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Samuel J. Vine a , Lee J. Moore a & Mark R. Wilson a
a Department of Sport and Health Sciences, University of Exeter, Exeter, UK
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Quiet eye training: The acquisition, refinement and resilient performance of targeting skills

SAMUEL J. VINE, LEE J. MOORE, & MARK R. WILSON

Department of Sport and Health Sciences, University of Exeter, Exeter, UK

Abstract

How we learn and refine motor skills in the most effective manner and how we prevent performance breakdown in pressurised or demanding circumstances are among the most important questions within the sport psychology and skill acquisition literature. The quiet eye (QE) has emerged as a characteristic of highly skilled perceptual and motor performance in visually guided motor tasks. Defined as the final fixation that occurs prior to a critical movement, over 70 articles have been published in the last 15 years probing the role that the QE plays in underpinning skilled performance. The aim of this review is to integrate research findings from studies examining the QE as a measure of visuomotor control in the specific domain of targeting skills; motor skills requiring an object to be propelled to a distant target. Previous reviews have focused primarily on the differences in QE between highly skilled performers and their less skilled counterparts. The current review aims to discuss contemporary findings relating to 1. The benefits of QE training for the acquisition and refinement of targeting skills; 2. The effects of anxiety upon the QE and subsequent targeting skill performance and 3. The benefits of QE training in supporting resilient performance under elevated anxiety. Finally, potential processes through which QE training proffers this advantage, including improved attentional control, response programming and external focus, will be discussed and directions for future research proposed.

Keywords: Quiet eye, visuomotor control, anxiety, skill acquisition, pressure, attention

Introduction

The majority of sporting tasks are performed in a dynamic, ever-changing environment, under conditions of extreme anxiety where the limits of human behaviour are continually challenged. The ability to control attention and remain focused under elevated anxiety has frequently been discussed as a key component of success (Janelle, 2002). However, what exactly should performers focus on in order to acquire skills and produce their best performances? Why might performers become distracted and ‘lose’ concentration in anxiety-provoking environments?

The development of lightweight eye tracking technology has significantly advanced our understanding of what individuals fixate and/or attend to while performing sport skills. A growing body of evidence suggests that how gaze is controlled is critical for skills requiring precise cue selection, optimal timing and the ability to focus for long durations under extreme performance conditions (Vickers, 2011). Such research suggests that in order to be successful at aiming to a target, 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). This particular gaze strategy, termed the quiet eye (QE; Vickers, 1996), has been shown to be indicative of superior performance in a variety of sporting tasks (see Vickers, 2011). 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 visuomotor work-space within 3° of visual angle (or less) for a minimum of 100 ms (Vickers, 2007). The onset of the QE occurs before the critical phase of the motor task and the offset occurs when the final fixation deviates off the target by more than 3° of visual angle for more than 100 ms.

This review aims to integrate findings from research which has adopted the QE as an objective measure of visuomotor control underpinning the learning, retention and performance of skills under demanding and anxiety-provoking circumstances. The objective is not to provide an exhaustive review of all research that has examined the QE, but to focus on research examining targeting skills (see
Vickers, 2007) where the interacting roles of visual attention control and anxiety are particularly relevant.

**Aiming, attention and performance: the QE**

The QE was first proposed by Vickers (1996), and since its conception more than 70 published articles have adopted it as an objective measure of visuomotor control (see Vickers, 2007, 2011). The QE underpins successful performance, differentiating both expertise (inter-individual) and proficiency (intra-individual), with experts and successful sporting attempts characterised by longer QE durations. Vickers (1996) carried out the first examination of the QE in basketball free-throw shooting, and revealed that experts displayed significantly longer and earlier final fixations to the hoop than their near-expert counterparts. Secondly, both experts and near-experts had significantly shorter QE durations when they missed a shot compared with when it was successful. Since this seminal study, similar findings have been uncovered in targeting tasks as varied as dart throwing (Vickers, Rodrigues, & Edworthy, 2000), rifle shooting (Janelle et al., 2000), billiards potting (Williams, Singer, & Frehlich, 2002), golf putting (Wilson & Pearcey, 2009) and shotgun shooting (Causer, Bennett, Holmes, Janelle, & Williams, 2010). Indeed, in a meta-analysis of measures of perceptual–cognitive expertise, Mann, Williams, Ward, and Janelle (2007) found that the QE was one of the three key indices of expertise. While QE durations varied between tasks, experts had significantly (62%) longer QE durations than less expert groups across all tasks included in the meta-analysis.

**QE training: fine-tuning performance**

As well as being indicative of skilled performance, the QE can be trained, with subsequent benefits for targeting skills that are already well practised. Therefore, the QE is not just a by-product of expertise, but appears to be an important mediator of skilful performance. QE training involves guiding decisions about where and when to fixate areas of interest within the visuomotor work-space whilst performing a skill. Using video modelling and verbal feedback, performers are guided to develop the same QE focus and visual control as expert performers.

Harle and Vickers (2001) were the first to examine the benefits of QE training for performance in a targeting task, free-throw shooting, using near elite basketball players. Team A took part in a QE training regime and Teams B and C acted as control groups. The gaze of each member of team A was recorded and viewed relative to an elite prototype in a feedback session. Participants were then taught a three-step QE training regime to improve their visual control. Unsurprisingly, Team A increased their QE duration compared with Teams B and C following training, but also revealed a performance advantage in laboratory tests of free-throw performance. Importantly, the performance advantage transferred to the court, with Team A improving their free-throw by 23% after two seasons of competitive play, while the performance of Teams B and C remained relatively constant.

Recent studies examining the utility of QE training in targeting skills, including shotgun shooting (Causer, Holmes, & Williams, 2011b), football penalty taking (Wood & Wilson, 2011) and golf putting (Vine, Moore, & Wilson, 2011), have also revealed similar benefits. In Causer et al.’s (2011b) study, 20 international level skeet shooters were assigned to either a QE trained or control group and tested before and after an 8-week intervention. The QE trained group were shown video feedback of their eye movements and taught a pre-shot routine aimed at lengthening their QE. After training, the QE trained group had a significantly earlier onset of QE on the clay, tracked it for longer and demonstrated significantly improved performance, while the control group revealed no significant changes in QE or performance.

Vine et al. (2011) revealed similar benefits for a brief (1 hour) QE training intervention for low handicap (mean = 2.4) golfers. Again, relative increases in QE and performance in a laboratory-based putting task were found, compared with a control group. The benefits also transferred to the competition environment with the QE trained golfers revealing a relative improvement in golf putting performance on the course; taking 1.92 fewer putts per round and holing 5% more putts from 6 to 10 feet following the training. Again, the control group revealed no significant changes in on-course putting performance.

**QE training: expediting skill acquisition**

Alongside the research that has examined QE training for fine-tuning the performance of skilled individuals, a parallel programme of research has examined if QE training can help novices to acquire targeting skills more quickly than when taught using ‘typical’ technical instructions. Vine and Wilson (2010, 2011) examined the effect of QE training on the gaze control and performance of novice participants performing golf putts and basketball free throws, respectively. In both studies, two groups of novices, QE trained and control (technique-focused instructions), performed 360 acquisition trials. Learning was assessed using retention tests,
where no guidance or instructions were provided. In both studies, the QE trained group demonstrated better performance than their control group counterparts in these retention tests (although this advantage only approached significance in the 2010 golf putting study). The control groups also improved performance over the training period (and increased their QE durations significantly), however, QE training promoted a longer and more expert-like QE, resulting in a level of performance that was further along the learning curve.

Anxiety and the QE

As top level sport is characterised by a demand to perform at peak levels in anxiety-provoking situations, research has focused on understanding how performers are affected by, and learn to overcome, heightened levels of cognitive anxiety (Wilson, in press). There is considerable research evidence that for targeting tasks, anxiety causes a disruption to attentional control leading to degradation in task performance (see Janelle, 2002; Wilson, in press, for reviews). As a result, several studies have revealed that the QE may be a useful index of optimal attentional control in targeting tasks, and sensitive to the influence of increased anxiety (Behan & Wilson, 2008; Causer, Holmes, Smith, & Williams, 2011a; Vickers & Williams, 2007; Wilson, Vine, & Wood, 2009). For example, Wilson et al. (2009), in a basketball free-throw task, found that under conditions of elevated cognitive anxiety, QE durations were reduced, as participants took more fixations around the vicinity of the target compared with a low-anxiety condition. These findings are consistent with previous research by Behan and Wilson (2008) in simulated archery. Furthermore, Causer et al. (2011a) found that in a clay-pigeon shooting task, anxiety shortened QE durations by delaying the onset of QE under conditions of elevated anxiety. In all three studies, these reductions in the efficiency of attentional control were also associated with poorer performance.

This anxiety-focused research provides additional support for the importance of the QE in underpinning successful targeting skill performance. Indeed, Vickers and Williams (2007) found that elite biathletes who increased their QE duration during simulated competition compared with practice were less susceptible to the adverse effects of anxiety. As such, the authors suggested that the act of allocating attention externally to critical task information (via the QE) may insulate athletes from the debilitating effects of anxiety. Behan and Wilson (2008) suggested that QE training programmes might therefore be a useful intervention to enhance attentional control and maintain performance in anxiety-inducing environments.

In support of this assertion, the previously discussed training studies by Vine and Wilson (2010, 2011) for novices, and Vine et al. (2011) for experienced performers also included manipulations of anxiety, to determine any additional benefits of QE training upon performance in an anxiety-provoking environment. The authors found that control groups displayed significantly shorter QE durations and performed significantly worse in pressure tests, compared with retention tests, whilst QE trained groups maintained effective QE durations and performance. Thus, the results indicate that QE training acted to protect performers from the adverse effects of anxiety upon attentional control and performance by maintaining effective QE durations.

How does QE training ‘work’?

While the recent training studies provide the strongest support for a mediating role for the QE in underpinning successful targeting skill performance (Causer et al., 2011b; Vine & Wilson, 2010, 2011; Vine et al., 2011), there has been a lack of explicit tests of the processes through which QE training interventions exert their positive effect. A number of potential processes have been tested, or inferred, by researchers, and these are outlined in the following sections.

Attentional control

Either when gained through experience or as a result of specific training, a long QE duration has been proposed to facilitate targeting skill performance by ensuring that optimal attentional control, fixating the right target at the right time, is maintained (Wilson, in press).

An attentional control function for the QE is supported by contemporary cognitive-neuroscience models of attention (e.g. Corbetta, Patel, & Schuman, 2008) that implicate the importance of attentional control for goal-driven tasks (see Land, 2009 for a discussion of attentional control in visually guided motor tasks). Corbetta et al.’s model reflects the delicate balance between a goal-directed, top-down (dorsal) and stimulus-driven, bottom-up (ventral) system. First, a top-down, goal-directed attentional system (dorsal attention), which is centred on the dorsal posterior parietal and frontal cortex is important for response or action selection and is involved in linking relevant stimuli to response planning. Second, a stimulus-driven attentional system (ventral attention), centred on the temporoparietal and ventral frontal cortex, is recruited.
during the detection of salient and unattended stimuli and acts as a circuit breaker for top-down control (Corbetta et al., 2008). Therefore, Vickers’ (1996) suggestion that longer QE periods may allow performers an extended duration of response programming, while minimising distraction from other cues, can be explained using the language of Corbetta et al.: the QE helps maintain effective goal-driven attentional control, while reducing the impact of the stimulus-driven attentional system.

A recent theoretical development from cognitive psychology, attentional control theory (Eysenck, Derakshan, Santos, & Calvo, 2007), has utilised these attentional systems (goal-directed vs. stimulus-driven control) to help explain the adverse effects of anxiety upon performance, and has subsequently been adopted as a framework to interpret findings showing that a breakdown in the QE leads to a degradation in targeting skill performance (Wilson, in press). Anxiety increases the sensitivity of the stimulus-driven system, making individuals more distractible, at the expense of goal-directed control. Therefore, if top-down (dorsal) attentional control is required to effectively complete a task, such stimulus-driven (ventral) processing will likely impair effective attentional control and task performance. As such, a long QE duration prior to and during task performance may be needed to suppress competing stimuli/emotions and allow the dorsal network to carry out the action as planned.

Response planning

Vickers (1996) originally postulated that longer QE durations extend the duration of critical pre-programming during which the parameters of the movement (e.g. direction and force), as well as the timing and coordination of the limbs, are fine-tuned. Thus, longer QE durations pass visually acquired goal position information to the motor control systems, resulting in movement kinematics and patterns of muscle activation that are more effective for successful targeting skill performance (Vickers, 2011). More efficient movement patterns may therefore be considered as an indirect measure of effective response programming. Indeed, several QE training studies have reported changes in the movement patterns of performers (Causer et al., 2011b; Vine & Wilson, 2010). Causer et al. (2011b) reported that a QE trained group displayed significantly reduced gun barrel displacement and absolute peak velocity, despite neither of these variables being overly trained. Moore, Vine, Cooke, Ring and Wilson (in press) reported that, in a golf putting task, a QE trained group displayed lower lateral and vertical clubhead acceleration than their control group counterparts. Furthermore, vertical clubhead acceleration was found to mediate between-group differences in performance during retention tests. These findings are potentially important as they indicate that QE training may craft indirect changes in the mechanics of the motor skill through enhanced response programming, despite the instructions focusing only on gaze control.

Williams et al. (2002) explicitly examined the QE’s role in response programming by experimentally increasing the complexity of a billiards shot and reducing the time available to complete it. As more complex motor responses require longer response programming (see Vickers, 2011), it was expected that a longer QE duration would be displayed for more complex shots. While, general expertise and proficiency effects were similar to previous studies, the results also revealed that more complex shots were characterised by longer QE durations compared with less complex shots. When the time available to prepare the shot was reduced by 25 and 50% of each participant’s ‘normal’ preparation time, shorter QE durations resulted, accompanied by poorer performance.

Direct measures of cortical activation in areas related to motor planning and control have also been examined to support the contention that longer QE durations provide extended time to programme accurate movements. Janelle et al. (2000) examined the QE duration and cortical activation (via electroencephalography, EEG) of expert and near-expert rifle shooters. Their results showed that experts displayed longer QE durations and more efficient cortical processing (indexed by the pattern of alpha and beta power in left and right hemispheres). A higher magnitude of hemispheric asymmetry among the expert, as opposed to near-expert shooters, implicated the role of specific relevant neural pathways during the pre-programming of visual-guided movements (Janelle et al., 2000).

Janelle and colleagues (Mann, Coombes, Mousseau, & Janelle, 2011) extended their previous EEG study by correlating a proxy measure of QE with a specific event-related potential linked to motor control: the Bereitschafts potential (BP). The BP is a negative potential that precedes an actual, intended or imagined event by 1–1.5 s (similar to the time frame for the QE). The early slow rising negativity (BP\textit{early}) reflects the activation of the supplementary motor area (SMA) and occurs approximately 1500 ms prior to movement onset. The BP\textit{late}, characterised by a change in the steepness of the waveform, reflects the activation of the primary motor cortex (M1) and occurs approximately 400–500 ms prior to movement onset. Finally, the BP\textit{peak} occurs approximately 50–60 ms prior to movement onset and reflects the coordinated activation of both the SMA and M1
(see Swinnen & Wenderoth, 2004, for an overview of the principal brain areas involved in motor control). Mann et al (2011) proposed that as the BP is representative of the cortical mechanisms responsible for movement preparation, skilled performers would display greater BP negativity and longer QE durations than their less-skilled counterparts. Indeed, longer QE durations and greater BP negativity were identified for expert compared with non-expert golfers, alongside more accurate and less variable performance, offering more direct support for a response planning function for the QE. Importantly, however, other research investigating the BP has suggested that a reduced BP negativity is indicative of expert performance, as it reflects the reduced efforts required to plan and perform the motor task (see Wright, Holmes, & Smith, 2011 for a review). Further, research is therefore still required to ascertain how the QE might provide a motor planning and/or preparation function, and how cortical measures, such as the BP, reflect these processes.

Focusing externally and psychomotor quieting

The QE may also provide a more generalised benefit for targeting skill performance, by promoting an external focus of attention. A number of research programmes have advocated the advantages of focusing externally during the learning and performance of motor skills. For example, Singer (2000) incorporated focusing attention on a key external component of the task (e.g. dimples on a golf ball) as the third step of his five-step pre-shot routine for motor learning. He proposed that such an external focus helped to create an optimal state for performance, and prevented learners from focusing on internal thoughts or body mechanics (Singer, 2000). Similarly, Wulf and Colleagues (see Wulf, 2007 for a review) have consistently demonstrated that an external focus of attention (on the effect of the movement) is superior for motor learning than an internal focus of attention (on the mechanics of the skill).

According to the Intake-Rejection Hypothesis (Lacey & Lacey, 1980), an external focus of attention induces a deceleration in heart rate immediately prior to task execution, aiding targeting skill performance. For example, Radlo, Steinberg, Singer, Barba, and Melnikov (2002) found that focusing attention externally towards the target whilst performing a dart throwing task was associated with a pronounced deceleration in heart rate prior to the throw and more accurate performance. Research has also demonstrated that an external focus of attention is associated with additional quieting of the psychoneuromuscular system; evidenced via reduced electromyographic activity. For example, Lohse, Sherwood, and Healey (2010) found that an external focus of attention (on the bull’s-eye and flight of the dart), resulted in reduced muscle activity in the triceps brachii of the dart throwing arm and superior performance.

A QE strategy might therefore aid the acquisition and resilient performance of a targeting skill by ensuring that an effective external focus of attention and accompanying physiological state (i.e., reduced heart rate and muscle activity) is both developed and maintained under heightened anxiety. A recent study by Moore et al. (in press) offers some support for this contention. A QE trained group performed more accurately and displayed longer QE durations, greater heart rate deceleration and reduced muscle activity during retention and pressure tests than a control (technique-focused instructions) group. However, mediation analyses failed to establish causal relationships between these physiological measures and performance, suggesting that future research is still required to un-pick if and how QE-training exerts its advantage for performance through an external focus of attention and quieting of the psychomotor system.

Directions for future research

Direct (neural) measurements

The research to date has revealed that QE training is beneficial in expediting learning, fine-tuning performance and protecting performance under heightened anxiety for targeting skills. However, in order to understand how such benefits arise, future studies will need to assess more direct measures of response programming, attentional control and neural quieting. EEG perhaps offers the most productive way forward, as it can be used to examine movement-related cortical activity in ecologically valid targeting skills with high temporal resolution (Wright et al., 2011). Furthermore, EEG induced responses and evoked potentials have been successfully aligned to both motor planning and attentional processes in visually guided tasks.

We previously discussed how the response programming benefits of QE training have been examined using both induced response (Janelle et al., 2000) and event-related potential (Mann et al., 2011) EEG measures. While, attentional control and motor planning neural networks are likely to have considerable overlap, specific neural indices of attentional control related to the balance between enhancing goal-directed processing and limiting stimulus-driven processing (Corbetta et al., 2008) have been examined. For example, the attentional selection of a target presented among distracting stimuli has been indexed by a specific event-related
potential component, N2pc (Hickey, Di Lollo, & McDonald, 2008). The N2pc is proposed to reflect the mechanisms of attention involved in the spatial location of a target (target negativity) and the spatial location of distracting stimuli (distractor positivity) and occurs approximately 175 ms after the presentation of a stimulus. Future research could examine changes in the N2pc during the acquisition of a skill, to assess changes in attentional control as a result of QE training.

Furthermore, Baumeister, Reinecke, Liesen, and Weiss (2008) in putting and Doppelmayr, Finkenzeller, and Sauseng (2008) in rifle shooting discuss increased frontal midline (Fz) theta activation (power) as an indicator of increased target-related focused attention. This particular activation is related to the preparatory phase of a task, and is likely generated in the anterior cingulated cortex; an important component of the human attentional system. In both studies, experts revealed higher Fz theta as well as better performance than novice counterparts, and in the Doppelmayr et al. study, expert theta activity increased steadily towards trigger pull (from 3 s to 500 ms before), whereas novices’ activity decreased over time. Both studies suggest that experts increase their focused attention during the preparatory period of a skilled aiming task. By concurrently measuring both increased midline theta activation (via EEG) and the QE, future research could examine the extent to which a long QE duration supports effective attentional control.

When performing targeting skills, experts have frequently been shown to reveal greater neural efficiency/quieting than their novice counterparts (Yarrow, Brown, & Krakauer, 2009), and such differences might be evident for QE trained as opposed to technically trained individuals. To date, there has been little research investigating the effects of training interventions on neural efficiency measures. However, Masters and colleagues (e.g. Zhu, Poolton, Wilson, Maxwell, & Masters, 2011) have measured EEG co-activation (coherence) between the verbal-analytical (T3) and motor planning (Fz) regions to compare implicit and explicit motor learning interventions in golf putting. The authors found that participants who had learned the putting task implicitly revealed less verbal-analytical involvement in movement control (as indicated by reduced T3–Fz co-activation) than those taught explicitly; a pattern similar to the neural efficiency of expert performers. Future research could establish the extent to which QE training might also limit verbal control of movement via similar cortical coherence markers.

Controlled experimental manipulations

Williams et al.’s (2002) study represents the only attempt at experimentally manipulating characteristics of the QE in order to reveal potential underlying processes. Future research should further manipulate the location, duration and timing of the QE, to help understand the relative importance of each component for targeting performance. Such experiments can be performed with skilled participants, manipulating characteristics of the QE and observing subsequent changes in performance under conditions of varying demand (e.g. multi-tasking or social evaluative threat). Alternatively, placing participants in different experimental learning groups (with different durations, timings or locations of QE) may further our understanding of what components of the QE are most important for skill acquisition and resilient retention of targeting skills.

Psychological control

To date, the proposed explanations for the positive benefits of QE training have focused on direct influences on the control structures underpinning the performance of the targeting skill. However, it is possible that QE training might support an indirect benefit to targeting skill performance via improved perceived psychological control. For example, preliminary data suggest that QE training supports performance in anxiety-provoking environments by providing a repeatable pre-performance cue that enhances perceptions of control (Wilson & Wood, 2011) and develops more positive (i.e. challenge as opposed to threat) cognitive appraisals (Moore, Vine, Wilson, & Freeman, 2011). As a form of pre-performance routine, it is likely that some of the performance benefits of QE training arise from improvements in indirect (perceived) psychological control, as well as direct visuomotor and attentional control. Future research should further explore these psychological processes, as there are clear implications for the development of psychological skills training programmes for athletes (see Wilson, in press).

Alternative domains

There is also the potential to extend the focus of QE research to skills outside of sport. Future research could examine the benefits of QE training in safety critical industries, where visually guided skills must be acquired and performed under elevated anxiety (e.g. medicine, emergency services and military). Recent research has identified expert–novice differences in QE tasks as varied as fire arm scenarios in law enforcement (Vickers & Lewinski, 2012) and
laparoscopic surgery (Wilson et al., 2011a). Vickers and Lewinski found that expert fire arms officers displayed longer QE durations on the assailant’s weapon/cell prior to firing, leading to improved decision making and more accurate shots, compared with novice counterparts. Wilson and colleagues found that consultant surgeons had longer QE durations on about to-be-grasped objects in a virtual reality laparoscopic environment, than novice surgeons. In a similar vein to their sport-based novice training programmes (Vine & Wilson, 2010, 2011), Wilson, Vine and colleagues have applied this knowledge to training interventions for novice surgeons (Wilson et al., 2011b; Vine, Masters, McGrath, Bright & Wilson, in press). Following gaze training interventions, novices reveal expedited learning and are better able to perform laparoscopy tasks under demanding conditions than participants trained using technical training (explicit motor learning) or discovery learning approaches (Wilson et al., 2011b; Vine et al., in press). Future research is needed to confirm the clinical utility of gaze training interventions in surgery and to determine whether such interventions are useful in other environments where accurate targeting is important.

Conclusion

The QE has been shown to underpin successful targeting skill performance; differentiating both expertise (inter-individual) and proficiency (intra-individual), with experts and successful sporting attempts characterised by longer QE durations. Recent research has identified that the QE is susceptible to breakdown in demanding and anxiety-provoking circumstances (Wilson et al., 2009) and that QE training may be beneficial for the acquisition (Vine & Wilson, 2010), refinement (Causer et al., 2011b; Vine et al., 2011) and resilient performance (Vine & Wilson, 2011) of targeting skills. While several processes underpinning the QE have been inferred, future research should continue to unpick these processes, potentially through the adoption of neural imaging techniques, and by imposing strict experimental manipulations on the location, duration and timing of the QE.

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