance pressure ($p < .01$, NOTP/PP: M = 833.010 ms, SE = 72.003 ms; TP/PP: M = 651.773 ms, SE = 72.637 ms).

Figure 5

Mean Quiet Eye Duration across Time and Performance Pressure Levels by (A) Competitive-Elite and (B) Semi-Elite Players



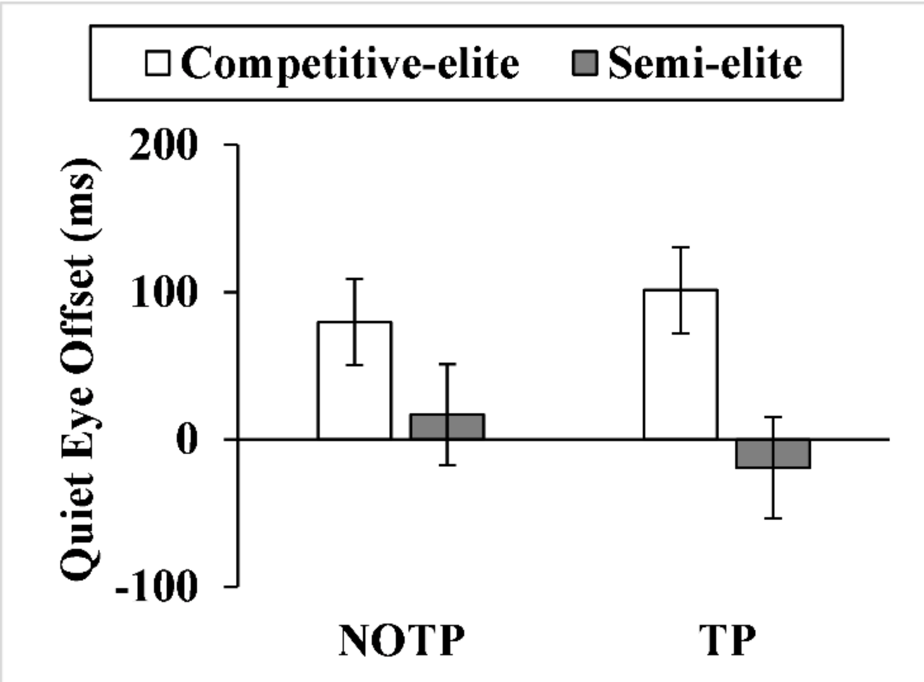
Note. NOTP = no time pressure; NOPP = no performance pressure; TP = time pressure; PP = performance pressure.

5.4.6 QE Offset

Findings showed a significant effect for expertise ($F(1, 21.444) = 4.405$, $p < .05$, $\eta 2p = .170$) and a significant interaction effect about expertise x time pressure ($F(1, 819.277) = 7.041$, $p < .01$, $\eta 2p = .009$). Pairwise comparisons of expertise x time pressure interaction (Figure 6) exhibited that competitive-elites performed a later QE offset than semi-elites when time pressure occurred ($p < .05$, competitive-elites: M = 101.445 ms, SE = 29.241 ms; semi-elites: M = -19.220 ms, SE = 34.288 ms) and that time pressure led semi-elites to anticipate the QE offset ($p < .05$, NOTP: M = 16.937 ms, SE = 34.254 ms; TP: M = -19.220 ms, SE = 34.288 ms).

Figure 6

Mean Quiet Eye Offset by Expertise Levels across Time Pressure Levels



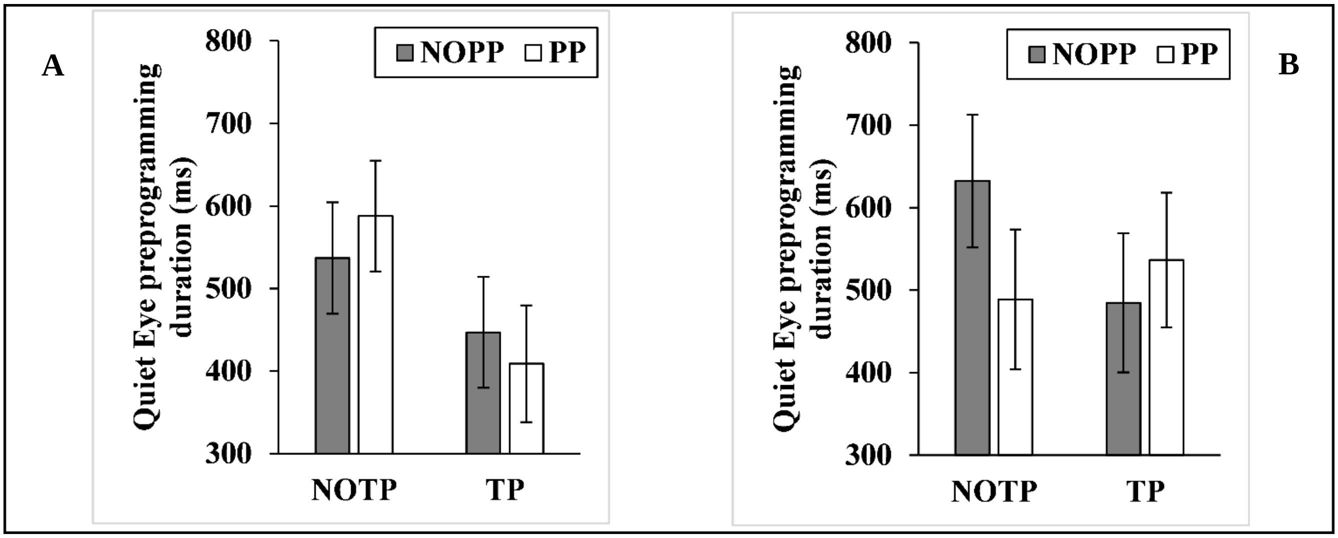
Note. The quiet eye offset is reported in milliseconds. A negative value represents a quiet eye offset ended before the critical movement. NOTP = no time pressure; TP = time pressure.

5.4.7 QE Preprogramming

Results showed a significant effect for time pressure ($F(1, 629.886) = 6.614$, $p < .05$, $\eta 2p = .01$). The findings about interaction effects showed a significant expertise x time pressure x performance pressure ($F(1, 630.379) = 3.910$, $p < .05$, $\eta 2p = .006$). Pairwise comparisons of expertise x time pressure x performance pressure interaction (Figure 7) exhibited that the time pressure shortened the QE preprogramming duration of competitive-elites during trials with performance pressure ($p < .05$, NOTP/PP: $M = 587.721$ ms, $SE = 67.000$ ms; TP/PP: $M = 408.854$ ms, $SE = 70.732$ ms).

Figure 7

Mean Quiet Eye Preprogramming Duration across Time and Performance Pressure Levels by (A) Competitive-Elite and (B) Semi-Elite Players.



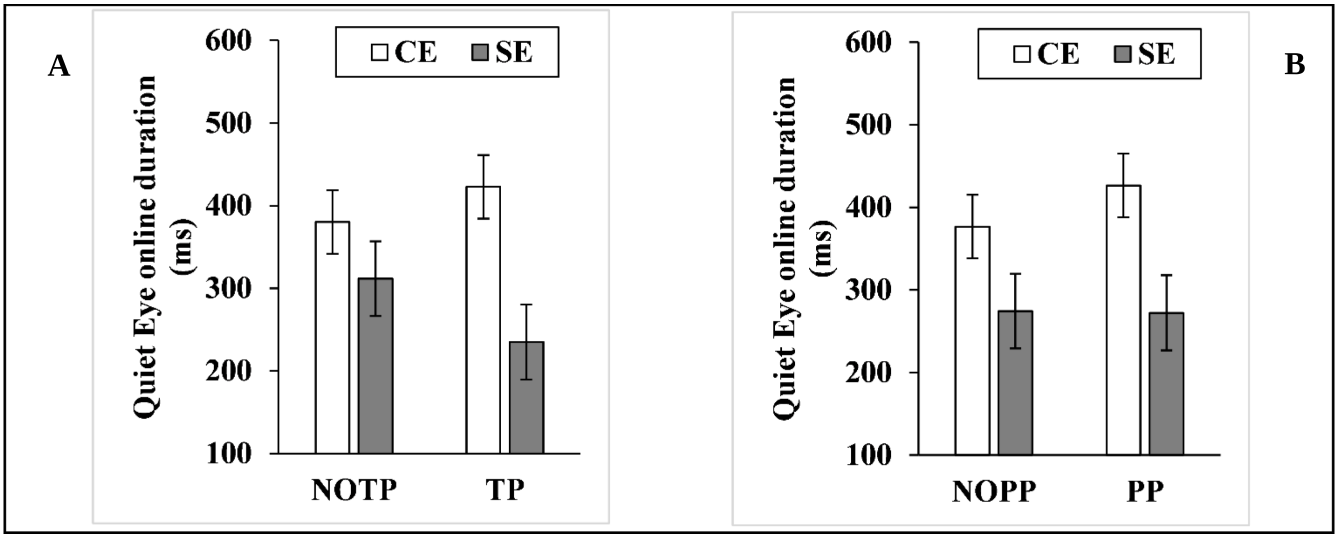
Note. NOTP = no time pressure; NOPP = no performance pressure; TP = time pressure; PP = performance pressure.

5.4.8 QE Online Duration

Findings showed a significant effect for expertise (F(1, 21.343) = 4.876, p < .05, η2p = .186) and a marginally significant effect for performance pressure (F(1, 789.131) = 3.445, p = .06, η2p = .004). The results about the interaction effects showed significant effects about expertise x time pressure (F(1, 789.520) = 21.179, p < .001, η2p = .026), expertise x performance pressure (F(1, 789.131) = 4.025, p < .05, η2p = .005), and time pressure x performance pressure (F(1, 789.217) = 4.624, p < .05, η2p = .006). Results showed also a marginally significant interaction effect about expertise x time pressure x performance pressure (F(1, 789.217) = 2.783, p = .09, η2p = .004). Pairwise comparisons of expertise x time pressure interaction (Figure 8A) exhibited that time pressure led semi-elites to shorten the QE online duration (p < .001, NOTP: M = 291.546 ms, SE = 47.418 ms; TP = 216.273 ms, SE = 47.452 ms), whereas competitive-elites exhibited the opposite pattern (p < .05, NOTP: M = 378.569 ms, SE = 40.570 ms; TP = 417.969 ms, SE = 40.637 ms). Moreover, competitive-elites had a longer QE online duration than semi-elites during time pressure (p < .01, semi-elites: M = 216.273 ms, SE = 47.452 ms; competitive-elites: M = 417.969 ms, SE = 40.637 ms). Pairwise comparisons of expertise x performance pressure (Figure 8B) interaction showed that performance pressure produced an extension of the QE online duration of competitive-elites (p < .01, NOPP: M = 373.341 ms, SE = 40.593 ms; PP = 423.197 ms, SE = 40.613 ms). Furthermore, competitive-elites had an extended QE online duration than semi-elites during performance pressure ($p < .05$, semi-elites: M = 247.438 ms, SE = 47.415 ms; competitive-elites: M = 423.197 ms, SE = 40.613 ms). Pairwise comparisons of time pressure x performance pressure interaction (Figure 9) revealed that TP/PP trial had, regardless of other factor, longer QE online control than TP/NOPP trial ($p < .01$, TP/NOPP: M = 289.464 ms, SE = 32.729 ms; TP/PP: M = 344.779 ms, SE = 32.404 ms). For what concern the role of time pressure, this factor led to a diminution of the QE online duration, but only without performance pressure ($p < .01$, NOTP/NOPP: M = 344.258 ms, SE = 32.348 ms; TP/NOPP: 289.464 ms, SE = 32.729 ms). Pairwise comparisons of expertise x time pressure x performance pressure showed that competitive-elites had a longer QE online duration than semi-elites both in the TP/NOPP trial ($p < .05$, competitive-elites: M = 373.156 ms, SE = 40.073 ms; semi-elites: 232.806 ms, SE = 48.389 ms) and in the TP/PP trial ($p < .001$, competitive-elites: M = 472.428 ms, SE = 40.075 ms; semi-elites: 237.099 ms, SE = 47.219 ms). Moreover, the performance pressure led to a longer QE online duration only for the competitive-elites during time pressure ($p < .001$, TP/NOPP: M = 373.156 ms, SE = 40.073 ms; TP/PP: 472.428 ms, SE = 40.075 ms). About the role of time pressure, this factor led to a reduction of the QE online duration for the semi-elites during trials without performance pressure ($p < .05$, NOTP/NOPP: M = 315.719 ms, SE = 46.951 ms; TP/NOPP: 232.806 ms, SE = 46.389 ms) and with performance pressure ($p < .05$, NOTP/PP: M = 307.549 ms, SE = 48.179 ms; TP/PP: 237.099 ms, SE = 47.219 ms). Instead, the competitive-elites extended the QE online duration, under the effect of time pressure, during trials with performance pressure ($p < .001$, NOTP/PP: M = 380.498 ms, SE = 39.931 ms; TP/PP: 472.428 ms, SE = 40.075 ms), while no differences emerged during trials without performance pressure ($p = .749$).

Figure 8

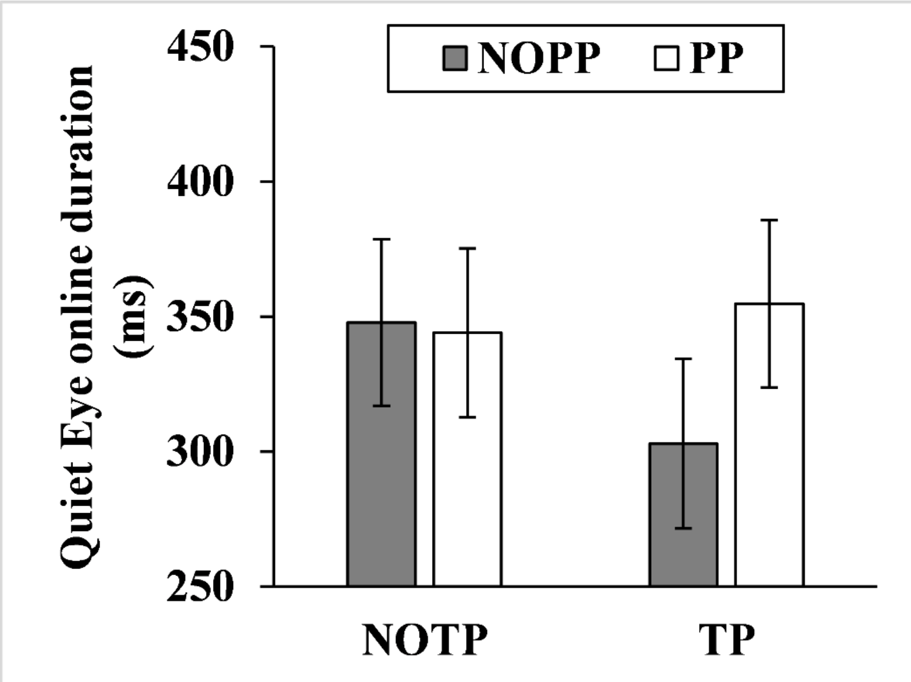
Mean Quiet Eye Online Duration by Expertise Levels across (A) Time Pressure Levels and (B) Performance Pressure Levels.



Note. CE = competitive-elite; SE = semi-elite; NOTP = no time pressure; TP = time pressure; NOPP = no performance pressure; PP = performance pressure.

Figure 9

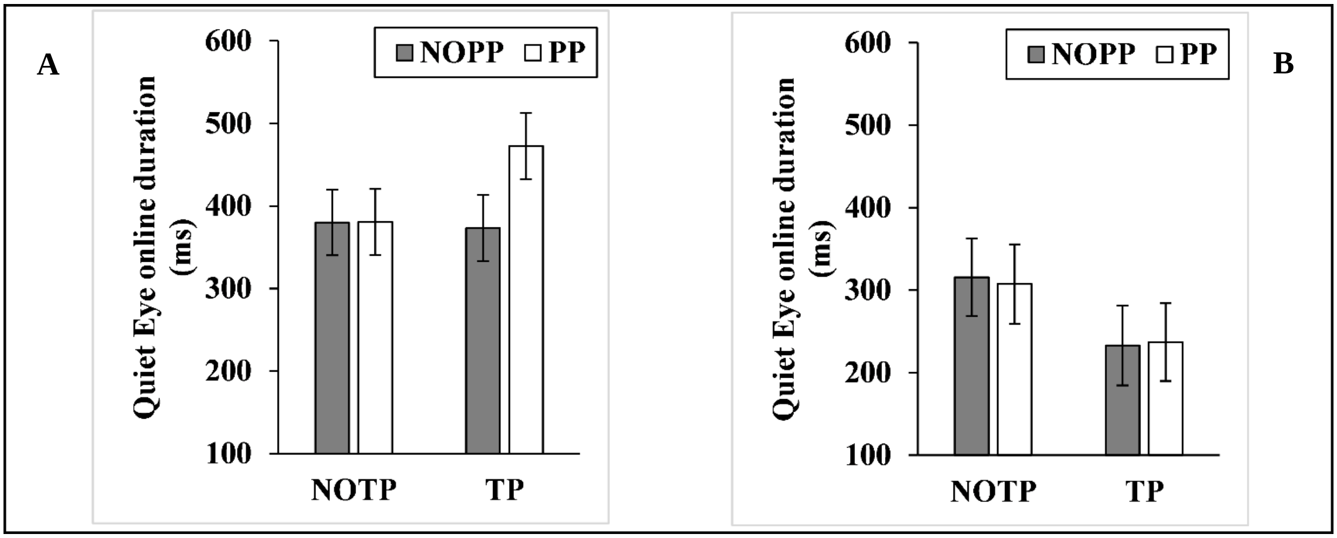
Mean Quiet Eye Online Duration by Time Pressure Levels across Performance Pressure Levels.



Note. NOTP = no time pressure; TP = time pressure; NOPP = no performance pressure; PP = performance pressure.

Figure 10

Mean Quiet Eye Online Duration across Time and Performance Pressure Levels by (A) Competitive-Elite and (B) Semi-Elite Players.



Note. NOTP = no time pressure; NOPP = no performance pressure; TP = time pressure; PP = performance pressure.

5.5 Discussion

In the current study, we assessed the QE of athletes with different levels of expertise, according to Swann, Moran, and Piggott (2015). We manipulated simultaneously the time provided to athletes (i.e., time pressure) and the relevance of the performance (i.e., performance pressure), also considering the perceived task demands and resources (DRES) during a three-point shot task, evaluation both early and late QE components.

We expect that the manipulations that we implemented would affect the appraisal of the stressful situation (i.e., DRES). We hypothesized such an effect given that time and performance pressure are two factors that act during high-pressure conditions, like the ones that may arise in the last quarter of a very close score game (Gómez Ruano et al., 2016). Our results showed that time and performance pressure had a large and significant effect on diminishing the DRES, supporting the effectiveness of the experimental manipulations.

Since the ACT predicts that high-pressure conditions would impair the goal-directed attentional system, we assumed consequences on QE characteristics by the effect of time and performance pressure. As we expected, the findings showed that time and performance pressure affected the QE characteristics, particularly the semi-elites. Indeed, semi-elites showed a more unstable QE than competitive-elites across the trials. The findings showed that the effect of a single manipulation (time or performance pressure) was sufficient for the semi-elites to shorten the QED. In contrast, competitive-elites reduced and delayed the QE only in the presence of both time and performance pressure (Figures 3-5). In other words, the competitive-elites showed a superior attentional control than semi-elites across the trials, in line with the ACT (Eysenck & Wilson, 2016; Eysenck et al., 2007).

The large effect sizes of expertise on QE late components (i.e., QE offset and QE online duration) and the small effect size on QED and QE early components (i.e., QE onset and QE preprogramming duration) seems to suggest a relevant role of QE late components on maintaining the goal-directed attention during a three-point shot. In this regard, it is interesting to note that competitive-elites performed a longer QE online duration than semi-elites, especially when time and performance pressure occurred (Figures 8-10). The results about the QE offset reported a similar picture, given that during time pressure the competitive-elites delayed this QE late component, also performing a later QE offset than semi-elites (Figure 6). Given the results of action time, the extension of the QE late components could be aided by an increase of the action time carried out by the competitive-elites. Such behavior is comparable to the one performed by the sole high-style shooter of Vickers et al. (2019), who performed an extension of the action time during three-point shots hindered by a defender. Given our results and the one by Vickers et al. (2019), it is possible to suppose that competitive elites with a high shooting style slow their action speed to watch the basket for a longer time in tough-game conditions.

Interestingly, while the competitive-elites extended the QE late time components, especially during harsh game conditions, an opposite trend was observable for the QE preprogramming duration. Indeed, while semi-elites maintained a stable QE preprogramming duration across trials, competitive-elites decreased this QE early time component under the influence of time and performance pressure (Figure 7). It is important to note that all the players performed three-point shots using a high shooting style regardless of their expertise. Accordingly, this factor cannot explain the difference in gaze behavior between competitive-elites and semi-elite.

Summarizing, the findings of QE characteristics seem to suggest that the late components of this fixation have a relevant role on three-point shots compared to the early components, given that competitive-elites had longer QE offset and online duration than semi-elites, particularly in the harshest game conditions. Moreover, a comparison between our sample, composed of high-style shooters, with the one of Vickers et al. (2019), consisting of low-style shooters, suggests a difference in the QE considering the shooting style during three-point shots. Such statement is in line with the literature on the jump shots and high-style shooters (De Oliveira, 2016; De Oliveira et al., 2006, 2007, 2008; Klostermann et al., 2018; Oudejans et al., 2012; Oudejans et al., 2002; Zwierko et al., 2016). Indeed, this literature suggests that athletes with a high shooting style could monitor the ongoing motor action using late visual information to adjust the action that is taking place (Vine et al., 2017). Accordingly, it is possible to speculate that, during three-point shots performed with a high-shooting style, the superior attentional control of the most experienced athletes passes through the late components of QE.

Differently from what we assumed, we did not find a statistically significant detrimental effect of time and performance pressure on shooting accuracy. Indeed, the results showed only a statistically significant higher accuracy of competitive-elites than semi-elites (Figure 1). On the other hand, in terms of the percent accuracy of shots, it is possible to note that the conditions in which the manipulations were present showed a deflection of the performance on three-point shots (Table 2). To deeply explore such results, we employed a two-way mixed ANOVA on percent accuracy, with a "between-subjects" factor named "expertise" (competitive-elite; semi-elite) and a "within-subjects" factor named "trials" (NOTP/NOPP; NOTP/PP; TP/NOPP; TP/PP). The results of the two-way mixed ANOVA on percent accuracy overlap with the mixed-model ANOVA with fixed and random effects on shot accuracy, showing that the deflection of the percent accuracy was not statistically significant (Table 2). Given all the above, it is possible to suppose that athletes performed fewer hits than misses in conditions in which at least time or performance pressure were present (cf. Table 2 and Supplementary Material – Table 1). At the same time, athletes performed the hits on these conditions with a high shot accuracy (e.g., a hit without rim contact). Even if different from what we predicted, the results about shot accuracy are in line with the ACT theoretical framework, which states that anxiety impairs processing efficiency more than performance effectiveness, given that athletes could attempt to compensate by putting extra processing resources (Eysenck & Wilson, 2016). Accordingly, it is conceivable to observe a larger impairment of QE characteristics without a consequent significant decline in performances. About the additional processing resources, it is interesting to note that in the condition in which both time and performance pressure were present, competitive-elites extended their QE online duration. Such a strategy seems very similar to the one investigated by Vickers and Williams (2007) in some elite biathlon athletes. Their results showed that the athletes who augmented their QED in high-pressure conditions did not experience performance degradation, instead of the athletes who did not adopt such strategy (Vickers & Williams, 2007).

It was also possible to describe an alternative explanation of the not statistically significant detrimental effect of time and performance pressure on shooting accuracy, relying on the findings of the effect sizes. Indeed, the results reported very small effect sizes of time and performance pressure on the QE characteristics. Accordingly, it could be possible that the manipulations implemented were not powerful enough to determine a relevant detrimental effect on the QE characteristics and consequently on shooting accuracy. Alternatively, it could be possible to speculate that the high level of experience of the participants (competitive-elites and semi-elites) could have cushioned the detrimental effect of time and performance pressure on the QE characteristics. Indeed, experts can efficiently regulate their affective state (e.g., Costanzo et al., 2016). Our findings would seem to suggest that future QE literature should also focus on designing experimental settings for getting closer to actual high-pressure sport situations, along with using instruments to assess not only the challenge or threat states but also the strategies employed to regulate them.

In a nutshell, our study investigated the effect of time and performance pressure on three-point shots by the expertise level of the participants. Considering all the above results, the competitive-elites are characterized by stable QE characteristics in response to time pressure and performance pressure, and by a longer QE online duration, especially in the harshest game condition. Such results are in line with the gaze behavior variation when experimental manipulations are similar to actual game demands (cf. Dicks et al., 2010; Klostermann et al., 2018; Vickers et al., 2019) and the QE literature on jump shots and high-shooting style (De Oliveira, 2016; De Oliveira et al., 2006, 2007, 2008; Klostermann et al., 2018; Oudejans et al., 2012; Oudejans et al., 2002; Zwierko et al., 2016), suggesting that QE online control function could be particularly relevant in three-point shots performed by athletes with a high-shooting style.

5.6 Limitations

Our work clearly has some limitations. The first refers to the unequal sample size of the groups. We recruited an unequal number of participants according to their expertise level (n = 9 semi-elites; n = 12 competitive-elites), collecting an unequal number of hits and misses (310 hits and 530 misses; Supplementary Material – Table 1). Accordingly, we employed mixed-models ANOVA with fixed and random effects, given the advantages in terms of unbalanced data sets (Baayen et al., 2008; Bagiella et al., 2000; Dixon, 2008) and its previous application on QE and gaze behavior research (Hüttermann et al., 2018; Vickers et al., 2019).

The second potential limitation of the present study regards the sample size of participants. Drawing from the effect sizes provided by Lebeau et al. (2016) for the between-individuals (i.e., the "expertise" effect: Cohen's d = 1.04, 95% CI [.71 , 1.38]) and the within-individuals (i.e., the "accuracy" effect: Cohen's d = .58, 95% CI [.34 , .82]) differences in the QE period, we conducted a power analysis using the ''pwr'' R package (Champely, 2020), employing a significance level equal to .05. The results showed that to obtain a power equal to the 80% probability of truly detecting the expertise effect, we should have recruited 12 participants per group. We obtained such a result using the average value of the effect size (d =1.04). Instead, using the highest value of the 95% CI (d = 1.38), we should have recruited a minimum of 7 participants for each expertise level. According to the actual number of participants, we exceeded this latter required sample size. At the same time, we were distant from the necessary sample size according to a d = .71 (n = 25 for each group). Concerning the accuracy effect, we calculated that to obtain a power equal to 80%, we should have collected, overall, a minimum of 37 hits and 37 misses (using the average value of the effect size d = .58). According to the actual numbers of throws collected, we exceeded the required sample size. Interestingly, the same applies using a d = .34 (the lowest value of the 95% CI). Indeed, the sample size needed according to a d = .34 was equal, overall, to 108 hits and 108 misses. Accordingly, we could state that we reached the minimum sample size of participants to have an 80% power of truly detecting the expertise effect (given a medium-to-large effect: d = .71). About the accuracy effect, we largely exceeded the 80% power (given a small-to-medium effect: d = .34.).

The third limitation regards the sampling method adopted. Indeed, we implemented a non-probability-based sampling method (convenience sampling). On one side, the present work results should consequently be treated with caution, given that from a methodological point of view, such a sampling method does not permit generalizing results to the population of interest. On the other side, it is essential to note that the convenience sampling method is commonly implemented in QE research. Thus, rather than a specific limitation of the present study, implementing a convenience sampling method could be considered an issue globally affecting QE literature. Moreover, our results are in line with the one provided by the QE literature that investigated this gaze behavior during jump shots and with a high-shooting style. Accordingly, we could affirm that, at least, the sample we collected should not be differently "biased" than other samples available in the QE basketball literature.

The fourth and last limitation is about the apparatus. The eye tracker model that we used is very light and comfortable, and it has already been used in the QE research on basketball throws (Kredel et al., 2017;

Marques et al., 2018). However, it should be noted that it is still equipment that athletes do not usually use, so it is plausible to think that it can annoy athletes.

5.7 Conclusion

We aimed to deepen the knowledge on the QE fixation in the basketball three-point shot through the current work. We conducted a mixed factorial design research, focusing on the role of expertise and its effect on QE characteristics during high-pressured conditions. The results confirmed previous evidence about the QE behavior during jump shots performed with a high shooting style, extending the results of such literature to three-point shots. Moreover, the results are in line with the ACT, confirming the superiority of the attentional control of the highest expertise levels. A core finding of the present work is that the online function of the QE seems to have a relevant role in the conditions that resemble those of an actual sport situation. We believe that our work could be helpful to scholars interested in QE and the entourage of basketball athletes, mainly coaches and sports psychologists. The former should care about creating conditions as similar as possible to actual game situations, to bring out ocular behaviors like those that the athletes would perform in real competition, for the benefit of the external validity of their results. The latter should instead focus on implementing a QE training program according to the shooting style of players to overcome the deleterious effect on attentional processes and performances of harsh game conditions.

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Supplementary Material

Table 1

Numbers of Throws across Expertise Levels and of the Total Sample

Sample	Trial	Throw outcome		
		Hit	Miss	Total
Competitive-elite	NOTP/NOPP	60	60	120
	NOTP/PP	64	56	120
	TP/NOPP	49	71	120
	TP/PP	46	74	120
	Total	219	261	480
Semi-elite	NOTP/NOPP	26	64	90
	NOTP/PP	20	70	90
	TP/NOPP	19	71	90
	TP/PP	26	64	90
	Total	91	269	360
Total sample	NOTP/NOPP	86	124	210
	NOTP/PP	84	126	210
	TP/NOPP	68	142	210
	TP/PP	72	138	210
	Total	310	530	840

Note. NOTP = no time pressure; NOPP = no performance pressure; PP = performance pressure; TP = time pressure.

Table 2

Statistical Outputs of the Non-Significant Effects of the Mixed-Model ANOVA, with Fixed and Random Effects, for the Action Time

Results	df, df error	F	p - value	Partial η²
Action Time				
EXP	1, 21.193	2.487	.130	.105
TP	1, 819.123	1.129	.288	.001
TO	1, 820.537	.112	.738	.000
EXP * TO	1, 820.537	.042	.837	.000
TP * TO	1, 819.883	.364	.547	.000
PP * TO	1, 819.601	.278	.598	.000
EXP * TP * TO	1, 819.883	.000	.996	.000
TP * PP * TO	1, 820.218	.062	.803	.000
EXP * TP * PP * TO	1, 820.218	.391	.532	.000

Note. EXP = expertise; TP = time pressure; TO = throw outcome; PP = performance pressure.

Table 3

Statistical Outputs of the Non-Significant Effects of the Mixed-Model ANOVA, with Fixed and Random Effects, for Shot Accuracy

Results	df, df error	F	p - value	Partial η²
Shot Accuracy				
TP	1, 819	2.552	0.111	0.003
PP	1, 819	0.885	0.347	0.001
EXP * TP	1, 819	2.023	0.155	0.002
EXP * PP	1, 819	0.656	0.418	0.001
ETP * PP	1, 819	0.253	0.615	0.000
EXP * TP * PP	1, 819	2.023	0.155	0.002

Note. EXP = expertise; TP = time pressure; PP = performance pressure.

Table 4

Statistical Outputs of the Non-Significant Effects of the Mixed-Model ANOVA, with Fixed and Random Effects, for the Demand and Resource Evaluation Score

Results	df, df error	F	p - value	Partial η²
DRES				
EXP	1, 21	.076	.786	.004
TP * PP	1, 819	.035	.851	.000
EXP * TP * PP	1, 819	.317	.574	.000

Note. DRES = demand and resource evaluation score; EXP = expertise; TP = time pressure; PP = performance pressure.

Table 5

Statistical Outputs of the Non-Significant Effects of the Mixed-Model ANOVA, with Fixed and Random Effects, for Quiet Eye Onset

Results	df, df error	F	p - value	Partial η²
QE Onset				
EXP	1, 22.077	.000	.994	.000
PP	1, 819.361	1.605	.206	.002
TO	1, 827.054	.072	.788	.000
EXP * TP	1, 819.662	.753	.386	.001
EXP * PP	1, 819.361	.445	.505	.001
TP * PP	1, 820.517	.048	.826	.000
TP * TO	1, 823.806	.799	.372	.001
PP * TO	1, 822.314	1.956	.162	.002
EXP * TP * TO	1, 823.806	.453	.501	.001
TP * PP * TO	1, 825.514	.001	.977	.000
EXP * PP * TO	1, 822.314	.329	.566	.000
EXP * TP * PP * TO	1, 825.514	.172	.678	.000

Note. QE = quiet eye; EXP = expertise; PP = performance pressure; TP = time pressure; TO = throw outcome.

Table 6

Statistical Outputs of the Non-Significant Effects of the Mixed-Model ANOVA, with Fixed and Random Effects, for Quiet Eye Duration

Results	df, df error	F	p - value	Partial η^2
QED				
EXP	1, 21.899	.884	.357	.039
PP	1, 819.307	1.625	.203	.002
TO	1, 825.807	.003	.955	.000
EXP * TP	1, 819.557	.000	.987	.000
EXP * PP	1, 819.307	.630	.427	.001
EXP * TO	1, 825.807	2.688	.101	.003
TP * PP	1, 820.268	.073	.788	.000
TP * TO	1, 823.028	.638	.425	.001
PP * TO	1, 821.769	1.327	.250	.002
EXP * TP * TO	1, 823.028	.168	.682	.000
TP * PP * TO	1, 824.48	.104	.747	.000
EXP * PP * TO	1, 821.769	.003	.953	.000
EXP * TP * PP * TO	1, 824.48	.102	.749	.000

Note. QED = quiet eye duration; EXP = expertise; PP = performance pressure; TO = throw outcome; TP = time pressure.

Table 7

Statistical Outputs of the Non-Significant Effects of the Mixed-Model ANOVA, with Fixed and Random Effects, for Quiet Eye Offset

Results	df, df error	F	p - value	Partial η^2
QE Offset				
TP	1, 819.277	.433	.511	.001
PP	1, 819.152	.010	.919	.000
TO	1, 822.528	.339	.561	.000
EXP * PP	1, 819.152	.209	.648	.000
EXP * TO	1, 822.528	1.367	.243	.002
TP * PP	1, 819.634	2.399	.122	.003
TP * TO	1, 821.045	.086	.770	.000
PP * TO	1, 820.394	.433	.511	.001
EXP * TP * PP	1, 819.634	1.029	.311	.001
EXP * TP * TO	1, 821.045	.488	.485	.001
TP * PP * TO	1, 821.81	.686	.408	.001
EXP * PP * TO	1, 820.394	2.292	.130	.003
EXP * TP * PP * TO	1, 821.81	.067	.795	.000

Note. QE = quiet eye; TP = time pressure; PP = performance pressure; TO = throw outcome; EXP = expertise.

Table 8

Statistical Outputs of the Non-Significant Effects of the Mixed-Model ANOVA, with Fixed and Random Effects, for Quiet Eye Preprogramming Duration

Results	df, df error	F	p - value	Partial η²
QE Preprogramming				
EXP	1, 21.317	.216	.647	.010
PP	1, 630.059	.301	.584	.000
TO	1, 635.397	.083	.773	.000
EXP * TP	1, 629.886	1.391	.239	.002
EXP * PP	1, 630.059	.536	.464	.001
EXP * TO	1, 635.397	2.391	.123	.004
TP * PP	1, 630.379	.552	.458	.001
TP * TO	1, 633.510	.393	.531	.001
PP * TO	1, 630.790	1.085	.298	.002
EXP * TP * TO	1, 633.510	.013	.908	.000
TP * PP * TO	1, 635.075	.060	.806	.000
EXP * PP * TO	1, 630.790	.130	.719	.000
EXP * TP * PP * TO	1, 635.075	.002	.965	.000

Note. QE = quiet eye; EXP = expertise; TO = throw outcome; PP = performance pressure; TP = time pressure.

Table 9

Statistical Outputs of the Non-Significant Effects of the Mixed-Model ANOVA, with Fixed and Random Effects, for Quiet Eye Online Duration

Results	df, df error	F	p - value	Partial η²
QE Online				
TP	1, 789.520	1.734	.188	.002
TO	1, 791.456	.136	.712	.000
EXP * TO	1, 791.456	.717	.397	.001
TP * TO	1, 790.853	.092	.762	.000
PP * TO	1, 790.285	.003	.953	.000
EXP * TP * TO	1, 790.853	.900	.343	.001
TP * PP * TO	1, 791.066	1.333	.249	.002
EXP * PP * TO	1, 790.285	.161	.688	.000
EXP * TP * PP * TO	1, 791.066	.368	.544	.000

Note. QE = quiet eye; TP = time pressure; TO = throw outcome; EXP = expertise; PP = performance pressure.

Table 10

Average Action Time (in milliseconds) across Levels of Throw Outcome, Expertise, Time Pressure, and Performance Pressure

Throw Outcome	Expertise	Trial			
		NOTP/NOPP	NOTP/PP	TP/NOPP	TP/PP
Hit	CE	471.457 (32.184)	481.058 (32.036)	439.017 (32.789)	558.023 (32.993)
	SE	428.201 (39.261)	427.911 (40.703)	409.33 (40.938)	388.696 (39.28)
Miss	CE	489.865 (32.184)	473.809 (32.371)	461.523 (31.821)	528.297 (31.734)
	SE	428.158 (36.31)	445.221 (36.132)	394.545 (36.098)	402.67 (36.313)

Note. Levels: throw outcome (hit; miss); expertise (CE = competitive-elite; SE = semi-elite); time pressure (NOTP = no time pressure; TP = time pressure); performance pressure (NOPP = no performance pressure; PP = performance pressure). Standard errors are presented inside the round brackets.

Table 11

Average Quiet Eye Onset time (in milliseconds) across Levels of Throw Outcome, Expertise, Time Pressure, and Performance Pressure

Throw Outcome	Expertise	Trial			
		NOTP/NOPP	NOTP/PP	TP/NOPP	TP/PP
Hit	CE	-617.982 (76.96)	-724.137 (75.702)	-595.13 (81.888)	-581.808 (83.507)
	SE	-775.285 (105.4)	-695.28 (115.823)	-662.332 (117.533)	-668.324 (105.523)
Miss	CE	-785.191 (76.96)	-784.518 (78.513)	-682.497 (73.847)	-509.903 (73.088)
	SE	-746.578 (81.466)	-580.77 (79.863)	-588.525 (79.561)	-569.064 (81.492)

Note. Levels: throw outcome (hit; miss); expertise (CE = Competitive-Elite; SE = Semi-Elite); time pressure (NOTP = no time pressure; TP = time pressure); performance pressure (NOPP = No performance pressure; PP = performance pressure). A negative value represents a quiet eye onset before the critical movement (i.e., a greater value in absolute value correspond to an earlier quiet eye onset). Standard errors are presented inside the round brackets.

Table 12

Average Quiet Eye Duration (in milliseconds) across Levels of Throw Outcome, Expertise, Time Pressure, and Performance Pressure

Throw Outcome	Expertise	Trial			
		NOTP/NOPP	NOTP/PP	TP/NOPP	TP/PP
Hit	CE	712.865 (82.791)	805.442 (81.574)	707.968 (87.593)	665.884 (89.174)
	SE	787.087 (111.765)	690.507 (122.059)	624.239 (123.74)	654.558 (111.888)
Miss	CE	851.576 (82.791)	860.578 (84.3)	762.975 (79.784)	637.662 (79.052)
	SE	801.38 (88.458)	584.907 (86.921)	567.075 (86.63)	566.588 (88.484)

Note. Levels: throw outcome (hit; miss); expertise (CE = competitive-elite; SE = semi-elite); time pressure (NOTP = no time pressure; TP = time pressure); performance pressure (NOPP = no performance pressure; PP = performance pressure). Standard errors are presented inside the round brackets.

Table 13

Average Quiet Eye Offset Time (in milliseconds) across Levels of Throw Outcome, Expertise, Time Pressure, and Performance Pressure

Throw Outcome	Expertise	Trial			
		NOTP/NOPP	NOTP/PP	TP/NOPP	TP/PP
Hit	CE	95.27 (33.255)	81.494 (32.949)	112.338 (34.49)	86.152 (34.901)
	SE	14.178 (42.615)	-4.256 (45.403)	-39.25 (45.855)	-14.186 (42.65)
Miss	CE	65.998 (33.255)	75.845 (33.64)	80.822 (32.502)	126.467 (32.32)
	SE	53.837 (36.619)	3.989 (36.243)	-21.141 (36.171)	-2.305 (36.626)

Note. Levels: throw outcome (hit; miss); expertise (CE = competitive-elite; SE = semi-elite); time pressure (NOTP = no time pressure; TP = time pressure); performance pressure (NOPP = no performance pressure; PP = performance pressure). A negative value represents a quiet eye offset ended before the critical movement (i.e., a greater value in absolute value correspond to an earlier quiet eye offset).Standard errors are presented inside the round brackets.

Table 14

Average Quiet Eye Preprogramming Duration (in milliseconds) across Levels of Throw Outcome, Expertise, Time Pressure, and Performance Pressure

Throw Outcome	Expertise	Trial			
		NOTP/NOPP	NOTP/PP	TP/NOPP	TP/PP
Hit	CE	494.350 (82.013)	603.010 (79.108)	393.001 (84.676)	398.276 (90.629)
	SE	661.638 (107.892)	553.010 (121.287)	497.613 (120.392)	563.390 (108.157)
Miss	CE	579.245 (77.711)	572.431 (79.452)	500.240 (74.365)	419.431 (80.224)
	SE	603.171 (84.690)	424.537 (83.138)	471.901 (83.258)	509.705 (87.754)

Note. Levels: throw outcome (hit; miss); expertise (CE = competitive-elite; SE = semi-elite); time pressure (NOTP = no time pressure; TP = time pressure); performance pressure (NOPP = no performance pressure; PP = performance pressure). Standard errors are presented inside the round brackets.

Table 15

Average Quiet Eye Online Duration (in milliseconds) across Levels of Throw Outcome, Expertise, Time Pressure, and Performance Pressure

Throw Outcome	Expertise	Trial			
		NOTP/NOPP	NOTP/PP	TP/NOPP	TP/PP
Hit	CE	386.740 (42.581)	388.454 (42.353)	378.659 (43.991)	464.759 (44.260)
	SE	285.777 (53.898)	305.124 (58.350)	242.300 (59.104)	228.001 (54.829)
Miss	CE	373.178 (42.581)	372.542 (42.971)	367.652 (41.945)	480.097 (41.712)
	SE	345.660 (47.614)	309.975 (47.280)	223.311 (47.207)	246.196 (47.686)

Note. Levels: throw outcome (hit; miss); expertise (CE = competitive-elite; SE = semi-elite); time pressure (NOTP = no time pressure; TP = time pressure); performance pressure (NOPP = no performance pressure; PP = performance pressure). Standard errors are presented inside the round brackets.

Chapter 6: General discussion and summary of findings

Despite 25 years of research on QE, there is still no agreement about the QE function that could explain the relationship between this fixation and the highest levels of sports expertise and performance. To date, several authors suggested and tested diverse hypotheses, like the ones related to the programming or the online control of the action (De Oliveira et al., 2007; Gonzalez et al., 2017), to the attentional control to prevent distraction (Eysenck & Wilson, 2016); to the inhibition of suboptimal motor solutions (Klostermann & Hossner, 2018); to the increase of postural stability (Gallicchio & Ring, 2019). In a recent meta-analysis, Lebeau et al. (2016) suggested that the type of sports task could represent a relevant factor that could influence the role of QE. Accordingly, the QE function might differ according to the specific task demands (Klostermann et al., 2013, 2018; Vickers, 2009).

On this basis, the present doctoral thesis aimed to comprehend the QE underlying functions by exploring novel aiming tasks and manipulating well-known sports tasks in the QE literature. Accordingly, the first step was to understand QE's state of the art in terms of its role in sport aiming tasks, the variables that affect this fixation, and the sports tasks explored.

The narrative review reported in Study 1 showed that the scholars implemented several research designs, as observational, quasi-experimental, and intervention. The results of the observational and quasi-experimental studies exhibited that QE characteristics are related to the performers' characteristics (i.e., expertise, attention focus, and competitive anxiety levels), performance characteristics (i.e., outcome and accuracy levels), and task demands (i.e., task difficulty). The intervention studies even reported that the QE of non-experts could be trained, with successful outcomes regarding sports performances also in high anxiety conditions. For what concerns the investigated tasks, the results of the narrative review showed that the QE literature did not focus on several aiming sports, nor did implement experimental manipulations in those tasks in which there is strong evidence to support a specific function of QE.

Accordingly, the following steps of the present doctoral thesis regard: (1) the investigation of the relationship between QE, performance, and expertise in novel sport aiming tasks; (2) the manipulation of the demands of well-known tasks in QE literature to assess its specific QE function. In doing so, the main focus was to compare different levels of expertise (e.g., experts vs. near or non-experts) in terms of several QE characteristics related to its duration and timing.

Overall, the results (Study 2-4) showed that the QE is related to the highest sports expertise and performance levels. However, the relevance of the QE duration or its timing seems affected by the task's kinematical and timing characteristics. Indeed, Study 2 results showed that an early QE onset is more important than an extended QE in a task where the movement speed strongly determines the aiming outcome (Chirico et al., 2019). Instead, Study 3 highlighted the relevance of QE duration during basketball free throws (Giancamilli et al., 2022). In contrast, the QE late components (QE offset and QE online control) in the three-point jump shots are related to the most expert players (Study 4). Regarding the manipulations implemented (i.e., time and performance pressure; Study 3 and 4), the results showed that experts had superior attentional control than near-experts. Despite this, their QE was not immune to the effects of manipulations.

On the whole, the findings suggest that the acquisition of environmental visual information through the QE occurs at different times during the ongoing action, according to the kinematical and timing specificity of the task (e.g., before the critical movement for the Laser-Run and the basketball free throw; in the last phases of the action during a basketball three-point jump shot). Therefore, the difference in QE timing between tasks should represent a different underlying function. Indeed, the results from Study 2 and Study 3 suggested that the QE could be related to a preprogramming function, as an early QE onset characterized experts and hits during the Laser-Run (Study 2) and that during time-pressured free throws, athletes had poor performances, along with a QE onset delay (Study 3). Instead, a late QE offset and an extended QE online duration could represent an online control function during the three-point jump shots (Study 4). In any case, all the results reported above are in line with the attentional control function, which states that the QE aid the goal-directed attentional system to acquire environmental visual information (Eysenck & Wilson, 2016; Eysenck et al., 2007; Gonzalez et al., 2017). In such a way, athletes attenuate the bottom-up attentional system's effect, and they do not get distracted (Corbetta & Shulman, 2002). After all, the ability to not get distracted (or to concentrate) during a motor action has been long given attributed to sports experts and successful performances (cf. Eysenck & Wilson, 2016).

In light of the results reported in the present doctoral thesis, it seems plausible to speculate that the time at which such a process must occur depends on the specific task, in line with the suggestions of Lebeau et al. (2016), who suggested that the specific role of the QE could depend by the type of sports task.

Besides the research value, the findings of the present doctoral thesis have important implications from an applied point of view. The literature showed that QE training protocols permit novices the acquisition of a "like an expert" gaze behavior. Indeed, the novice participants involved in the QE training protocols extended their QE duration and performances, also exhibiting stable QE characteristics during conditions characterized by high sports performance pressure (Moore et al., 2012; Vickers et al., 2017; Vine et al., 2011, 2013; Vine & Wilson, 2010, 2011; Wood & Wilson, 2011, 2012). On the one hand, the results of the present doctoral thesis stretched the relevance to establish a QE prototype specific to the task before implementing any QE training protocols to non-experts, following Vickers's (2016) guidelines. Indeed, according to this author, a QE training program should develop according to seven steps: (1) define expert QE prototype, (2) test trainees in the same task, (3) provide instructions of the five QE characteristics, (4) provide QE feedback, (5) decision training, (6) blocked and random training, (7) assess competitive QE. Consistent with this framework, we suggest that future QE training protocols on Laser-Run should highlight the anticipation of the QE onset. In contrast, the same protocols apply to three-point jump shots would emphasize visual information acquisition during and beyond the ongoing action. On the other hand, the results reported in the present doctoral thesis suggest that the QE training protocols should also be applied to expert athletes to permit the transfer of the QE characteristics to complex game conditions, allowing athletes to perform successfully, regardless of the trickiness of the sport situation.

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