

# GAZE CONTROL DURING THE HITTING PHASE IN TENNIS

Research Proposal

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## **Abstract**

The aim of this study is to investigate the role of the eyes and head position while playing tennis, especially during the hitting phase. Despite coaches and players recognize the importance of the visual side of tennis little research has been done especially during the hitting phase. However, recent observations of Roger Federer and Rafael Nadal suggested that elite players follow a typical and probably optimal visual control process. Elites differ significantly from near elites in having a fixation of long duration on the contact zone until the end of the follow through. The consistency of this visual pattern underlies the concept of gaze control which was developed based on research on visual skill in different sports. The aim of this study is to examine the difference in gaze patterns between elite and near-elite tennis players. To understand and model this optimal visual pattern we need to examine the gaze behaviors in dynamic context, i.e. in on-court conditions. To that end, the gaze behaviour of elite tennis players will be determined as they performed during the different phases of the hitting action. The gaze of elite and near-elite tennis players will be assessed while they performed, wearing an eye-movement helmet that permitted normal mobility in the tennis court. In this study the gaze behaviour of elite tennis players will be analysed as they will perform in on-court conditions. From this study, the near-elite players are expected to use variable form of gaze control in which the gaze is directed either in the fog zone, either in the opponent's court direction. The elite players, in contrast, are expected to use a gaze control with longer fixation durations on the contact zone. The main objective is therefore to explain these observations which depart from current models, in particular to determine in detail the duration and location of tracking and fixation phases of the hitting action what should lead to the definition of the Quiet Eye in tennis.

**Keywords:** Tennis; Vision; Contact; Control; Gaze

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# 1. Introduction

We've all heard the phrase "Watch the ball!" many times. In tennis it is often assumed that, at the very best, everyone can keep their eyes on the ball until the moment that the ball actually strikes the racquet. Thus, player was told to keep his eye on the ball at the moment of impact and keep it there after the impact. Some players even claim they can watch the ball almost to the point of impact.

## Visual limitation

One of the most important tennis skills is one the players often take for granted, vision (Williams, 2000). Looking in the right place at the right time is particularly important in tennis in which a player needs to determine the future trajectory of the ball and the timing of contact with it (Land and McLeod, 2000). However, the players can never see impact – that is, the ball striking the strings of the racquet. This is due to limitations in our ability to track fast objects. Indeed, the human eye is unable to see, or register, the contact of a fast approaching tennis ball with the strings of the racquet (Brabanec and Stojan (2006). That is the great visual delusion of tennis is that one can see the ball at all times and keep it in focus. The optical illusion is called completion phenomenon in which a player believes he sees the ball during its entire flight (Stein and Slatt, 1981). Stein and Slatt (1981) recognized that some players can definitely follow the ball longer than others, they argued that is not productive to track the ball close to the racquet when dealing with a fast ball. It will come as something of a shock since all player have been taught from the first day they ever took a tennis lesson, "Watch the ball hit your strings."

## New paradigm in tennis

Here's probably a totally new perspective on what really happens in tennis. Recent studies showed significant differences for head and eye-head stabilization during the hitting sequence among professional tennis players (Yandell, 2005; Murphy, 2007; Lafont, 2007a, Lafont, 2007b). In brief, these studies suggested that gaze patters of elite tennis players have a specific fixation stage and that head and eyes stabilization on the contact zone has a strong influence on the success of hitting. In addition, these studies suggested a close relationship between head/eye stabilization at and after contact and level of skill expertise. These preliminary studies are beginning to figure out what separates elite players from the rest of the players (elite players were defined as those with consistent results in Grand Slam tournaments, often cited as "great players" (cf. Brabenec and Stojan, 1997).

Over the last century, the tennis has been dominated by an approach that only focused upon **ball-tracking**. This old paradigm posited ball-tracking as the guiding model for hitting excellence. Hence, it is customary for coaches and teacher in tennis to tell their players to hold their gaze on the ball. This advice is given because intuitively, one would think there is a direct link between the ability to maintain fixation on the ball and hitting accuracy. However, a new paradigm is emerging dominated by the possibility to partly suppress vision during the hitting phase and the potential benefits produced by a fixation stage on the contact zone after the impact (during the follow-through).

## Need for hitting phase-centred study in tennis

A weight of evidence is beginning to favour the contact zone focus as relevant visual strategy during the hitting process. However the photo analysis (Lafont, 2007a) highlights the head position but does not provide sufficient accuracy to give the gaze location and duration. Moreover, actual “hit-centred studies” are rare, i.e. few studies have written technically about visual processes in hitting. So, there is a need for experiments focused on the relationship between eye and head of tennis players during the hitting phase.

### Objectives

The main aim in this study is to determine how players coordinate head and eye movements to acquire the necessary visual information for successful performance on the tennis task of hitting. A secondary objective is to obtain gaze data from sample of elite tennis players during hitting in order to highlight the differences with the rest of professional players.

## 2. Research on gaze control in sports

Schmidt (1991) defined **gaze** as “the absolute position of the eyes in space and depends on both eye position in orbit and head position in space.” Usually, the term “**gaze behaviour**” is used when the subject’s head and eye system moves naturally, unlike eye movement recordings where the head is often fixed (Vickers, 1996a,b). Research on gaze control shows that three types of eye movements are used:

- Fixations – gaze is stable on one location or object for minimum of 100 ms within 1 degree of visual angle (e.g. gaze on ball, contact zone, opponent). 100 ms is the minimum time needed to be aware of an object or a location.
- Pursuit tracking – gaze is stable on a moving object for a minimum of 100 ms within 1 degree of visual angle (e.g. gaze follows rolling ball, moving club head).
- Saccades – gaze moves very rapidly between objects and locations. Information is suppressed during saccades (e.g. look from ball to hole, ball to green, ball to shaft, etc.).

Successful performance in interceptive tasks depends upon the acquisition of visual information about the approaching object. An athlete who looks in the right place at the correct time is more likely to predict accurately the ball’s future trajectory and time of arrival. Information on gaze behaviour may, therefore indicate which parts of ball flight are important (Land and McLeod, 2000).

A considerable amount of research has focused on gaze control during the performance of sport skills. Several characteristics of performance have been investigated, including visual search (Bahill and LaRitz, 1984; Haywood, 1984; Abernethy, 1990, 1991), eye-head-arm coordination (Carnahan and Marteniuk, 1991, 1994; Carnahan, 1992).

Also, from a methodological perspective, researchers have progressed from static slide (Bard and Fleury, 1976, 1981) to dynamics film (Helsen and Pauwels, 1993; Williams et al., 1994; Williams and Davids, 1998) and field-based protocols (Vickers,

1992, 1996a; Singer et al., 1998; Land and McLeod, 2000). The collection of data in situ represents an important evolution, since the gaze and motor characteristics observed under laboratory conditions may not provide an accurate reflection of participants' natural behaviour (Williams and Davids, 1998). Moreover, investigations conducted in situ have revealed important mechanisms and strategies involved in the acquisition of visual information.

One of the earliest studies in the field setting was undertaken by Ripoll and Fleurance (1988), who wished to determine whether expert table tennis players follow the coach's instruction to 'keep your eyes on the ball'. The visuo-motor behaviour of five international players was examined as they performed three different strokes (forehand, forehand with top spin and backhand drive). Experts did not track the ball throughout its entire flight path, preferring only to track the ball at the very beginning of its trajectory. The tracking characteristics observed varied according to the type of stroke. The ball was tracked more often and for longer when it moved towards the midline of the body (i.e. backhand drive) compared to when it moved laterally in relation to the body (i.e. forehand and forehand drive with top spin). During the final portion of ball flight, Ripoll and Fleurance (1988) observed the mechanism of **eye-head stabilization**. Before ball-bat contact, between the final ball bounce and the strike, the eyes were stable and aligned with head orientation. The head and eyes were stabilized on the area of ball-bat contact before the ball's arrival.

Land and McLeod (2000) studied the gaze behaviour of cricket players as the ball entered the field of view. They showed that an anticipatory saccade was made and the fovea 'lay in wait' for the bounce and that gaze was kept stable for a period before and after the bounce. The ball was then tracked accurately for at least 200 ms after the bounce, and tracked 'more loosely' on the final part of its flight. The elite players showed more pursuit tracking than the near-elite, using an optimal combination of smooth pursuit and saccadic eye movements to get to the bounce point.

An important point is that neither elites nor near-elites are able to track the ball to contact, supporting other studies on baseball (Bahill and Laritz, 1984), table tennis (Ripoll and Fleurance, 1988) and tennis (Singer et al., 1998).

Abrams et al. (1990) proposed three eye-movement hypotheses that describe the coordination of the gaze when aiming at near targets. In **the position-only hypothesis**, the eyes locate the target and remain fixated through completion of the movement. In this hypothesis, information derived directly through fixation on the target is necessary to complete the movement accurately. In the **movement-only hypothesis**, the eyes move in a coupled fashion with the aiming limb. In this case, information arising from the oculomotor commands or proprioceptive inflow from the eye muscles is needed to ensure the accurate completion of the movement. The third hypothesis, **movement-plus-position**, is a hybrid of the first two.

Thus, different eye-movement strategies can be observed with the level of expertise. The gaze control of expert and lower skilled sports performers has been determined in a number of closed and open skills. In closed skills such as the golf putt (Vickers, 1992) or the basketball free throw (Vickers, 1996a) performers orient their gaze to fixed targets, such as the ball in golf, the hoop in basketball. Skilled basketball players orient their gaze toward the basket sooner and maintain vision in the region of the target longer than do lower skilled individuals (Ripoll et al., 1986). High-skilled golfers fixate the ball throughout the putting stroke, whereas the lower skilled golfers often track the golf club head prior to contacting the ball (Vickers, 1992). Overall,

highly skilled subjects appear to make greater use of information of a critical target location or object, thereby adhering more to [Abrams et al.'s \(1990\)](#) position-only hypothesis. Less skilled individuals shift their gaze to more locations and visually monitor their own movements, the object being aimed, or both, thereby displaying the movement-only or movement-plus-position strategy. Highly skilled subjects display a greater economy of gaze behaviours, recording lower frequencies and longer duration on critical locations in the targeting space.

Studies that require individuals to physically move as their gaze behaviours are recorded ([Helsen and Pauwels, 1993](#); [Ripoll et al., 1985](#); [Ripoll et al., 1986](#); [Vickers, 1992](#)) have found significant differences in the frequency, duration, and location of gaze of experts and non experts.

Although differences in visual behaviour appear to differentiate expert and near-expert or novice performers, eye movement and gaze control research in sport has evolved to where a debate exists over two main issues. There is disagreement about whether the visual search of performers differs because of expertise, as well as whether visual behaviour is a critical factor in superior performance ([Abernethy, 1990](#); [1991](#)).

### **3. Gaze control in tennis**

#### **Previous studies on gaze control in tennis**

Eye movement and gaze control studies in motor skills are beginning to shed some light on the visual behaviour of tennis players. For example, research has shown that different head/eye movement strategies are used depending on the timing constraints in tennis ([Flotat and Keller, 2004](#)). The eye movement of athletes have been measured to determine visual search strategies used in tennis, especially for the anticipation phase ([Mester and von Mares, 1982](#)). However, although these studies have identified important components of performance, eye movement research in tennis is still rather limited and suffers of a lack of on-court studies. In particular, there is a need for sound methodological and experimental studies dedicated to the hitting phase.

In addition, although past studies tried to identify the pattern associated to expert and non-expert, the gaze pattern of elite tennis players has never been highlighted. Thus, a great part of this study will focus on one of things which contribute to the thin separation between elite and near-elite players.

#### **Hypotheses**

Several working-hypotheses can be set from the above considerations on gaze control. In particular, it is hypothesized that the gaze behaviour of elite and near-elite will match one or more of eye-movement hypotheses proposed by [Abrams \(1990\)](#). More specifically, if participants exhibited the *position-only strategy*, they should fixate on the contact zone throughout the movement, with no saccades or tracking behaviours. Alternatively, if subjects use the *movement-only strategy*, shifts should occur in gaze to and from the ball during the preparation phase as well as after the impact. In this case, we should see eye movements "time-locked" with the ball movement. If the *movement-plus position strategy* is used, subjects should use a sequence of gaze

behaviours in which shifts of gaze are found during the preparation phase, followed by a fixation as the hitting action occurs.

## **Near-elite characteristics**

In high-speed photography analysis, there was a profound disparity in the head position during the hitting phase among professional players. While making contact with the ball, most of professionals have their head oriented out ahead of the racket (fig. 1). Moreover, after contact, their head either remain oriented where the ball was last seen clearly or already directed toward the opponent's court. Thus, a sort of head and gaze instability, i.e., a shift of gaze and a more mobile head and gaze during the hitting phase are expected for the near-elite players.

Since, when the racket contacts the ball the gaze moves with the ball. Near-elite players are expected to follow a movement only strategy.

## **Elite player's gaze control**

Significant differences were found for head and eye head position and stabilization between elite and near-elite players. Indeed, it was initially expected that the elite players use the movement-only strategy. That was not what it was suggested by high-speed photo observations. Elite players have developed efficiency in their head movement control during the hitting phase that differs greatly from near-elite and more broadly from the rest of professional players. The elite players maintain a fixation on the contact zone and they don't begin moving their head until they had complete their follow-through (time has to be determined), whereas the near-elite initiated their first head movement often before the hit was delivered (fig. 2 to 5) (Lafont, 2007a, Lafont, 2007b). These observations suggest elite players also use typical eye movements with a significant gaze fixation stage on the contact zone during the follow-through. Thus, from this preliminary investigation elites are expected to use a location-only strategy, maintaining fixation on the contact zone as they completed the hitting action.

## **Location-suppression**

The experimental study should confirm that a great part of the hitting phase is completed under visual suppression. Indeed, fixation onset occurs probably for the elite players as the ball enters their fog zone, i.e. when vision on the ball is suppressed. An analysis of individual fixation onset and offset data should show that elite players do not gain visual information once the ball enters in the fog zone. In addition, preliminary observations suggest the possibility of location-suppression strategy for elite tennis players. As they hit, near-elites have to control their racket/arm, their heads and their gaze. The elites who use the location-suppression sequence of gaze behaviors do not have to control as many systems; by using a location-suppression of gaze behaviors they let each system specialize in turn, the visual first, followed by the motor system.

## **“Dead-eye” gaze**

This fixed, straight-ahead gaze moved toward the contact zone suggests that elite players are following a form of gaze control in hitting named “dead-eye” gaze. It is

well illustrated on figure 5 where Roger Federer's gaze seems to remain fixed. The theory is that spatial analysis for voluntary goal-directed movement (hitting) is only partially a matter of vision and is more importantly the relating by vision, vestibular processes, and proprioceptive body-sense of the state and location of the body in relation to the target for purposes of generating an effective stroke.

The dead-eye gaze pattern generates visual and other spatial-analysis cues in a complementary, synergistic fashion that takes advantage of the underlying neurophysiological processes more effectively than the "common" saccadic gaze pattern. In addition, the pattern eliminates variable signaling during targeting occasioned by the brain having to account for shifting eye positions as well as variable head motions (Bach-y-Rita et al., 1971; Howard and Templeton, 1966; Senders et al., 1978; Wurtz and Goldberg, 1989). This "dead-eye" pattern maintains a steady relation between the eyes and the head at all times.

## 4. Quiet Eye in Tennis

### Quiet Eye

All of these observations could be related to the concept of the Quiet Eye developed by Vickers (2004). Indeed, in an effort to understand how vision can control and guide the body's movements, Vickers showed that elite athletes have a Quiet Eye, which is the ability to detect critical information before the movement must be made. The Quiet Eye is based on the optimum location of the eyes' focus in space, when the eyes begin to focus and when the players' gaze leaves the optimum location. In brief this concept signifies that the athletes don't need to see everything - just the right thing at the right time.

Quiet Eye is determined by eye tracker technique which consists in video record of the displacement of the gaze of the athlete. Essentially, an eye tracker monitors the movement of the eye and head, i.e. the gaze, in order to track where athletes look during play and provide his visual strategy (for a tennis application see Mester and Von Marees, 1982).

Quiet Eye is an objective measure of the location, onset, offset and duration of the gaze recorded while the participant performs a motor skill (Vickers, 1996a, 1996b; Vickers and Adolphe, 1997). It is a period of time when the gaze is stable on spatial information critical to effective motor performance.

The Quiet Eye has four characteristics (Vickers, 2007):

- it is directed to a critical location or object in the performance space;
- its onset occurs before the final movement common to all performers of the skill;
- its duration tends to be longer for elite performers;
- it is stable, confirming the need for an optimal focus on one location or object prior to the final execution of the skill.

Quiet Eye has been shown to be a characteristic of higher levels of skill and accuracy in open interceptive timing skills, where an object moves at high speeds toward the performer, such as the ball in baseball (Bahill and LaRitz, 1984): the highly skilled

performer maintains a longer duration of fixation or tracking on a critical location than those with lower skill.

More precisely, in interceptive timing skills, research shows that different gaze behaviours have been found depending on the predictability of flight of the object. When the object's flight is predictable, there is an early onset of pursuit tracking, followed by a long duration of tracking the ball, which rarely occurs to contact (Bahill and LaRitz, 1984; Ripoll and Fleurance, 1988; Rodrigues et al. 2002; Shank and Haywood, 1987; Vickers and Adolphe, 1997; Vickers et al. 2002; Williams and Ward, 2003).

But in interceptive timing skills where the flight of the object is unpredictable, such as in cricket batting (Land and McLeod, 2000), a different form of gaze control is required that is exhibited only by highly skilled batsmen. There is an early onset of pursuit tracking followed by a rapid anticipatory saccade to the bounce point, and a period of ball tracking before the ball is struck. It is only in this way that the uncertainty of late flight information is handled and effective batting occurs.

## **Quiet Eye in tennis**

Two hypotheses aiming to define Quiet Eye in tennis should be explored.

### **Quiet Eye in the early flight of the ball...**

In tennis, the first part of ball flight is most critical. The ball should be tracked closely as it comes off the opponent's racquet and during the first part of its flight. During the preparation phase a fixation of long duration is needed to adequately set the parameters of the hit, such as the trajectory on the ball, the timing, and the coordination of the limbs, which allow the hitting action to be set up and organized correctly.

In the first part of the ball flight, anticipatory pattern of saccades, the visual search pattern used by athletes, closely matches the motion of the object that is being tracked (Bahill and LaRitz, 1984; Haywood, 1984; Ripoll and Fleurance, 1988). For example, Ripoll and Fleurance (1988) showed that players visually tracked the ball for a mean of 150 ms during regular forehand drives and for 185 ms during forehand drive with top spin. Similarly, Land and McLeod (2000) found that cricketers tracked the ball for 150-200 ms before initiating an anticipatory saccade.

If we defined Quiet Eye as the duration of tracking before the first movement to play the ball, then the location of Quiet Eye in tennis is very early in ball flight. As such, the Quiet Eye is the player last acquisition of ball, opponent and opponent's court information before the hitting movement was initiated. In this case, the elite are expected to differ from the near-elites in having an earlier onset on tracking on the ball and also a longer duration of tracking, which will be defined as the Quiet Eye period.

### **... or Quiet Eye during the follow-through?**

In the case of golf, Vickers (1992, 2004) found that almost all novices follow the ball with their eyes after they hit it whereas the good player maintains fixation on the same location at the point of impact through the swing, forward swing, contact and for almost half a second after the ball is hit (cf. fig. 6).

One can put forward the hypothesis that the same type of characteristics could be observed in tennis. Indeed, Federer looks steadily at the ball and lets his gaze stay

there even after the ball is hit. Hence, Federer provides us valuable information on what should be the Quiet Eye in tennis. More broadly, Federer demonstrates that it is possible to play a great part of tennis without watching the ball, the eyes focused on the contact zone. In a sense, it confirms the work of [Ford et al. \(2002\)](#) about the possibility and benefits of focusing only on the contact zone during the stroke execution.

Despite the previous definition of Quiet Eye in tennis can be applied to the vast majority of tennis players, it doesn't account for the above mentioned observation of a fixation stage during the follow-through. Another definition is needed for elites. General definition specifies that during Quiet Eye, fixation or tracking is maintained on specific location or object in space. From this definition, and if we consider the follow-through as the final movement of the hitting phase, Quiet eye in tennis could be defined as the fixation that occurs on the contact zone – beginning at/prior to impact and continuing during the follow-through. More simply, it is the amount of time that fixation was maintained on the contact zone before the end of the follow-through. It should be noted that this definition supposes that Quiet Eye occurs once the information the player needs to make the hit have been gathered. In addition, the fixation stage characterizing this Quiet Eye occurs only for elite players, whereas it is missing for near-elite and the rest of players who let their gaze move during the hitting process.

This definition of Quiet Eye in tennis can be related to previous research in other interceptive sports ([Bahill and LaRitz, 1984](#); [Ripoll and Fleurance, 1988](#); [Vickers and Adolphe, 1997](#); [Land and McLeod, 2000](#)), participants kept their eyes on the ball early in flight but not during the final portion of its trajectory. Before interception, the participants even maintained a stable gaze on a location in advance of the ball (cf. [Ripoll et al., 1986](#); [Ripoll and Fleurance, 1988](#); [Land and McLeod, 2000](#)). [Land and McLeod \(2000\)](#) even showed that in general elite batsmen do not watch the ball continuously. They have a distinct eye and head movement strategy to view the ball at crucial moment during its flight. Hence, contrary to the coach's advice "keep your eye on the ball," when a ball moves fast, the ball-tracking strategy may not always be possible or appropriate.

## **Hypotheses on the function of quiet eye in tennis**

Despite the processing of quiet eye information has been identified as a potential key to the successful execution of many sport skills, it has never been studied in tennis.

### **Early flight**

When trying to intercept an approaching object, athletes have to deal with the time latency necessary to adjust motor commands based on visual information. Thus, the hitting sequence is a complex skill that requires the integration of visual information mainly gained in the first part of the ball trajectory. [Ripoll and Fleurance \(1988\)](#) and [Land and McLeod \(2000\)](#) showed that the quiet eye period is important in providing information on the ball's trajectory and likely location of bounce and in planning the ensuing motor response. In addition, [Ripoll and Fleurance \(1988\)](#) suggested that eye-head stabilization may facilitate the extraction of information from the final portion of the ball's flight. In tennis, the elite's early fixation may prevent the intake of interfering information from the moving ball in the visual field, and may help to stabilize the ball's image early in flight.

## **Follow-through**

On other hand, Federer's and Nadal's performances, suggest that there are certainly fundamental benefits in adopting the fixation strategy during the follow-through, and support the hypothesis that this is an optimal gaze control pattern. While this alone certainly does not guarantee a optimal hitting pattern (it also depend of footwork, anticipation ... etc), without proper gaze control, it does tend to minimize the hitting performance.

Past research in sport has shown that experts exhibit superior response selection performance (tactical decision making) as well as superior motor skill execution (McPherson and Vickers, 2004). For example, in the model of « ideal athlete » of Nougier et al. (1991), expert athletes show higher attentional focus towards relevant information. Compared to novice, expert focus only on the most relevant information (La Rue and Ripoll, 2004).

Thus, Federer demonstrates that the strategy which consists of focusing on the contact point is an efficient way to use the eyes in a fast-moving ball sport such as tennis. In particular, it eliminates the source of input errors present in the classical visual pattern, i.e. focusing on the ball, and generated by the numerous fixations as the ball traverses along its flight path (continuous refocusing) (Ford et al., 2002).

At this time, it can be hypothesized that the information on the ball trajectory is gathered during the first part of the ball flight, then the fixation stage allow a better integration of the information in order to provide in turn better motor response.

## **5. Research protocol**

Gaze behaviour in tennis can be defined as the manner in which individual moved their heads and eyes to take in available information while preparing and executing the hit. Thus, gaze behaviour will be specified by the frequency, duration, onset and offset of gaze behaviours in the hitting phase.

Here we examine the eye and head movements of tennis players. To date, no study has examined the coupling between head and eye movements during the hitting phase in a realistic and dynamic environment. For this study two areas will be researched: the moment of impact gaze direction and head position and the post-impact gaze direction and head position, both for classical groundstrokes.

### **Participants**

Professional tennis players (elite and near-elite) will be invited to be subjects. The term elite refers to players with consistent results in Grand Slam tournaments. The study could be also extended to lesser skilled tennis player and novice.

### **Recording gaze of a tennis player**

In order to fully understand how vision is used during the hitting phase, it is necessary to know what player looks as they complete the stroke. A live protocol where the athlete's eye movements are recorded as they hit will be used. The aim is to acquire the athlete's gaze in contexts very like those experienced in games.

The analysis of the hitting skills of tennis players can be conducted using an optoelectronic system, especially using an eye tracking system adapted for use in motor skills. Thus, gaze data will be collected using the mobile helmet based on an eye tracker. This is a corneal reflection system that measures eye-line-of-gaze with respect to the helmet. This technology permits the participant near-normal mobility.

It is a lightweight helmet outfitted with two miniature cameras and a visor that looks like clear glass but acts like a mirror to the cameras (recently simplified to a headband-like apparatus with a monocle visor). This system measures the positions of two features of the eye: the pupil and the corneal reflex (CR). The CR is the reflection of a small helmet-mounted light source from the surface of the cornea. By measuring both features the system can accurately measure eye-line-of-gaze with respect to the helmet. The eye camera (mounted on top of the helmet) is directed at the eye via the reflective visor. The eye is illuminated by near infrared light source. The illuminator (which is invisible to the participant) retroreflects from the retina, producing an image of a backlighted bright pupil rather than a dark pupil.

When the gaze is recorded in such live setting, the vast amount of information available in the performance environment is ignored in favour of fixations or tracking gaze to specific locations (Patla and Vickers, 1997; Ripoll and Fleurance, 1988, Vickers, 1992; Vickers, 1996b, Williams et al., 2002). Thus, using the eye-movement tracker technology, it is possible to monitor precisely what the eyes focus on, and for how long.

## **Vision-in-action coupling**

The vision-in-action system (Vickers, 1996a,b) integrates a mobile eye tracker with an external camera that assesses participants' eye and body movements, a time code generator and two video mixers that couple participant's gaze, motor and ocular behaviour. The eye tracker is interfaced to the external video camera and to the digital video mixers to produce the frame of video data.

The first camera focuses on the center of the pupil and the corneal reflex, which is the reflection of a small light source on the cornea. The corneal reflection is produced by a small helmet-mounted infrared light source. The second camera records the player's gaze, which is indicated by a cursor. The location of the gaze is accurate to less than 1 degree of visual angle. Last, a third camera is positioned to record the player's movements at the same time.

Thus, a portion of the frame is recorded by the scene camera attached to the helmet and shows the participant's location of gaze relative to the environment. Location of gaze is indicated by a cursor. Another portion of the frame shows the participant performing the tennis task as recorded by the external camera. In this way, both the subject's gaze and his movements were monitored simultaneously with all three images sequenced allowing to record what the eye, gaze and stroke are doing for a given time lapse.

## **Procedures**

To examine the limits of head and gaze stabilization, the ball will be presented under different temporal conditions, which progressively reduced the amount of time available to execute arm action (slow, fast, very fast). Thus, gaze behaviours will be

recorded during the execution of a tennis forehand/backhand stroke under these different spatial and temporal constraints.

After a warm-up, players will be tested in one control condition. Players' gaze patterns will be recorded whilst they performed groundstrokes. The patterns of ball flight produced by the opponent should be quite consistent. To that end, an experienced tennis player should hit using the same effect and velocity for each trial. In order to examine in detail the gaze behaviour, the hitting phase should be divided at least in three movements: **The preparation phase**, before the ball-racket impact; **The hitting phase** which begins with the frame showing the first motion of the ball from the racket; **The flight phase** which begins with the frame after the ball left the player's racket until the ball went into the opponent's court, or hit the net. By recording throughout the hitting action, it will be possible to determinate the mean duration of the each movement phase (preparation, backswing, follow-through).

## **Dependent variables**

During data collection, the video allows to examine visual search and movement simultaneously. In the present study, gaze and head behaviours should be recorded simultaneously and two variables should be identified: quiet eye and eye-head stabilization at contact and after contact.

### **Quiet Eye duration and location**

There are two important aspects to the quiet eye: location and duration, which can be measured with eye-tracker technology and the vision-in-action system.

If it is assumed that Quiet Eye is defined as the duration of fixation on the contact zone, the Quiet Eye onset may occur before the impact and the offset is usually defined by a gaze deviation off the location by more than  $3^\circ$  of the visual angle for a minimum of 100 ms (the minimum duration required for visual information extraction is 100 ms, [Vickers, 1996a,b](#); [Vickers and Adolphe, 1997](#)).

### **Eye-head stabilization**

Eye-head stabilization was defined as the stable alignment of the eye and head before contact ([Ripoll and Fleurance, 1988](#)). For eye-head stabilization to occur, the visual angle between line of gaze and the x-axis of the transmitter coordinate system had to remain stable.

## **6. Summary**

This study is primarily an exploration into the visual facets of tennis – especially into the area of gaze control during stroke production. The study is placed in the context of recent research showing a shift of the gaze from the ball to the contact zone until the end of the hitting movement for the elite tennis players: the player fixate the contact zone for a significantly long duration. In summary, the major objective of this study is to flesh out and examine the tennis' advice "keep your eye on the ball" that people have been repeating since years and years without really understanding. More specifically, the purpose of this study is to determine how tennis players control their

gaze when hitting the ball. To that end, eye-tracker technology now permits to work in dynamic conditions. Thus, it will be possible to document several effective body, head, and eye movement strategies for tennis. In particular, the introduction of the concept of gaze control, and more specifically the Quiet Eye should provide a background as to how this specific skill can help tennis players to optimize the hitting process.

Some fundamental questions emerge from these considerations on gaze patterns in tennis:

- Do the gaze fixation and head motion are coincident until the end of the follow-through?
- Does the eye stabilization is initiated before ball-racket contact?
- Do they elite players allocate the same mean durations to each gaze, independent of type of stroke?
- Does this skill have a decisive role?
- How to train this skill?

We can hope that several new findings will emerge from the exploration of these different issues, and will increase our understanding of the effects of spatio-temporal constraints on visual information acquisition during the hitting phase in tennis.

## 7. Future lines of research

Several directions for future research emerge especially toward mental skills connection, cognitive analysis, method of training and learning, all of which allowing a better understanding of **the Quiet Eye in tennis**.

### Tennis and psychology

I have suggested ([Lafont, 2007c](#)) that fixation during the hitting phase may favour mental skill such as concentration, control, confidence, all mental skills need for peak performance in tennis.

In hitting as well as in other hand-eye-target skills, the Quiet Eye is emerging as an indicator of optimal focus and concentration. The relationship between Quiet Eye and attention control is an important issue. Indeed, can we say that when an athlete's gaze is focused on a specific location that their visual attention is also directed there as well? The question of whether the location of the gaze is an indicator of visual attention has been debated since it became possible to record eye movements. Especially influential was a study by [Posner \(1980\)](#), who provided evidence that it is difficult to equate the location of the gaze with the location of attention. But recently, new evidence has emerged showing that a shift in gaze to a new location is invariably preceded by a shift in attention, either before or during the saccade.

Another issue is the assessment of stress and anxiety on gaze behaviour (see [Williams et al, 2002](#) for a table tennis study on the effect of anxiety) . It can be expected that, the Quiet Eye would stabilize player's gaze as they hit through the reduction of uncertainty, ambiguity and fear. Hence, Quiet Eye could be complete the existing mental routines mainly dedicated to between-point time.

## **Cognitive study**

Quiet eye provides the information the motor system needs to get organized and perform optimally. If Quiet eye is a critical factor in the organization of the neural structures underlying hitting in tennis, then experimental reduction of this time should result in a decrease in performance. Conversely, an increase to optimum in Quiet eye duration should improve performance. By studying how the elite players become exceptionally accurate in skills like hitting we will be able to understand more fully the contribution of the higher neural systems and visual attention networks in motor control.

Moreover, [Crews \(2004\)](#) demonstrated differences in brain activation between good and poor golfers. Similarly, it should be possible to examine the brain activation and cognitive states create by gaze control during the hitting phase in tennis (despite the dynamical nature of the hitting process in tennis may constitute a limitation). In particular, an interesting issue is whether the brain activation and the cognitive states recorded during the fixation are comparable to those recorded in flow states or zone defined by [Jackson and Csikszentmihalyi \(1999\)](#)? At this time [Ford \(1984\)](#) and [Ford et al. \(2002\)](#) suggested that fixation could promote flow in tennis, but it never has been demonstrated. More recently, [Vickers \(2007\)](#) argued that the oneness of quiet eye information puts the athlete in the zone more often.

## **Training Quiet Eye in tennis**

Finally, the vast majority of the best players are not aware of visual judgments they must make. They play the game properly but have little insight into the role of their eyes and limitation of vision. Thus, a perspective of this study is to determine a training method of Quiet Eye in tennis.

In addition, as the Quiet Eye of elite players differs significantly from that of the lower skilled, this information could be used for training purposes. Indeed, once defined what is Quiet Eye in tennis it should be possible to develop the modelling and setting of pertinent visual strategy.

For example, the method proposed by [Lafont \(2007d\)](#), which emphasizes the fixation of the contact zone until the end of the follow-through, needs to be developed. The key is to get out of the usual gaze routine and to develop the fixation routine used by elite players. It could be possible once Quiet Eye will be well defined in tennis.

## **Biomechanics**

More research is needed to study the biomechanical effects of head and eye control. Quiet eye probably contributes to better balance, therefore to better technical skills.

## **Other applications**

More broadly, what will be found in tennis may be applied in other racket-sports concerned with head and eyes fixation on the contact zone. For example, it seems that elite players in squash show similar fixation stage during the hitting phase (fig. X). The same sort of fixation stage can be observed in hitting task in closed sports as golf (fig. 7) or baseball (fig. 8).

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**Fig. 1.** Examples of top player's moments of impact. Their head and eyes are not directed toward the contact zone.



**Fig. 2.** Federer's backhand at impact



**Fig. 3.** Federer's backhand after impact



**Fig. 4.** Federer's forehand at impact.



**Fig. 5.** Forehand after impact.



**Fig. 6.** Moment of impact in squash.



**Fig. 7.** Tiger Wood.



**Fig. 8.** Baseball.