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Visual Scanning in Sports Actions: comparison between Soccer Goalkeepers and Judo Fighters

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Abstract

Visual search and oculomotor behaviour are believed to be very relevant for athlete performance, especially for sports requiring refined visuo-motor coordination skills. Modern coaches believe that a correct visuo-motor strategy may be part of advanced training programs.

In this thesis two experiments are reported in which gaze behaviour of expert and novice athletes were investigated while they were doing a real sport specific task. The experiments concern two different sports: judo and soccer. In each experiment, number of fixations, fixation locations and mean fixation duration (ms) were considered. An observational analysis was done at the end of the paper to see perceptual differences between near and far space.

Purpose: The aim of the judo study was to delineate differences in gaze behaviour characteristics between a population of athletes and one of non athletes. Aspects specifically investigated were: search rate, search order and viewing time across different conditions in a real-world task. The second study was aimed at identifying gaze behaviour in varsity soccer goalkeepers while facing a penalty kick executed with instep and inside foot. Then an attempt has been done to compare the gaze strategies of expert judoka and soccer goalkeepers in order to delineate possible differences related to the different conditions of reacting to events occurring in near (peripersonal) or far (extrapersonal) space.

Judo Methods: A sample of 9 judoka (black belt) and 11 near judoka (white belt) were studied. Eye movements were recorded at 500Hz using a video based eye tracker (EyeLink II). Each subject participated in 40 sessions for about 40 minutes. Gaze behaviour was considered as average number of locations fixated per trial, the average number of fixations per trial, and mean fixation duration.

Soccer Methods: Seven (n = 7) intermediate level male volunteered for the experiment. The kickers and goalkeepers, had at least varsity level soccer experience. The vision-in-action (VIA) system (Vickers 1996; Vickers 2007) was used to collect the coupled gaze and motor behaviours of the goalkeepers. This system integrated input from a mobile eye tracking system (Applied Sciences

Laboratories) with an external video of the goalkeeper's saving actions. The goalkeepers took 30 penalty kicks on a synthetic pitch in accordance with FIFA (2008) laws.

Judo Results: Results indicate that experts group differed significantly from near expert for fixations duration, and number of fixations per trial. The expert judokas used a less exhaustive search strategy involving fewer fixations of longer duration than their novice counterparts and focused on central regions of the body. The results showed that in defence and attack situation expert group did a greater number of transitions with respect to their novice counterpart.

Soccer Results: We found significant main effect for the number of locations fixated across outcome (goal/save) but not for foot contact (instep/inside). Participants spent more time fixating the areas in instep than inside kick and in goal than in save situation. Mean and standard error in search strategy as a result of foot contact and outcome indicate that the most gaze behaviour start and finish on ball interest areas.

Conclusions: Expert goalkeepers tend to spend more time in inside-save than instep-save penalty, differences that was opposite in scored penalty kick. Judo results show that differences in visual behaviour related to the level of expertise appear mainly when the test presentation is continuous, last for a relatively long period of time and present a high level of uncertainty with regard to the chronology and the nature of events. Expert judoist performers "anchor" the fovea on central regions of the scene (lapel and face) while using peripheral vision to monitor opponents' limb movements. The differences between judo and soccer gaze strategies are discussed on the light of physiological and neuropsychological differences between near and far space perception.

1. Introduction

1.1 Visual Perception in Sports

Considerable debate has taken place concerning the role of vision in sports. Vision is the signal that directs the muscles of the body to respond. Vision provides the athlete with information regarding *where* and *when* to perform (Erickson 2007).

Vision involves two basic categories of function: visual motor and visual perceptual skill. Visual motor skill is probably the easiest category to relate to sport-specific performance. If athletes can not move their eyes quickly and effectively, they can not perform sport-specific tasks optimally. In fact, one of the primary differences between good and elite level athletes, other physical skills being equal, is that elite athletes can move their eyes more effectively and efficiently for the duration of the game. There are three basic ocular motor skills used in the visual motor system, they are vergence, focusing and tracking. Consider the ocular motor skills needed to read this thesis: first, both eyes have to converge, that is, their view must cross, to see each word. Next, the eyes have to focus equally to make the words on the page clear. Finally, the eyes have to track from word to word to understand the text. Now consider the similar sequence on the field of play. It is important for the eyes to be able to converge (or cross) as the ball comes toward the athlete or diverge (or uncross) as it goes away. It is also necessary for the athlete to be able to focus on the target smoothly through space. Tracking is the ability of the eyes to follow an object from one point to another. Tracking is done with two separate categories of eye movement. The first is pursuit eye movement, which is the ability of the eye to smoothly follow an object through space, as when a wide receiver follows the ball from the release by the quarterback into his hands. The second category is saccadic eye movement, which is the quick jump of the eyes from one point to another (Wilson 2004).

Oculomotor function is an aspect of the perceptual mechanism in information processing and can include evaluation of pursuit eye movements, saccadic eye movements and steadiness of fixation. The ability to initiate a pursuit eye movement to maintain fixation of a rapidly moving object can be critical aspects for allowing visual processing of crucial information in sports. The ability to initiate an accurate saccadic eye movement to shift fixation from one location to another is also an essential aspect of many sports tasks. Athletes have not demonstrated shorter latencies for the initiation of pursuit or saccadic eye movements (Deshaies 1976; Bahill 1984; Kukla 1993); although if a target trajectory is predictable, shorter latency periods can be learned for these eye movements (Whittaker 1982; Elmurr 1997). The quality of pursuit and saccadic eye movements in athletes, however, has been found to be better than in nonathletes (Trachtman 1973; Christenson G.N. 1988; Hofeldt 1993). In precision sports such as target shooting, skilled athletes demonstrated better ability to maintain steady fixation despite distractions (DiRusso 2003).

The visual search patterns of experts compared with novices during specific sports demands have been the focus of many studies. The study paradigms typically used attempt to discriminate differences in the number of fixations to determine the amount of information assessed by the observer and differences in the duration of fixations to determine the amount of time expended to collect the visual information from each specific fixation. Most studies have found that experts have a lower number of fixation for longer durations than do novices during the viewing of specific sports situations (Bard 1976; Ripoll 1986; Vickers 1992; Vickers 1996; Vickers 1997; Piras 2010).

Processing of information from the peripheral visual fields is a universally beneficial element to successful sports performance, whether is to monitor teammates and opponents or maintain steady balance. Results indicate that athletes have a larger extent of horizontal and vertical visual fields than nonathletes (Williams 1976; Berg 1995) and that athletes have better form recognition at more peripheral locations (Christenson G.N. 1988; Kukla 1993). The restriction of peripheral vision has also been found to increase the latency and accuracy of head movements during eye movement localization tasks, as well as significantly degrading balance ability, therefore, peripheral sensitivity also appears to be enhanced in athletes (Erickson 2007).

The perception of depth has generated a considerable amount of interest relative to visual performance. The relation between depth perception abilities and athletic performance was a logical correlation to explore because many sports tasks require judgments of spatial localization. Several studies have demonstrated that binocular vision can improve performance on certain tasks compared with performance by individuals using only one eye (Savelsbergh 1992; Graydon 1996).

The visual attention demands for an athlete can be primarily central (e.g., target shooting), peripheral (e.g., seeing the release of the clay pigeons in skeet shooting), or split between central and peripheral processing (e.g., the kicker in soccer seeing the goal and goalkeeper while simultaneously monitoring the movements of teammates and opponents). Peripheral vision can be argued to be relevant in almost every sport because it is a critical element of balance maintenance. Therefore, even in predominantly central processing sports such as target shooting, archery and baseball, peripheral processing is a performance factor. However, in this types of sports situations the attentional focus is predominantly central, and processing of extraneous peripheral information can degrade performance (Erickson 2007).

In some sport situations, the time factor exceed the human capacity to process the important visual information before initiating a motor phase, so the motor response must be initiated with anticipation of the most likely scenario that will unfold. For example, in a penalty shot in hockey, the puck can cross the goal line within approximately 100 ms of being struck. The typical simple visual reaction time is approximately 150 to 200 ms; therefore the goaltender can not wait until the puck has been hit to predict the trajectory of the shot (Erickson 2007).

Sports researchers have adopted a study design used with chess in which experts were able to recall more structured chess positions from brief exposures than non experts (Chase 1973). However, the experts did not exhibit superior recall when presented with unstructured chess position, suggesting that the superior recall of experts was the result of task-specific experience rather than exceptional memory abilities. The same results have been found when speed of recognition has been evaluated in athletes using numerical stimuli rather than sport-specific stimuli (Christenson G.N. 1988). These same structured versus unstructured recall differences between experts and novices have been found with athletes in various team sports, including basketball (Allard 1985), field hockey (Starkes 1987) and football (Garland 1990).

The information from the perceptual and decision mechanisms concerning the space time behavior of critical factors in fast action sports should contain the vital information necessary for the motor responses to occur at the proper time and location. For successful performance, the motor responses must also be sufficiently adjustable to allow modification on the basis of continuing input from the perceptual and decision mechanisms as the sport action continues (Erickson 2007).

Visual motor reaction time refers to the amount of time that elapses between the initiation of a visual stimulus and the completion of a motor response to that stimulus. The effector mechanism is responsible for translating the processed information to the neuromuscular system, which sends the information to the muscles that need to be stimulated to make the appropriate motor response. The measure of a simple reaction time (RT) reflex represents the minimal amount of time required to process a visual stimulus presentation and perform a simple motor response to that stimulus. The assessment of simple RT maybe the most direct method of evaluating the effectors mechanism because the requirements of the perceptual and decision mechanism are minimal. Several studies have found faster simple RTs in athletes, and it has been demonstrated to be a discriminator between expertise levels (Kukla 1993; Kioumourtzoglou 1998).

1.2 Origins of eye movement research

As Andrè Du Laurens (1596) so eloquently indicated, eye movements can provide windows to the mind, but it is not this aspect of their action that has excited researchers. After all, such a statement does not address the question of how the windows move. Eye movements have also been enlisted as a theoretical tool in support of empiricist philosophy. George Berkeley (1685-1753) proposed that muscular action, including eye movements, was essential in learning the third dimension of visual space (Wade 2005).

The origins of eye movement research have been accorded to a number of researchers. Boring (1942) suggested that the monograph by Johannes Muller (1801-1858) published in 1826 marked the onset of systematic studies. Carmichael (1926), on the other hand, argued that the article by Charles Bell (1774-1842) in 1823 was a more appropriate starting point. Bell (1823) described the muscle sense (or proprioception as Sherrington later called it) and distinguished by experiment the consequences of active and passive eye movements on visual direction. Because of his works linking the sense and their muscular attachments to brain function, Bell has been called the father of physiological psychology (Wade 2005).

Muller published two books on vision in 1826: one was on comparative physiology in which he gave detailed descriptions of eye position following eye movements; the other was on subjective visual phenomena that had been investigated by Jan Evangelista Purkinje (1787-1869). Eye movements were one of the many topics examined by Purkinje in his first book and he discussed them in the context of vertigo and strabismus in his second book. A decade later, Muller provided a more extensive survey of vision in his *Handbuch der menschlichen Physiologie*; this book was translated into English as *Elements of Physiology* and it has recently been reprinted (Muller 2003). One of the earliest areas of research to be generated by the discovery of the saccade-and-fixations strategy and the proliferation of eye movement research at the start of the twentieth century was the question of how our smooth and complete visual experience might arise from the discontinuous input supplied by the eye. Dodge and Holt debated the mechanism that might underline the suspension of vision during saccades and this question remained throughout the twentieth century and was the topic of much research and interest (Wade 2005).

An important recent development in eye tracking technology has been to produce device that are portable and thus can be worn under less constrained experimental conditions than most eye trackers. Portable eye trackers allow eye movement research to extend outside the laboratory and for the researcher to investigate the role of eye movements in real world activities. This real world experimentation represents a crucial component of the advancement of our understanding of vision in everyday life (Wade 2005).

1.3 Eye Movements

Eye movements place the image of things that interest us on the fovea, the part of the retina with the highest acuity. Since our eyes (and retinas) are attached to our heads, the greatest threat to clear vision during natural behaviour is head perturbations, especially those that occur during locomotion. If we had no eye movements, images of the visual world would "slip" on the retina with every such head movement. This would cause our vision to become blurred and our ability to recognize and localize objects to be impaired whenever we moved through the environment. To this end, two distinct mechanisms evolved to stabilize image on the retina in general, and the fovea in particular, during such head perturbations. The first comprises the vestibular-ocular reflexes, which depend on the ability of the labyrinthine mechanoreceptors to sense head accelerations. The second consists of visually-mediated reflexes (optokinetic and smooth pursuit tracking), which depend on the ability of the brain to determine the speed of image drift on the retina. Together, these reflexes stabilize the angle of gaze, so that the fovea of each eye remains pointed at the object of regard whenever the head is moving.

Eye movements are of two main types: those that stabilize gaze and so keep images steady on the retina, and those that shift gaze and so redirect the line of sight to a new object of interest (Leigh 2006). They are:

- Vestibular: holds image of the seen world steady on the retina during brief head rotations or translations;
- Optokinetic: holds image of the seen world steady on the retina during sustained head rotation;

- Visual Fixation: holds the image of a stationary object on the fovea by minimizing ocular drifts;
- Smooth Pursuit: holds the image of a small moving target on the fovea; or holds the image of a small near target on the retina during linear self-motion; with optokinetic responses, aiding gaze stabilization during sustained head rotation;
- Nystagmus quick phases: reset the eyes during prolonged rotation and direct gaze towards the oncoming visual scene;
- Saccade: bring images of objects of interest onto the fovea;
- Vergence: moves the eyes in opposite directions so that images of a single object are placed or held simultaneously on the fovea of each eye.

The vestibular system stabilizes gaze and ensure clear vision during head movements, especially those that occur during locomotion. The vestibulo-ocular reflex (VOR) generates eye movements to compensate for head movements at a latency of less than 15 ms, whereas visually mediated eye movements are initiated with latencies greater than 70 ms (Leigh 2006). The vestibular system can respond to movements that have angular (rotational) or linear (translational) components, the angular VOR depends on the semicircular canals. If a subject is rotated in darkness at a constant velocity, the slow phases of vestibular nystagmus, which are initially compensatory, decline in velocity and , after about 45 seconds, the eye become stationary and visually mediated eye movements can serve this function, because sustained responses do not require a short latency of action. Visually mediated eye movements also supplement the translational VOR, when the visual scene is close to the subject. In this case, smooth-pursuit eye movements are important, because they allow steady fixation of a small, near target, the position of which changes with respect to the background, as the subject translates. If we view distant objects, no eye movements are needed to compensate for head translation but, no matter what the viewing distance, eye movements are always needed to compensate for head rotations.

Here I will deepen saccade and fixation eye movements.

1.4 Saccades

Saccades are rapid eye movements that shift the line of sight between successive point of fixation (Leigh 2006). Saccades include a range of behaviours that encompass voluntary and involuntary shift of fixation, quick phases of vestibular and optokinetic nystagmus, and the rapid eye movements that occur during REM sleep. Saccadic eye movements consist of a hierarchy of behaviour, from the most rudimentary of all saccade – quick phases of vestibular nystagmus during passive rotation in darkness – through reflexive saccades made in response to the sudden appearance of a novel visual stimulus, to high level volitional behaviour such as saccades directed toward the remembered location of a visual target. The saccade do not last much longer than 100 ms, which is the response time of the visual system, this means that visual feedback cannot be used to change the size of a saccade once started (Leigh 2006). The relation between peak velocity and amplitude and duration and amplitude can be used to define ranges for normal saccades. There is a linear relationship between amplitude and peak velocity, above 20°, peak velocity shows a progressive "soft" saturation with asymptotic values of about 500 degrees per second. A common used equation to describe the main sequence relationship is:

$$\text{Peak Velocity} = \text{Vmax} \times (1 - e^{-\text{amplitude}/C})$$

where Vmax is the asymptotic peak velocity and C is a constant (Leigh 2006). The duration of saccades are approximately linearly related to their amplitudes from movements from 1 to 50 degrees. Saccade speeds and durations cannot be voluntarily controlled. Another measurement of saccade, which is related to the velocity waveform, can be calculated from the ratio: peak velocity/mean velocity (Q) (Harwood 2002). In humans, Q is about 1.6 and holds even for slow saccades made by fatigued subjects and some disorders of saccades.

During saccades, rotational velocities of up to $600° s^{-1}$ can be reached. Saccades are a family of ballistic eye movements with durations and peak velocities varying according to the amplitude of the rotation. For any particular amplitude of rotation, saccades show stereotyped position profiles, durations, and velocity profiles. The high velocities reached during saccades ensure that their duration is kept very short, ranging from approximately 30 ms for a 5° movements to 100 ms for 40° saccade. In this way the period of visual disruption resultant from saccadic eye movements is minimized. During saccades the observer is effectively blind owing to limitations of photoreceptor response time course and to active suppression of the visual pathways during these eye movements.

1.4.1 Neurophysiology of saccadic eye movements

In Primary Visual Cortex (V1, Brodmann area 17), the location of a visual stimulus is represented by the distribution of activity on the surface of the cortex: different parts of this cortical map correspond to different location on the retina. The neural representation of the motor command for the saccadic response by brainstem neurons is quite different. The ocular motoneurons encode the characteristics of the saccade in terms of their temporal discharge; the size of the saccade is proportional of the total number of discharge spikes. The ocular motoneurons lie in the third, fourth and sixth cranial nerves and cause the extraocular muscles to move the eyes with respect to the head (that is, in craniotopic coordinates). This means that the brain must transform the stimulus, which is encoded in terms of the location of active neurons within visual cortex (i.e. “place-coded”) into the saccadic command on ocular motoneurons, which is encoded in terms of discharge frequency and duration (i.e. “temporally coded”). Furthermore, a transformation from retinal coordinates into craniotopic coordinates is necessary (Leigh 2006).

Two types of neurons are critical components of the brainstem network that generates premotor commands for saccades: *burst* neurons and *omnipause* neurons. For horizontal saccades, burst neurons within the paramedian pontine reticular formation are essential, for vertical and torsional saccades, burst neurons within the rostral interstitial nucleus of the medial longitudinal fasciculus play the equivalent role. Omnipause neurons lie in the nucleus raphe interpositum, in the midline of the pons (see fig. 1). They discharge continuously except immediately before and during saccades, they cease discharge during saccades in any direction and during blinks, and their discharge rate is modulated by static vergence angle (Leigh 2006).

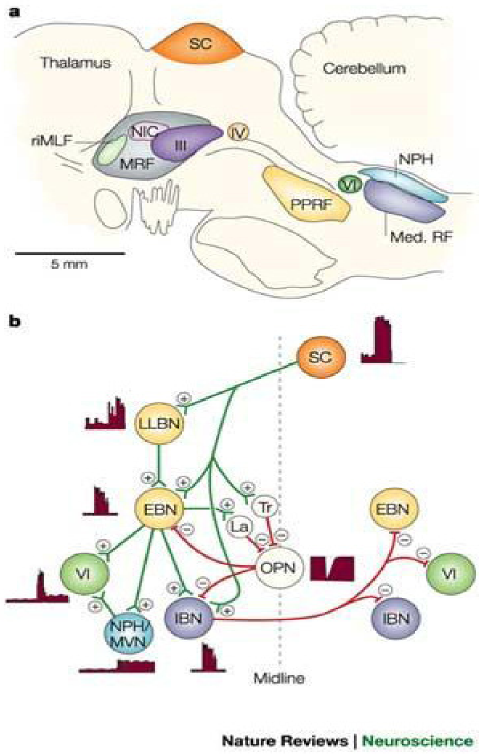


Figure 1. A: Drawing of the brainstem of a monkey: III, oculomotor nucleus; IV, trochlear nucleus; VI, abducens nucleus; Med. RF, medullary reticular formation; MRF, midbrain reticular formation; NIC, interstitial nucleus of Cajal; NPH, nucleus prepositus hypoglossi; PPRF, paramedian pontine reticular formation; riMLF, rostral interstitial nucleus of the medial longitudinal fasciculus; SC, superior colliculus.
B: A diagram of the connections of the cell types that are crucial components of models of the horizontal burst generator: VI, abducens motor neuron; EBN, excitatory burst neuron; IBN, inhibitory burst neuron; LLBN, long-lead burst neuron; NPH/MVN, cells in nucleus prepositus hypoglossi or medial vestibular nucleus; OPN, omnipause neuron; SC, superior colliculus. Note the crucial role of the OPNs. These cells inhibit the EBNs, which innervate the motor neurons, and the IBNs, which inhibit motor neurons that innervate antagonistic muscles. Saccades are initiated by a trigger signal (Tr) that inhibits the OPNs. The OPNs are prevented from resuming their tonic discharge during the generation of the saccade command by the activity of 'latch' neurons (La), inhibitory interneurons that relay an inverted output of the EBN burst. © 1996 Elsevier Science.

1.5 Fixations

Visual fixation of a stationary target may represent a special case of smooth pursuit-suppression of image motion caused by unwanted drift of the eyes, but it might be also due to an independent visual fixation system (Leigh 2006). To see a stationary object, its image must be held steadily upon the fovea. For clear vision of higher spatial frequencies, motion of the image should be less than about 5 degrees per second and the image should lie within 0.5 degrees of the center of the fovea (Carpenter 1991). During natural activities, the major threat to steady fixation comes from perturbations of the head (Grossman 1988). However, even if the subject's head is stabilized using a bite-bar, gaze is still disrupted by involuntary eye movements (Martinez-Conde 2004). The gaze instability during attempted fixation is more prominent in the torsional than the horizontal or vertical planes. It has three main components: a high frequency low amplitude tremor, small saccades, and slow drifts. The frequency of the tremor ranges up to 150 Hz and its amplitude is less than 0.01 degrees, which corresponds to less than the size of one photoreceptor (Kowler 1991).

During fixation stability is not absolute, small movements of the eye do occur, they undergo high frequency, low amplitude tremors onto which are superimposed slow drifts and rapid flicks or microsaccades. The small saccades, called microsaccades, are typically less than a third of a degree in amplitude, occur in all directions, and follow the main-sequence, like large saccade. Microsaccades can be suppressed during visual tasks that demand steady fixations, such as threading a needle, or sighting a gun (DiRusso 2003). They may also be influenced by attention shifts (Hafed 2002).

When a subject views a stationary target with the eyes close to center position, the slow drifts that occur during attempted fixation are small. When the eyes move away from the central to an eccentric position in the orbit, gaze-evoked nystagmus may develop because stability of gaze becomes susceptible to elastic restoring forces due to the passive properties of the orbital contents (Leigh 2006). During vision of the stationary target, any slip of images on the retina due to ocular drifts stimulates the brain to generate eye movements that will counter the drifts, and hold gaze steady. This response to drift of images upon the retina caused by instability of gaze during active fixation has been referred to as slow control, or a field-holding reflex (Epelboim 1993).

Although monocular cues such as motion parallax and overlay of contours be used to derive a sense of an object's distance, stereoscopic vision is necessary for an accurate perception of the third dimension, especially in the space around us in which we use our hands. Both stereopsis and bifoveal fixation of a single object of interest require precise alignment of the visual axes. Because of the horizontal separation of the orbits, each eye receives a slightly different image of an object. These dissimilar retinal images allow creation of a three-dimensional percept, stereopsis. For single vision to be derived from the inputs of the two eyes, however, the images of an object of interest must fall on corresponding retinal points, allowing for sensory fusion, the perception of an object seen by both eyes as single (Tyler 1991). The visual angle over which images can be separated, and still be perceived as one, is called Panum's area (Leigh 2006). If the two images of an object fall on non-corresponding retinal areas in each eye, then that object is simultaneously localized in two separate visual directions, causing double vision, or diplopia.

1.5.1 Neurophysiology of Visual Fixation

One line of evidence that fixation differs from smooth pursuit comes from electrophysiological studies in monkey. Thus, certain parietal lobe neurons discharge during steady fixation but not during smooth pursuit of a moving target and it seems important in the engagement and disengagement of fixation. There is also evidence for a mechanism to suppress both saccade and pursuit during attempted fixation. Microstimulation of parts of the frontal eye fields, and the rostral pole of the superior culliculus, will suppress or delay the initiation of a visually triggered saccade. Stimulation of the rostral pole of the superior culliculus, which seems important for fixation, also suppresses ipsilateral smooth pursuit movements; pharmacological inactivation increases ipsilateral pursuit. Thus, the electrophysiological properties of both the saccadic and the pursuit systems are changed during fixation of a stationary target, suggesting the influence of an independent, visual fixation system. There is also evidence from behavioural studies that visual fixation differs from smooth pursuit. Most such studies (Leigh 2006) have focused on differences between smooth pursuit of a moving target, and the eye movements that occur just after the target comes to a halt. In the later case, retinal image slip is due to eye motion rather than target motion, and the function is therefore equivalent to visual fixation. During smooth pursuit of a moving target, and especially at the onset, small ocular oscillations may occur. These oscillations are usually absent or minor after the target for pursuit comes to a halt suggesting that different mechanisms are involved in fixation than in pursuit. Other attempts to identify an independent fixation system have involved comparisons of the dynamic properties of visually mediated eye movements when the eye are either stationary or engaged in pursuit. First, the latency to onset of express saccades using the gap paradigm, in which the fixation light is turned off before the new target is displayed, is approximately the same whether the target is stationary (fixation) or moving (pursuit) (Leigh 2006). Thus, the trigger for these saccades does not recognize the differences between fixation and pursuit.

To summarize the evidence: on the one hand, a fixation mechanism has been demonstrated for the suppression of saccades; this mechanism depends on known structures, such as the rostral pole of the superior culliculus. On the other hand, it is still debated as to whether retinal image motion is reduced by a separate fixation system when the target is stationary and by smooth pursuit when the target is moving.

1.6 The retinotopic representation of the visual field and the Primary Visual Cortex

Each eye sees a part of visual space that defines its visual field. For descriptive purposes, each retina and its corresponding visual field are divided into quadrants. The vertical line divides the retina into nasal and temporal divisions and the horizontal line divides the retina into superior and inferior divisions. Corresponding vertical and horizontal lines in visual space (also called meridians) intersect at the point of fixation (the point in visual space that the fovea is aligned with) and define the quadrants of the visual field. Objects in the temporal part of the visual field are seen by the nasal part of the retina, and objects in the superior part of the visual field are seen by the inferior part of the retina. With both eyes open, the two foveas are normally aligned on a single target in visual space, causing the visual fields of both eyes to overlap extensively. This binocular field of view consists of two symmetrical visual hemifields (left and right). The left binocular hemifield includes the nasal visual field of the right eye and the temporal visual field of the left eye; the right hemifield includes the temporal visual field of the right eye and the nasal visual field of the left eye (see fig.2). The temporal visual fields are more extensive than the nasal visual fields, reflecting the size of the nasal and temporal retinas respectively. As a result, vision in the periphery of the field of view is strictly monocular, mediated by the most medial portion of the nasal retina. When the axons in the optic tract reach the lateral geniculate nucleus, they terminate in an orderly map of the contralateral hemifield (albeit in separate right and left eye layers).

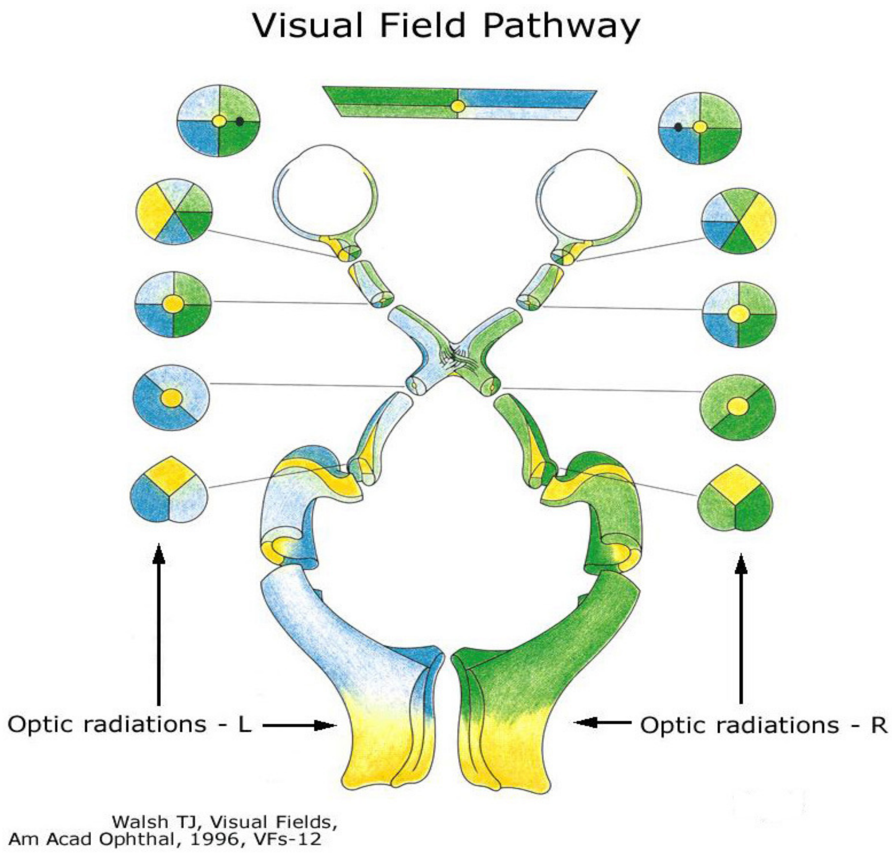
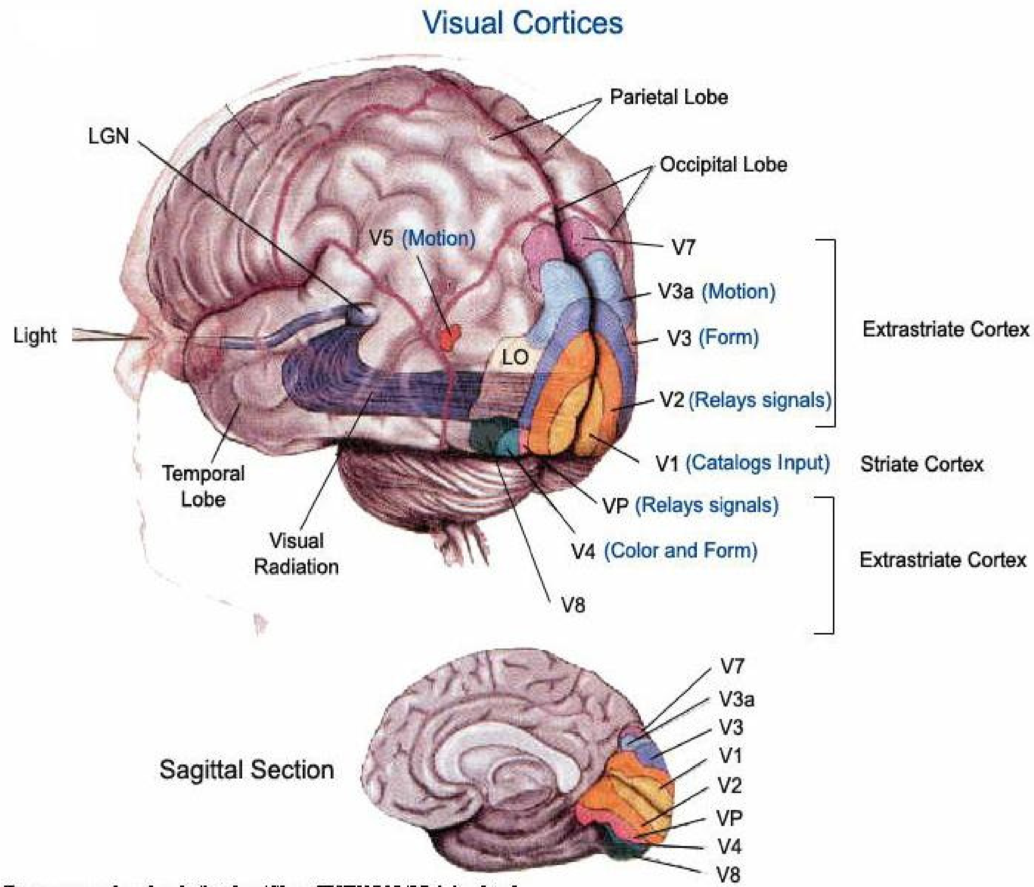


Figure 2. Human Visual Pathway begins with the eyes and extends through several interior brain structures before ascending to the various regions of the visual cortex (V1). At the optic chiasm the optic nerves cross over partially so that each hemisphere of the brain receives input from both eyes.

The fovea is represented in the posterior part of the striate cortex, whereas the more peripheral regions of the retina are represented in progressively more anterior parts of the striate cortex (see fig. 2).

Studies in the macaque monkey indicate that about half of the cortex is involved in visual processing (Tong 2003), and about 90% of projections from the eyes are channelled through the lateral geniculate nucleus (LGN) to V1 (see Fig 3). From V1, information is disseminated to various extrastriate visual areas for further analysis. Areas such as V4 and MT project directly to visual areas in the parietal and frontal lobes that are implicated in attention, working memory and motor planning. In V1, neurons are selective for orientation, motion direction, binocular disparity, colour, contrast, spatial frequency and ocular dominance.V1 therefore provides many feature analyses of the visual scene at a fine scale before selective aspects of this information are channelled to more specialized areas that comprise the dorsal - and ventral stream pathways.



From www.colorado.edu/intphys/Class/IPHY3730/07vision.html

Figure 3. The primary visual cortex, V1, is located in and around the calcarine fissure in the occipital lobe. Each hemisphere's V1 receives information directly from its ipsilateral lateral geniculate nucleus. Each V1 transmits information to two primary pathways, called the dorsal stream and the ventral stream. The dorsal stream begins with V1, goes through visual area V2, then to the dorso-medial area and visual area MT (also known as V5) and to the posterior parietal cortex. The dorsal stream, sometimes called the "Where Pathway" or "How Pathway", is associated with motion, representation of object locations, and control of the eyes and arms, especially when visual information is used to guide saccades or reaching. The ventral stream begins with V1, goes through visual area V2, then through visual area V4, and to the inferior temporal cortex. The ventral stream, sometimes called the "What Pathway", is associated with form recognition and object representation.

Two forms of visual processing have been identified, dorsal and ventral (Milner 1995). The dorsal stream is the pathway that conducts signals from the occipital cortex to the parietal lobe and is responsible for orienting the gaze and substaining attention at one location (Posner 1994). It is also know as the *where pathway* because it directs attention to location in space. The ventral stream is the pathway that conducts signals from the occipital cortex to the temporal lobe, it is also know as the *what* stream and it is associated with the cognitive processing of information and higher cognitive processes. The ventral stream is responsible for assigning meaning to objects and events, and it guides the anticipation and planning of actions. The dorsal and ventral stream are closely associated with the somatosensory cortex, which is located at the top of the head between the parietal and motor cortices, it is responsible for the sense of touch, pressure and feeling capacities that are extremely important in all forms of movements.

1.7 Vision-in-action paradigm

Two research methods, called the visual search and vision in action paradigms, have been developed to study the contributions of vision and gaze to motor performance (Vickers 2007). When the visual search paradigm is used, videotapes or other pictorial stimuli are shown to athletes as their eye movements are recorded. These studies have the advantage of showing the same stimuli to all participants, but the major limitation is that the motor behavior is rarely performed at the same time. Motor responses are limited to pressing a key, moving a joystick, stepping on a mat, or similar movements. The visual search paradigm is an observer paradigm, and it does not explain the relationship between control of the gaze and motor success and failure within realistic sport contexts. In contrast, researchers who use the perception action paradigm (Bard 1976; Bahill 1984; Ripoll 1988) record the performers' gaze as they perform in contexts that are similar to those encountered in the real world. More recently, the vision in action paradigm (Vickers 1992; Vickers 1996; Williams 2002) has evolved to the point where the gaze and motor behavior are recorded simultaneously as sport tasks are performed in situ, making it possible to objectively determine which gaze and attention characteristic are associated with successful and unsuccessful performance.

The visual search paradigm is older of the two paradigms and dates back to the beginning of psychology (James, 1890/1981). It has a long history of use in reading, art, mathematics and chess, and for the past 20 years it has also been used extensively in sport (Vickers 2007).

The vision-in-action paradigm (Vickers 1996) differs from the visual search paradigm in several way. First, an athlete's gaze is recorded as he or she physically performs in a manner that is very similar to that found in the sport; therefore, there is always a coupling of perception and action. Second, the athlete performs a well-know sport task that, whenever possible, as published international standards of achievements. In this way athletes can be grouped into skill categories based on objective standards of achievement. Third, the athlete performs the task until an equal number of successful and unsuccessful trials are accomplished.

In vision-in-action studies, the nature of the task and the athletes determine the field of view as the task is performed. The orientation of the head and gaze therefore exists as a function of both the task and the skill level of the athlete. The gaze is recorded in three dimensional space; therefore the participant's gaze behaviors are studied over the full length, breadth and deep of the visuomotor workspace.

It was not until the 1980s that researchers were able to record the eye movements of athletes in the live sporting setting. Bard & Fleury (1981) recorded the eye movements of elite and novice ice hockey goaltenders on ice using an eye tracker that did not permit any movement of the head. A plexiglas shield was placed in front of the goaltender for safety, and fixation were determined relative to the shooter's body, stick or puck. A trial ended when the goaltender made a movement with the glove hand or stick, signifying when a stopping action might occur in a game. The results showed that although both experts and novices focused the majority of their fixations on the puck and stick, the gaze of the expert goaltenders were more consistent than the gaze of the novice goaltenders across both the slap and wrist shot. The experts were also faster in initiating a response than the novices. Ripoll et al. (1982; Ripoll 1986) carried out two studies in basketball shooting. Their focus was to not only determine expertise differences, but also gaze differences during hits and misses. They found that expert shooters oriented their head towards the basket sooner and maintained their gaze in the region of the hoop longer than did non expert players. One of the main characteristics related to both expertise and accuracy was the rapidity with which the visual acquisition of the target was achieved. The elite shooters looked to the target sooner and then took more time to anchor the head in terms of eye-head stabilization before shooting. No significant differences were found in the duration of eye movement.

Bahill & LaRitz (1984) recorded the gaze of baseball players as they tracked a ball that was pulled toward them using the pulley device. The results showed that the players tracked the ball using a combination of head and eye movements as the ball approached. The professional players tracker the ball longer than the others and used an anticipatory saccade on some trials, where his gaze raced ahead of the ball to the point of ball-bat contact.

Ripoll et al. (1985) recorded the gaze of five international elite pistol shooters and compared their gazes with five national level near elite shooters. The near elite shooters shifted their gaze, arm and weapon as a unit to the target, while the elite shooters first fixated the target and then brought the pistol into line with the gaze before aiming and pulling the trigger. The national level shooters were slower aligning the arm and gun, but they took less time fixating the target once in position. The elite shooters used the opposite strategy, they brought the weapon quickly to the target and then took more time to aim and complete the shot.

Vickers (1992) recorded the gaze of high skilled golfers and low skilled golfers as they performed 3 m putts on a flat surface. The high skilled fixed the hole longer and used slow saccades of about 500 ms between the hole and ball. They did not spot-sight along the green and direct two to three fixations to the hole and then to the ball or club, with saccade linking the fixations. During the stroke, they maintained a steady fixation on the top or back of the ball. This final fixation occurred in 93% of all putts. For elite golfers, there were no fixations on the club-head as it moved through the backswing into the foreswing. At contact, the quiet eye remained on the putting surface for upward of 250 ms. In contrast, the low skilled golfers had a higher frequency of gaze , shorter fixations on the hole and faster saccades between the hole and ball, and they often used spot-sighting, fixating on the green along an imaginary line between the ball and hole. The final fixation was significantly shorter and their often tracked the club on the backswing, resulting in the gaze being off the ball at contact in 31% of trials. Irrespective of skill level or accuracy, the final fixation was a significant determiner of both accuracy and skill and had a duration that began before the backswing and was maintained at this location until after ball contact.

The vision in action paradigm was used in this study, recording the performers' gaze as they carried out in contexts that are similar to those encountered in the real world, in a manner that was very similar to that found in sport. The athletes were grouped into skill categories based on objective standards of achievement due to the colour of the belt. The same procedure was followed in soccer study.

1.8 Control of the gaze and visual attention

Posner (1980) quotes a Wundt's comment on the ability to separate the line of fixation from the line of attention. Natural language refers to the ability to look out of the corner of our eyes, and athletic coaches instruct their players to do so in order to confuse their opposition.

The behavioural evidence that attention can be shifted with eyes fixed, together with results showing enhancement of evoked potentials and of the firing rates of single cells, eliminates the idea that attention and eye movements are identical systems. These findings led Wurtz and Mohler (1976) to propose that attention shifts were programmed for the movement of the eyes. Posner (1980) quotes a Klein's comment on describing this view as follows: "When attention to a particular location is desired, the observer prepares to make an eye movement to that location.

Posner (1980) compared binocular viewing with conditions in which only the left or right eye viewed the stimulus. When the two stimuli occurred simultaneously, with binocular viewing there was no movement bias, but with monocular viewing subjects moved their eyes 80% of the time in the direction of the temporal visual field.

When we perform a motor task, the vast amount of information normally available in the environment is ignored in favour of specific information that is processed to the exclusion of all else. Skilled performers have learned to control their gaze so that the optimal information is perceived or attended to at the right time.

A comprehensive theory that explain how the billions of features are registered and then bound together into objects and locations is *feature integration theory*, as proposed by Treisman and Gelade (1980) and Treisman (1999). When an object is fixated, the stimulus properties are encoded into separate neural pathway, each of which generates a feature map for colour, orientation, size, distance, stereo distance and other factors. Selected features from these maps are then integrated into a master map where one object or location among many becomes the *spotlight for the attention* and pops out more than anything else.

Visual attention plays a central role in the control of saccades, a key finding in research about visual attention is that the orientation of attention can differ from the orientation of gaze position. In this case, the term covert attention is frequently used to indicate this separation, which is typically implemented in experimental condition of attentional cueing (Posner 1980).

The study of Engbert & Kliegl (2003) suggested that microsaccades can be exploited to map the orientation of covert visual attention by analyzing their directional distributions as a new measure to study the dynamics of allocation of visual attention.

A specific functional role for microsaccades could not be demonstrated (Engbert 2003), in particular because microsaccades can be suppressed voluntarily without training in high-acuity observational task like threading a needle or rifle shooting (Steinman 1967; Winterson 1976; Bridgeman 1980). Microsaccades, or tiny movements that take place during periods of fixation, are ballistic movements and create small linear sequences embedded in the trajectory, they occur at a rate of 1-2 per second (Ciuffreda 1995).

Also Hafed and Clark (2002) studied microsaccades, thinking that may be they are an overt measure of covert attention. Covert attention shifts have been shown to cause activation of the superior culliculus (SC), a structure in the brain responsible for saccade generation (Wurtz 1996).

1.9 Role of Eye Movements in Various Sporting Tasks

The ability to predict the arrival of an object or stimulus at a designed place can be measured with a motor response and is referred to as visual coincidence anticipation. A substantial body of research addresses the many factors that influence the impressive human ability to perform the complex visual-motor tasks encountered in sports. To hit or catch an approaching ball successfully, the athlete must judge the spatial information of height, rightward or leftward displacement and distance of the ball. In addition to these three-dimensional space judgments, the temporal aspect of time to contact must be calculated with exacting precision. Several visual cues are available to assist the athlete in making these judgments, including retinal image and disparity information. Some neurons in the visual cortex are tuned to binocular retinal image disparity, providing information about the depth position of an object (Barlow 1967). The differences in retinal locations for the ball have seen by the right eye and left eye constitutes binocular disparity, supplying the stereoscopic perception of relative distance (Regan 1991). In addition, evidence indicates that a system of binocular driven cortical neurons sensitive to motion in depth are separate from the position in depth system (Poggio 1981). The perception of motion in depth is also produced by a changing retinal image size information system that operates relatively independent of the changing retinal disparity system (Regan 1979). Ample evidence shows that human beings possess cortical neurons that are selectively sensitive to changing image size and that this “looming” detectors provide a significant amount of information for judging time to contact even under monocular viewing conditions (Regan 1978).

The retinal information concerning changing disparity and changing size is sufficiently accurate to judge time to contact with a ball; however, it does not provide exact information concerning the actual distance of the ball or its speed (Bahill 1993). Stereoscopic depth perception from calibrations within the vergence system and from motion in depth information provides precise information about relative depth but not about the exact distance location (Von Hofsten 1976). Ocular vergence information is notoriously unstable when the vestibular signals must contend with a freely moving head (Steinman 1982), and changes in vergence angle or changes in absolute disparity do not affect binocular fusion or the perception of motion in depth for images beyond a few meters when independently altered (Regan 1986). Comparison of binocular and monocular performance of a table tennis hitting task revealed that only stroke consistency was affected under monocular viewing, not accuracy or movement time (Graydon 1996).

All these informations from our body can help us to achieve in the best manner the sport task. Our studies were done with binocular (judo) and one with monocular (soccer) device. In judo the athletes had to judge spatial information regarding distance from the opponent paying attention to stay inside the maths (tatami) to avoid disqualifications. In soccer, goalkeeper has to judge spatial information about displacement of the ball without forgetting his position on the line of goal to avoid that the ball crosses this line. The visual system utilises techniques that maximise efficiency in game situations.

2. The Judo Study

2.1. Introduction

Judo is not a static task demanding sport in which the visual information is in motion, necessitating the constant processing of changes in the visual information.

Many sports have dynamic visual features that need to be rapidly processed by the athlete to determine the best motor response. These sports often require the athlete to balance attention between central and peripheral information for optimal performance. These types of dynamic reactive sports can be distinguished from other type of team sports in which central visual information for some aspects is often less important than peripheral information. Performance in combative sports such as boxing, fencing, martial arts and wrestling rely on responsiveness to peripheral visual information more than resolution thresholds for central vision. Therefore assessment of peripheral awareness and reaction factors is more important than visual acuity measurements (Erickson 2007).

The judgment of depth is a crucial factor in all the dynamic reactive sports listed, necessitating an assessment of the pertinent visual factors that contribute to accurate depth perception. In addition, an assessment of speed of recognition is valuable in all these sports because athletes are required to process visual information rapidly to determine the best motor response.

Judo is a modern Japanese martial art and combat sport, where the aim is to either throw one's opponent to the ground, immobilize or otherwise subdue one's opponent with a gripping manoeuvre, or force an opponent to submit by joint locking the elbow or by applying a choke.

Grappling is a mode of fighting used by many different martial arts around the world, it is a collection of techniques and strategies aimed at defeating an opponent. A gripping strategy is much more than which power hand you prefer to use. Your gripping strategy, the way you manage your hands, shoulders, hips and footwork, is nothing less than your chosen method of controlling the attacking space.

A considerable amount of research has focused on gaze control during the performance of sport skills in a field-based protocols (Vickers 1992; Vickers 1996; Singer 1998; Land 2000). All these researches have focused on ball tracking, there are no studies in literature on eye movements in sports fighting except those published by Kodokan and the studies of Mark Williams & David Elliott (1999) about anxiety and visual search strategy in elite karate fighters, and Ripoll, Kerlirzin, Stein & Rein (1995) in French Kick boxers.

In this study the gaze behaviour of elite and near elite judokas was analyzed as they attacked or defended by the grip performed in two standardised situations: lapel or sleeve. From ancient time the aspect of the eyes during judo has been considered important and was termed “Metsuke” (Matsumoto Y., Ikai M. et al. 1969).

In the study of Matsumoto Y. et al. (1969), an investigation was made into the visual fixation point of the Judo referees umpiring a match. They observed that in the most experimental subject, both trained and non trained referees, at the beginning, they fixed their eyes on the upper half of the bodies of the Tori (person performing the technique) and Uke (person receiving the technique), however, at the time that the technique was effected the line of vision moved to the Uke. All subjects fixed their eyes on the hands of the Tori at the moment of performing the technique, instead, at the moment the technique was effected, the eyes were fixed on the thrown Uke. The line of vision of the well trained referees, moved rapidly to the anticipated position of the fall of the Uke, when the Tori began to perform the technique. This shift was accomplished approximately 0,7 seconds before the technique was effected. The basic movement of the eyes at the time of performing the technique is to fix the eyes on the hands or the upper part of the bodies of the Tori and the Uke immediately prior to and following execution of the technique, in most cases, the visual fixation point suddenly shifted downward in order to observe the condition of the thrown Uke. In a few cases the eyes were fixed on the lower part of the bodies of the Tori and the Uke and then from the moment of execution of the technique the visual fixation point shifted to the thrown Uke. This type was common to both groups, the well trained referees were quicker to shift their visual point to the anticipated position of the fall of the thrown Uke.

The aim of the present study was to set how players utilise gaze behaviour to obtain the important visual information in attack and defence situation for successful performance on judo fight.

2.2 Methods

2.2.1 EyeLink II Eye Trackers: Binocular Vision

Most modern eye trackers are corneal-reflection systems that record the participant's eye movements on video using a camera mounted on a headband or glasses. Corneal reflection eye trackers direct a small, bright spot on the cornea of the eye while at the same time the optics of the system determine the center of the pupil. Since the position of the corneal reflection remains constant relative to the headband but the center of the pupil moves whenever the eye moves, the system is able to measure the difference between the center of the pupil and corneal reflection, and from this is determines the points of regard. The scene camera, also mounted on the headband or glasses, provides a video of what the athlete is looking at.

EyeLink II (SR Research Ltd, Mississauga, Canada), eye movement system, was used to collect visual search data (fig 4). The system consists of two miniature cameras mounted on a leather-padded headband with respect to a scene camera by computing the relative positions of the pupil in relation to the optics, location of gaze was indicated by the cursor (blue cross).

Figure 4. EyeLink II eye movements system consists of two miniature cameras (A) mounted on a leather-padded headband computing the relative positions of the pupil in relation to the image recorded by a scene camera (B).

The scene camera thus appears to “see” the world from the same position as the subject’s eyes and parallax problems are avoided (Vickers and Adolphe 1997). The entire system was designed to be lightweight (~ 420g) with a low center of mass for stability and minimal rotational inertia, all of which contribute to subjective comfort and low fatigue. Pupil tracking is performed at 500 samples/s, gaze resolution <0,005° and noise was limited at <0,01°. Data were superimposed as a cursor on the scene camera image, highlighting the participant’s point of gaze. The data sampling rate was 30 frame/s.

2.3 Design of the Study

2.3.1 Subject recruitment

Participants were 9 experienced (4 female and 5 male, M = 26.89 years, SD = 6.68) and 11 less experienced judoists (9 female and 2 male, M = 23.64 years, SD = 1.80). The experienced judoists had been playing judo for an average of 16 years in a national level. The less experienced judoists were students at the Faculty of Exercise and Sports Sciences in Bologna and they had been playing judo for 14 hours and received a white belt. They were all recreational players and they did not ever play any combat sport.

All Participants had normal or corrected to normal vision and they gave their informed consent prior to take part in this study.

2.3.2 Vision in Action Data

The athlete‘s gaze was recorded in a real-sport situation and they were grouped into skill categories based on objective standards of achievement due to the colour of the belt. The athletes perform the task, subdivided in attack (lapel, sleeve) and defence: lapel attack (LA), sleeve attack (SA), lapel defence (LD) and sleeve defence (SD). The test contained 40 randomized trial which were decided throughout a program and two monitor placed behind the athletes. When one athletes saw “attack lapel or sleeve” the other saw “defence” and vice versa.

The orientation of the gaze and head therefore exists as a function of both the task and the skill level of the athletes. The gaze was recorded in three-dimensional space, therefore the participant’s gaze behaviors was studied over the full length, breadth and depth of the visuo-motor workspace. Since the ability to handle the depth is important in all sports, the vision in action approach reveals how the athletes acquire information in all three dimensions (Vickers 2007).

The trial began when the referee said “Hajime” to the athletes and finished when one of athletes grasped the lapel or the sleeve of the opponent and the referee said “Matte”. All participants competed against Emanuela Pierantozzi (silver medal in Barcelona 1992; gold medal in Atlanta 1996; bronze medal in Sidney 2000) and she was informed to behave in a manner similar to a match situation. Prior to mounting the eye-tracker headband, a silicon swim red cap (fig. 5) was fit on the subject’s head to ensure positional stability (Turano 2003).

2.3.3 Experiment

Before the tests, the athletes did a individual general warming for about 10 minutes in which they were free to do what they wanted, then, they did a grip low intensity warming for twice 30 seconds separated by 1 minutes of recovery, and at the end, they did a test simulation with helmet to try the comfortably of the headband.

The system was initially calibrated and validated with a 9-point reference grid presented approximately 80 cm in front of the participant, and drift correction works by computing and applying a corrective offset to the raw eye-position data. Gaze accuracy was maintained by having participants fixate constant reference points before and after trial, and if it was inaccurate we made again calibration, validation and drift correction. The cable, connecting the receiver's head-mounted system, was embedded to reduce potential interference of the wires during the fight. None of the participants reported that these procedures interfered in any way with their normal movements or vision.

When the apparatus was ready the experiment started, the subject stayed on a regular judo mats in front of Emanuela Pierantozzi (Fig 5).

Figure 5. Procedure of Judo study showing gaze image (A), motor image (B) and gaze cursor (C). In the motor image, with Blue Judogi Emanuela Pierantozzi, and with White Judogi the participant who is wearing the silicon swim red cap and the EyeLink II.

2.3.4 Calibration

Calibration is used to collect fixations on target points, in order to map raw eye data to gaze position. Targets are presented for the participant to fixate on the display PC while feedback graphics are presented to the experimenter on the display. The calibration is automatically checked when finished, and diagnostics given. Calibration is performed when the subject keeps the head still and look consequently 9 (or less or much, depend from the study) points grid showed in a random order in a black background.

2.3.5 Validation

The validate screen displays target positions to the participants and measures the difference between the computed fixation position and the fixation position for the target obtained during calibration. This error reflects the gaze accuracy of the calibration, so that validation should only be performed after calibration. In a validation, targets are presented on the subject display in random order, similar to the calibration procedure. When the subject fixates these, the calibration is used to estimate the gaze position of the subject, and the error (difference between target position and computed gaze position) is estimated.

2.3.6 Depth Regulation

When a participant is fixating on a target at an uncalibrated plane, the cross of the cursor maybe drawn at a different position from where the participant intends to look at. This error is caused by the difference in the viewing angles between the scene camera and the eye (i.e., parallax error). Therefore a depth correction following calibration is critical for any experiment involving viewing targets at different viewing depths. For a calibration that is done close to the participant, the second point of the depth correction should be placed at a point in the calibrated space that is distant from the participant , and vice versa. As a rule of thumb, collecting 4-5 points across various depth planes should be sufficient for a good depth correction.

2.3.7 Drift Correction

The drift correct screen displays a single target to the participant and then measures the differences between the computed fixation position during calibration / validation and the target. This error reflects headband slippage or other factors, which are then corrected for by the measured error. A drift correction will be performed at the beginning of each trial. It is important that before performing a drift correction the subject be instructed to sit still and fixate on the drift correction target carefully. It is also possible to perform an online drift correction in the middle of trial recording by the experimenter. A reference position for drift correction could be defined when the subject looks at a particular point across trials.

2.4 Analysis of Visual Search Data

The data were encoded through a software (EyeLink Data Viewer, SR-Research, Mississauga, Ontario, Canada) that allows the display, the filtering, and the presentation of results. The analysis was carried out on the data from the right eye only.

A fixation was defined as a condition in which the eye remained stationary (1° visual angle) for a period ≥ 3 video frames (100 ms). Fixations detected using our criterion were initially cross-checked by visual inspection of the eye-on-scene movies. The frames of the scene movie that correspond to each identified fixation will be referred to as “fixation frames”. By definition, each fixation is associated with a minimum of three fixation frames.

Three thresholds were used for saccade detection: motion, velocity and acceleration. The velocity threshold is the eye movement velocity that must be exceeded for a saccade to be detected. A velocity threshold of 22 degrees per second allows detection of saccades as small as 0.3°/sec ideal for smooth pursuit and psychophysical research. Eye-movement acceleration was set to 4000°/sec^2 and saccade motion threshold was set to zero for detecting duration, amplitude and velocity of the saccades.

Blinks are the period of time where the pupil is missing. Blinks are always embedded in saccades, caused by artifactual motion as the eyelids progressively occlude the pupil of the eye and such artefacts were eliminated. Any short (less than 120 millisecond duration) fixations that precede or follow a blink were eliminated; these may be artificial or be corrupted by the blink.

Trial onset was held constant and occurred three seconds prior to the contact of the hand (grasp) with the opposite judogi. Seven fixation locations (Pierantozzi 2008) were identified: lapel, sleeve, jacket skirt, hand, face, legs and another area called “other” (any other location). In Pierantozzi et al.(2008) the intention was to analyze the time between hajime and the first grip, number of kumi kata fights and the Judogi percentage area of first grip through the video analysis of fights in a high level competition (world championship finals 2007). The aim was to know how much is relevant the first grip in judo fighting and data analysis showed that the majority of first grips is on the lapel area, both for female and male.

2.4.1 Search rate

This measure was comprised of the average number of fixation locations, average number of fixations and mean fixations duration per trial (in milliseconds). As in previous research (Williams 2002), *fixation location* was comprised of the average number of fixation in each location per trial. A fixation was defined as the eye remained stationary within 1° of visual angle and for at least 3 frame video (100 ms) (Panchuk and Vickers 2006).

Each search rate measure was analyzed separately using a two-way ANOVA in which skill (Expert/Novice) was the between-subjects factors and Situation (LA, LD, SA, SD) the within-participants variable.

2.4.2 Search Order

This variable was defined as the average frequency with which a combination of successive gaze behaviour was observed on each trial (i.e., fixations immediately prior to or following the current fixation). Initial analysis was performed descriptively using a series of transition matrices. Two variables were subsequently analyzed using separate one-way ANOVA, with skill (expert/novice) as a between-participants factor and the variables were the number of transition between all interest areas (lapel, sleeve, jacket skirt, legs, hand, face, other)(Williams 2002). The data were divided in attack and defence situation.

2.4.3 Perceptual Viewing Time

This measure was the percentage of time spent fixating on each area of the scene that was divided in six interest areas: Label, Sleeve, Wrist-Hand, Jacket-Skirt, Leg and Face. A further "unclassified" category was included to account for those fixations that did not fall within any of the above areas. Fixation locations were classified, frame by frame, objectively, by superimposing scan paths over the dynamic display. Fixation location referred to the areas of the display on which the eye fixated when a participant was attempting to anticipate an opponent's attack or attacking himself. This analysis provide percentage values for the mean time spent per trial fixating in each of these locations. Data were analyzed using a factorial analysis of variance in which fixation location (face, jacket skirt, lapel, legs, sleeve, hand and other) and Condition (LA, LD, SA, SD) were the within participant factors and skills (expert/novice) the between participant factors (Williams 2002). Mauchly's sphericity test were used to validate repeated measures factor ANOVA. Sphericity relates to the equality of the variances of the differences between levels of the repeated measures factor and which, exactly, requires that the variances for each set of difference scores are equal. Degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity altering the significance value of the *F*-ratio. There are different opinions about the best correction to apply. A good rule of thumb is to use the Greenhouse-Geisser estimate unless it leads to a different conclusion from the other two or if epsilon is >0.75 , use the Huynh-Feldt correction, if epsilon is <.075 use Greenhouse-Geisser correction.

2.5 Judo Results

Search rate

The means group scores for each variable area presented in Table 1. There was a significant group main effect for fixation duration $F(1, 720) = 5.65$, $p = .01$) (fig. 6) and number fixations per trial $F(1, 720) = 19.56$, $p = .00$) (fig. 7). The expert judoka used a less exhaustive search strategy involving fewer fixations (M = 3.7 vs. 4.1) of longer duration (M = 760.03 vs. 701.84 ms) than their novice counterparts. Mean number of fixation locations per trial (fig. 8) was not significant (p = .08) although we found the same condition with judoka as above mentioned (M = 3.3 vs.3.5). Bonferroni post-hoc test showed significant differences between SD and SA in mean number of fixations per trial.

Group	Condition	Mean Fixation Duration	Mean Number of Fixations	Mean Number of Fixation Locations
	LA	744.06 (325.17)	3.98 (1.31)	3.58 (0.16)
	LD	690.06 (339.37)	4.12 (1.31)	3.25 (0.16)
	SA	626.18 (301.61)	4.51 (1.31)	3.78 (0.16)
NE	SD	747.06 (307.62)	3.79 (1.31)	3.29 (0.16)
	LA	731.03 (295.65)	3.65 (0.14)	3.33 (0.18)
	LD	761.95 (378.55)	3.68 (0.14)	2.88 (0.18)
	SA	754.70 (361.84)	3.75 (0.14)	3.36 (0.18)
E	SD	792.44 (447.81)	3.60 (0.14)	3.50 (0.18)

Table 1. Mean fixation duration, number of fixations and number of locations fixated per trial across Expert (E) and Novice (NE) groups in different conditions (LA = lapel attack; LD = lapel defence; SA = sleeve attack; SD = sleeve defence) (mean ± s).

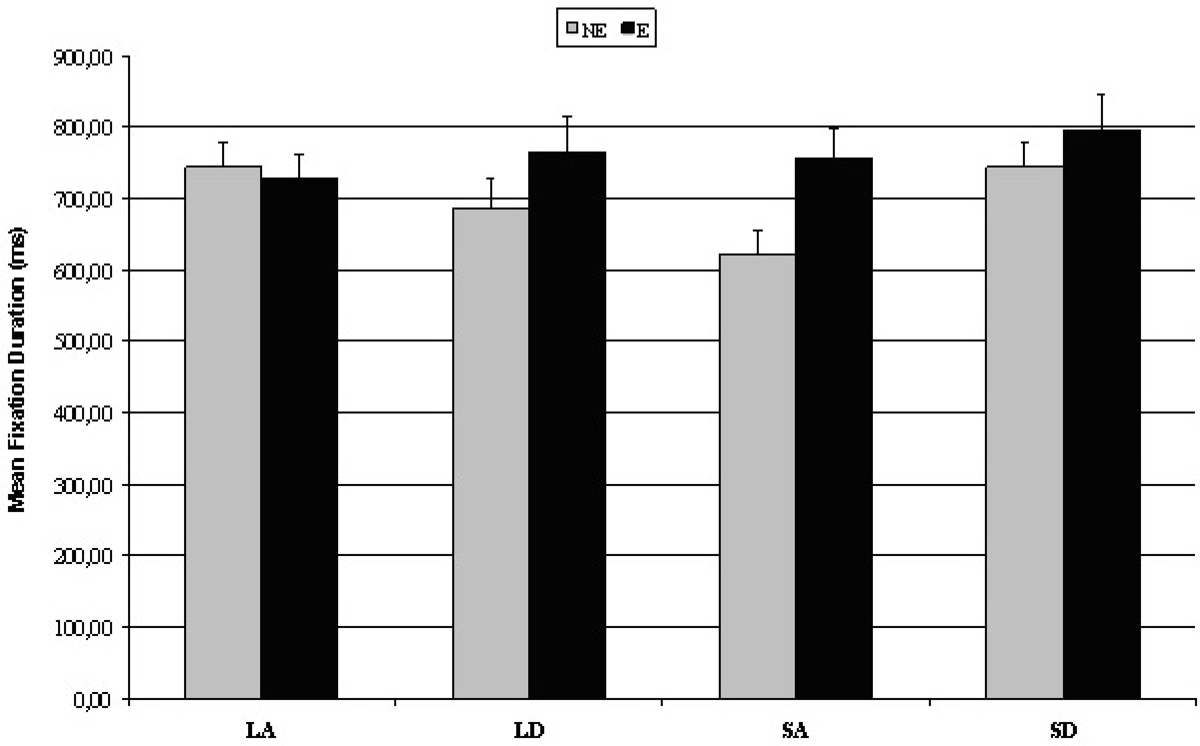


Figure 6. Mean (± se) fixation duration per trial in different conditions across group (E = experts; NE = novices).

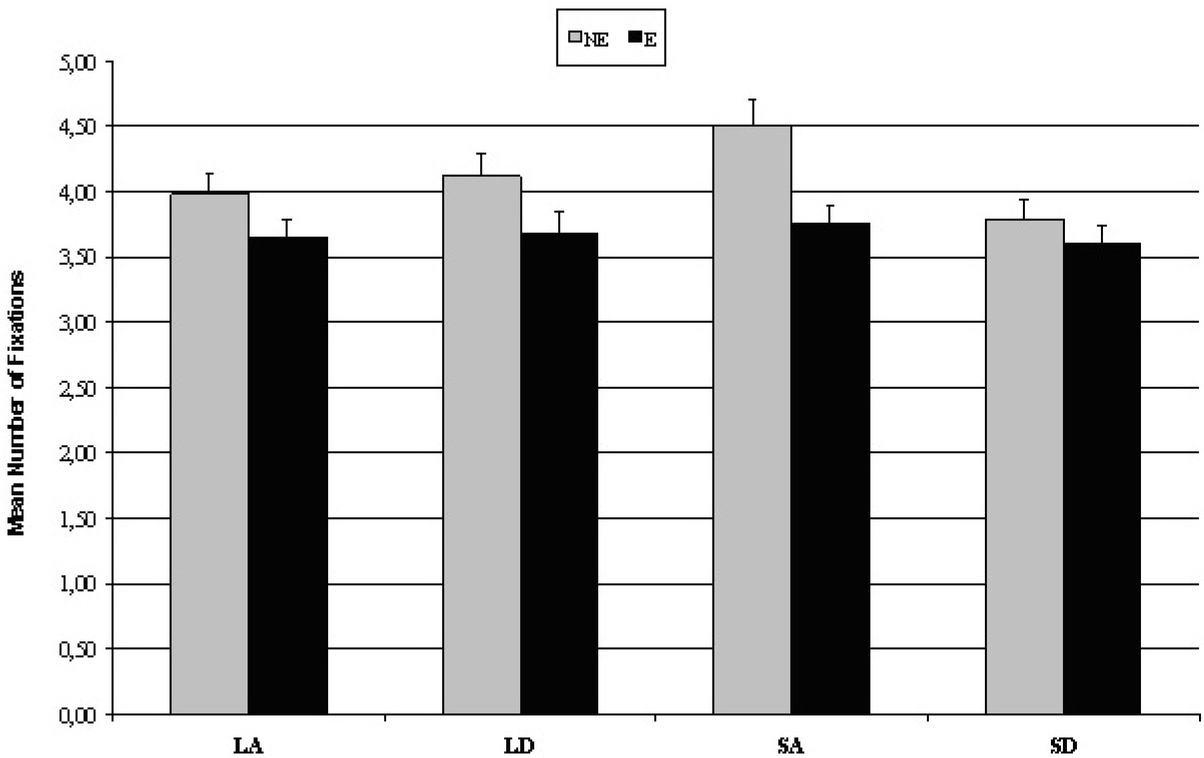


Figure 7. Mean (± se) number of fixations per trial in different conditions across group (E = experts; NE = novices)

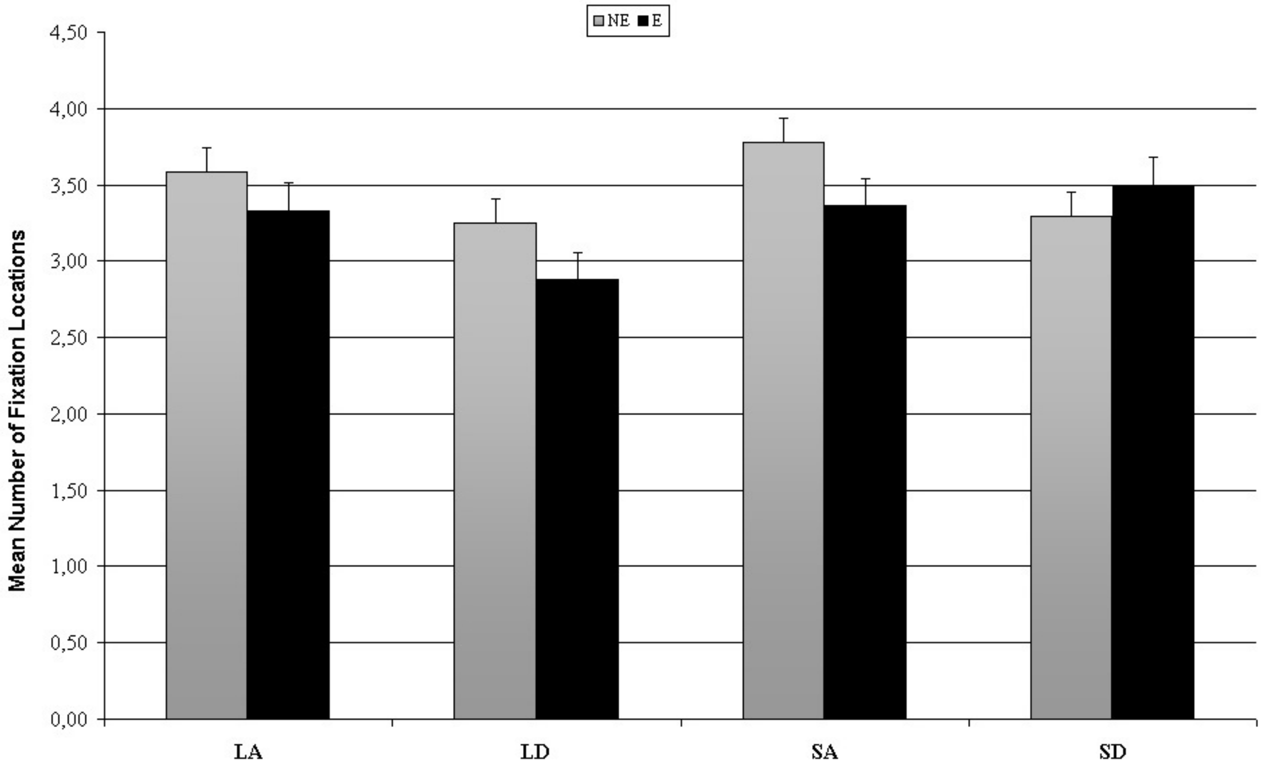


Figure 8. Mean (± se) number of fixation locations per trial in different conditions across group (E = experts; NE = novices).

Search Order

The results are highlighted in table 2. In the lapel attack situation (fig. 9) no significant transition fall on lapel interest areas but the analysis revealed significant differences between two groups in transition from hand to sleeve $F_{(1, 18)} = 11.03$, $p = .00$ (M = 1.66 ± .28 vs. 1.25 ± .27), from face to sleeve $F_{(1, 18)} = 14.61$, $p = .00$ (M = 2.80 ± .92 vs. 1.50 ± .59), from lapel to hand $F_{(1, 18)} = 7.42$, $p = .01$ (M = 2.00 ± .86 vs. 1.25 ± .27) and from face to hand $F_{(1, 18)} = 14.63$, $p = .00$ (M = 1.00 ± .00 vs. 1.33 ± .25). The same analysis was done for the sleeve attack (fig. 9)and here expert group showed significant differences in transition from face to sleeve $F_{(1, 18)} = 7.46$, $p = .01$ (M = 3.33 ± .81 vs. 2.16 ± 1.04) respect novice group who revealed a greater number of transitions from sleeve to lapel $F_{(1, 18)} = 8.02$, $p = .01$ (M = 2.66 ± 1.32 vs. 6.10 ± 3.41) and from hand to sleeve $F_{(1, 18)} = 7.25$, $p = .01$ (M = 1.66 ± .28 vs. 2.20 ± .52). In defence situation (lapel, sleeve) (fig 10) expert group did a greater number of transitions from lapel to hand $F_{(1, 18)} = 12.83$, $p = .00$ (M =

6.75 ± 1.82 vs. 3.75 ± 1.89), from sleeve to hand $F_{(1, 18)}$ = 14.63, p = .00 (M = 3.00 ± .00 vs. 2.66 ± .25) and from hand to sleeve $F_{(1, 18)}$ =16.44, p = .00 (M = 5.50 ± 1.56 vs. 3.40 ± .66) respect to their novice counterpart.

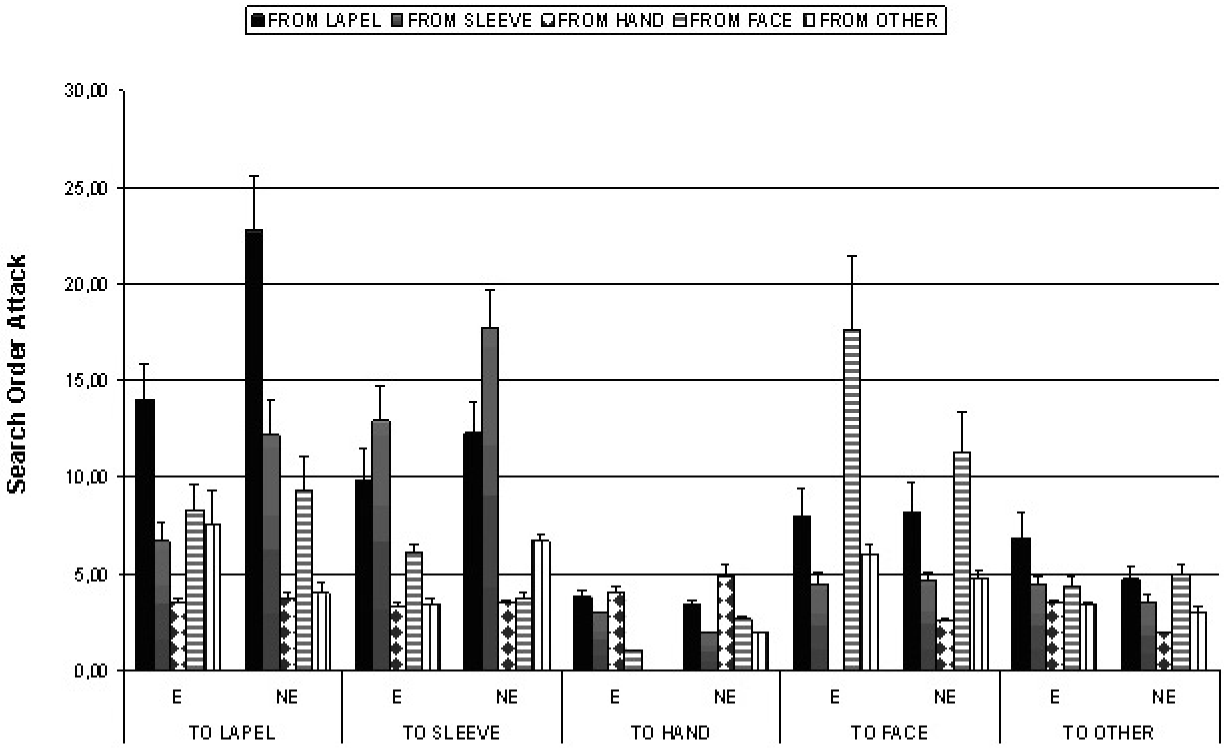


Figure 9. Histogram (experts and novices attack) concerning connection between cues, provide a dynamic description of visual behaviour and complete the analysis carried out on different cues considered separately (mean ± s).

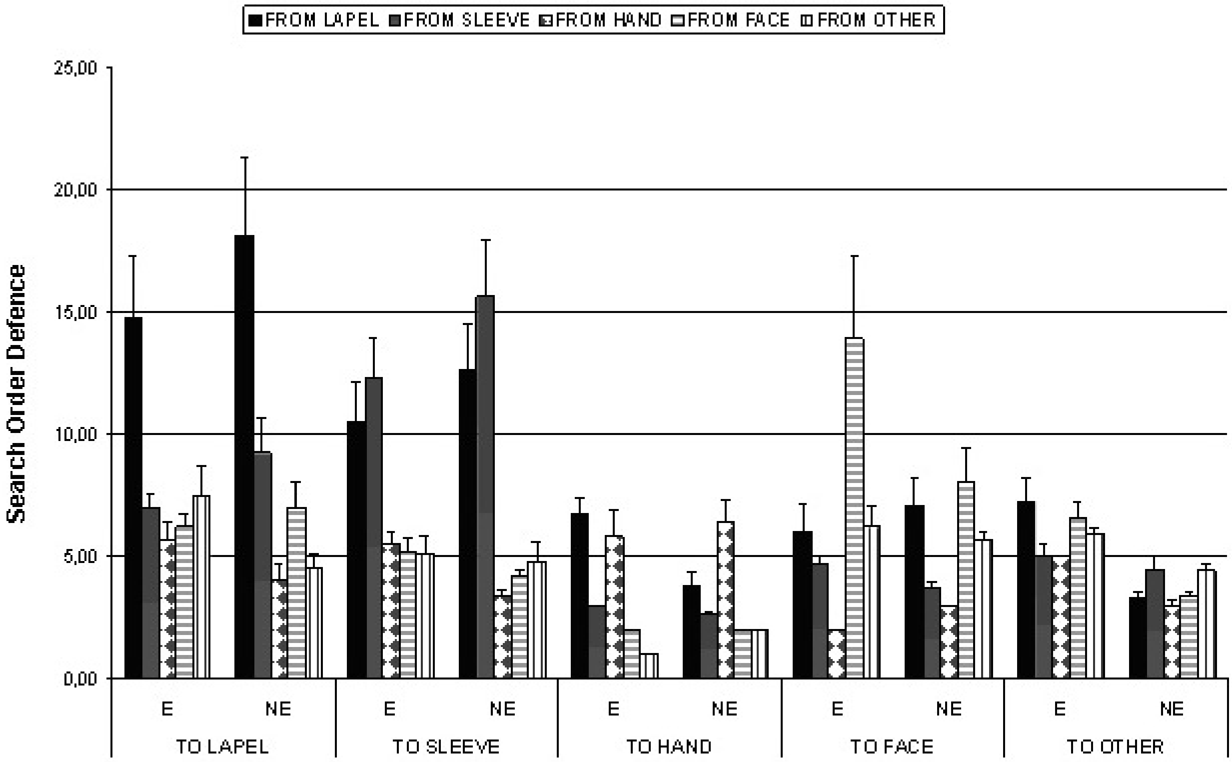


Figure 10. Histogram (experts and novices defence) concerning connection between cues, provide a dynamic description of visual behaviour and complete the analysis carried out on different cues considered separately (mean ± s).

Attack	To Lapel		To Sleeve		To Hand		To Face		To Other	
	E	NE	E	NE	E	NE	E	NE	E	NE
From Lapel	14.00 ± 1.83	22.74 ± 2.90	9.79 ± 1.67	12.30 ± 1.58	3.80 ± 0.32	3.38 ± 0.24	8.00 ± 1.41	8.14 ± 1.59	6.83 ± 1.36	4.70 ± 0.63
From Sleeve	6.67 ± 1.00	12.20 ± 1.73	12.89 ± 1.78	17.70 ± 2.02	3.00 ± 0.00	2.00 ± 0.00	4.47 ± 0.61	4.66 ± 0.39	4.46 ± 0.42	3.50 ± 0.44
From Hand	3.50 ± 0.24	3.68 ± 0.37	3.34 ± 0.15	3.45 ± 0.16	4.00 ± 0.33	4.89 ± 0.58	0.00 ± 0.00	2.58 ± 0.13	3.50 ± 0.08	2.00 ± 0.00
From Face	8.29 ± 1.32	9.36 ± 1.72	6.13 ± 0.42	3.67 ± 0.36	1.00 ± 0.00	2.66 ± 0.13	17.64 ± 3.76	11.30 ± 2.02	4.33 ± 0.50	5.00 ± 0.50
From Other	7.54 ± 1.80	3.97 ± 0.58	3.38 ± 0.33	6.71 ± 0.36	0.00 ± 0.00	2.00 ± 0.00	6.00 ± 0.53	4.75 ± 0.45	3.40 ± 0.13	3.00 ± 0.33

Defence	To Lapel		To Sleeve		To Hand		To Face		To Other	
	E	NE	E	NE	E	NE	E	NE	E	NE
From Lapel	14.78 ± 2.53	18.14 ± 3.22	10.50 ± 1.62	12.61 ± 1.88	6.75 ± 0.61	3.75 ± 0.57	6.03 ± 1.09	7.07 ± 1.10	7.26 ± 0.93	3.26 ± 0.25
From Sleeve	7.00 ± 0.53	9.23 ± 1.41	12.33 ± 1.62	15.64 ± 2.36	3.00 ± 0.00	2.67 ± 0.08	4.67 ± 0.32	3.67 ± 0.31	5.03 ± 0.48	4.44 ± 0.58
From Hand	5.67 ± 0.70	4.04 ± 0.65	5.50 ± 0.52	3.40 ± 0.20	5.83 ± 1.06	6.40 ± 0.92	2.00 ± 0.00	3.00 ± 0.00	5.00 ± 0.00	3.00 ± 0.23
From Face	6.23 ± 0.50	7.00 ± 1.04	5.20 ± 0.51	4.17 ± 0.23	2.00 ± 0.00	2.00 ± 0.00	13.93 ± 3.41	8.00 ± 1.44	6.55 ± 0.68	3.40 ± 0.17
From Other	7.47 ± 1.25	4.50 ± 0.56	5.13 ± 0.71	4.80 ± 0.77	1.00 ± 0.00	2.00 ± 0.00	6.20 ± 0.83	5.67 ± 0.34	5.90 ± 0.28	4.42 ± 0.27

Table 2. Search order transitions between and within different interest areas (mean ± se).

Perceptual Viewing Time

Mauchly's test indicated that the assumption of sphericity had been violated for repeated measures analysis of variance on location and location x condition main effect ($\chi 2$ = 197.48, p = .00), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (epsilon = .29). Test of within-subjects effects showed significant differences for condition ($F_{3, 54}$ = 9.04, p = .00), location ($F_{1.78, 32.12}$ = 41.78, p = .00), condition x location ($F_{5.25, 94.61}$ = 4.91, p = .00) and for condition x skill ($F_{3, 54}$ = 5.96, p = .00) but not for location x skill interaction (p = .05). Test of between-subjects effects showed that there were not significant differences between expert and novice group (p = .10) (M = 15.23 vs. 15.82 respectively). The mean percentage of fixations between groups across the four conditions is showed in table 3 instead the fig. 11 represents the mean results in each interest areas.

Participants focused on central regions of the body represented by lapel (M= 40,31%) respect to sleeve (M = 28.70) or face (M = 26.28), and, although the analysis indicated a non significant skill x location interaction, expert performers did spend a greater percentage of their time fixating on the lapel (M = 42.93 vs. 37.68), face (M = 34.26 vs. 18.29) and less time on the other areas (jacket skirt, legs, sleeve, hand, other) than their novice counterparts.

	LA	LD	SA	SD
E	14.46 ± 0.16	15.97 ± 0.71	15.91 ± 0.57	14.58 ± 0.50
NE	14.82 ± 0.14	18.17 ± 0.64	14.16 ± 0.52	16.13 ± 0.45

Table 3. Mean percentage (± se) of viewing time between groups (E= experts; NE= novices) across conditions (LA = lapel attack; LD = lapel defence; SA = sleeve attack; SD = sleeve defence).

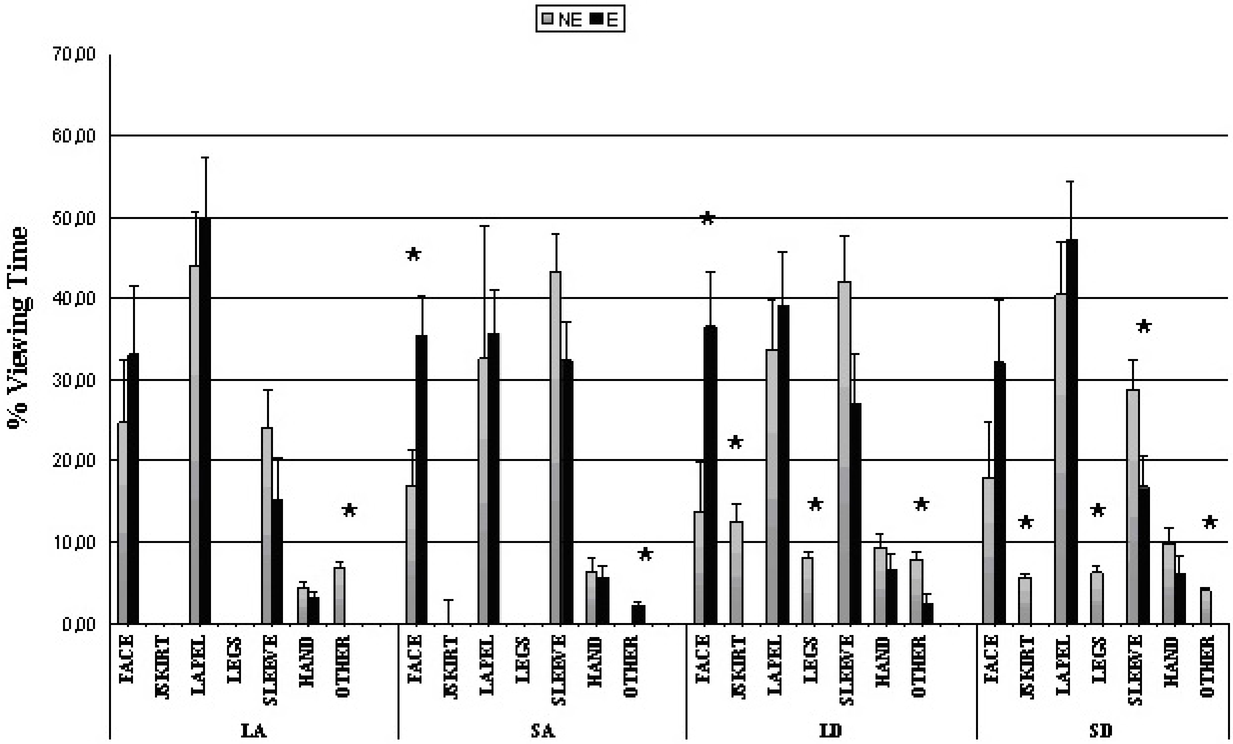


Figure 11. The percentage of time (mean ± se) spent viewing each fixation locations for the expert (E) and novice (NE) judoka subdivided in the four different conditions (LA, SA, LD, SD). The asterisks represents the significant differences (p<.05).

2.6 Judo Discussion

Recently, the question of which hand top level judo players employ first in gripping was raised (Pierantozzi 2008). The aim of the present study was to delineate a gaze behaviour of elite judo fighters who were submitted to forty trials divided in attack and defence. The primary objective in the game of judo is to control the space between you and your opponent. The one tool that you have to control that space is your gripping skills. The space is important because it is the reference for motor programming in order to get into position for attack, it is also the area that your opponent has to travel through to attack you. The analysis done on the grip is configured on placement of the power hand that is the side of the body with which you drive the defender's back toward the mat, during the through. The best grip fighters tend to prepare an opening for the power hand placement, in other words, the player reaches in with the non-power hand, pulls the lapel out for easier access, brushes aside the opponent's hands or simply sets a blind for the intended power hand placement and then takes the power hand grip. In this study the athletes did the first grip only and it was not defined a grip strategies but the athletes were free to choose the best side for their that was defined by the hand dominant. A gripping strategy is much more than which power hand you prefer to use, it is the way you manage your hands, shoulders, hips and footwork, is nothing less than your chosen method of controlling the attacking space.

The results showed that expert performers exhibit superior anticipation skills. There were a significant group main effect for fixation duration and number of fixations per trial (fig 6-7). Experts judoists used a less exhaustive search strategy involving fewer fixation of longer duration then their novice counterparts. Main hypothesis was that when the presentation was continuous, complex and long enough, visual behaviour is correlated to subjects' level of expertise. This is in agreement with Ripoll et al.(1995) who found that expert boxers made two and three times fewer fixations than intermediates and novices respectively and they were of longer duration. Generally, expert judoists focused on central regions of the body represented by lapel respect to sleeve or face, and although the analysis indicated a non significant skill per location interaction, expert performers did spend a greater percentage of their time fixating on the lapel and face respect to other areas of the scene (fig.11). Experts focused on central regions of the body such as the face and lapel, with less time spent fixating on peripheral areas of the display such as the sleeve, the hand, the legs and the jacket skirt regions. This reflect the same results found by Ripoll and William where specific fixations mainly concerned the central part of the body. The peripheral body was not fixated by experts who probably used information from their lower part of the body in peripheral vision without orienting their gaze toward it. These situations were visible not only in sleeve attack versus lapel attack but also in defence situations.

In the study of Matsumoto, Takeuchi and Nakamura (1972) the well-trained and beginners judo fighters were tested to see the correct posture and the distribution of attention in two kind of judo position (Shinzenhontai and Jigohontai). The results of the experiment were considered by dividing the stimuli board into 3 sections; the upper, the middle and the lower section. The upper section corresponded to the head and shoulders of the opponent, the middle section to the thorax and abdomen and the lower section to the legs. The well-trained judoists and the beginners in both position elicited quick response in the middle section, and it was due to the fact that it was in the center of the visual field. The well-trained judoists revealed better distribution of attention and wider visual field than the beginner in both Shinzenhontai and Jigohontai with faster response in the middle section and no response in the upper section respect to beginners.

Search order (fig.9-10) which showed that expert group did a great number of transitions from lapel to hand, from sleeve to hand, from face to sleeve and from face to hand, all of these gaze transition were eccentric, from the center to the periphery of the body, instead the significant number of transitions in near expert group was from sleeve to lapel and from hand to sleeve, that is, from periphery to central body regions (concentricity). Quoting A. M. Williams (1999), "*the manipulation of anxiety was lower than those expected during a real competitive situation, the changes in search strategy observed under high anxiety condition were characterized by an increase in search rate and the amount of time spent fixating on peripheral display areas*". This condition might have occurred, in this experiments in near expert judoists who found themselves in front of a very popular Olympic athlete and they felt a high anxiety. The suggestion is that anxiety causes some degrees of peripheral narrowing, which constrains the performer to extract more information from the scene via central rather than peripheral vision (Williams 1999). Although in this study it was not specifically searched for the level of anxiety, it could have increased the rate of visual scanning, as well as the number of foveal fixations directed toward peripheral areas of the scene in near expert judoists (sleeve, hands, legs and jacket skirt) respect to expert participants who were accustomed to this kind of situation.

In conclusion, it can be hypothesize that experts oriented their gaze at the connection of different and near interest areas close one each other. Such behaviour is used when information is complex, presented in different moving areas and when time and experimental condition is stressing.

3. The Soccer Study

3.1. Introduction

Although a large amount of research on soccer penalty kick has been published, no-one has investigated the differences on performance between kicking with the inside of the foot and instep kick. The side foot is often used to make a controlled pass. To make a side-foot kick, the foot has to be angled outwards so as to make contact on the medial aspect. This prevents the knee from flexing in the same way as it would for an instep kick. Therefore, the speed of the foot during a side-foot kick is less than for an instep kick (Lees and Nolan 1998). A further advantage is that the flatter side of the foot allows a more accurate placement of the ball. The instep kick is characterized by an approach to the ball of one or more strides, with placement of the supporting foot of the side, and slightly behind, the stationary ball. The kicking leg is first taken backward and the leg flexes at the knee. The support foot remains firmly planted as the kicking foot makes contact with the ball. As the support foot is planted, the kicking leg is left well behind the body, with the hip hyperextended and the knee maximally flexed. The trunk is also rotated backwards and sideways toward the kicking leg, to increase the length of the backswing and to add the force of trunk rotation forward into the kick. The arms are extended out the sides of the body, to aid in maintaining balance (Lees and Nolan 1998).

According to the law of the International Football Association Board (FIFA 2008), during a penalty kick the goalkeeper must remain on his/her goal line until the ball has been kicked from a distance of 11 m. Morya, Ranvaud and Pinherio (2003) have suggested that when the goalkeeper's movement is initiated 400 ms before the penalty taker reaches the ball, kicker's performance was effective, instead, when the goalkeeper's movement began 150 ms before ball contact, the kicker's performance decreased as determined by ball speed.

Ball speed is a measure of kicking success. Mean maximum ball speed has been reported to be in the range 15-22 m/s for children and young adults aged 10-17 years (Luhtanen 1988). Studies of the speed of penalty kicks have reported velocity usually higher than 75 km/h (Kuhn 1988), which gives the goalkeeper only approximately 400 ms to intercept the ball if the blocking action is initiate immediately after foot-ball contact. More recent studies have shown that the mean flight time of the ball is 648 ms at a mean speed of more than 16.8 m/s, or 64.8 km/h (Savelsbergh, Williams et al. 2002). Isokawa and Lees (1988) found that there were no significant differences in ball speeds between approach angles on foot and ball. Sanchez et al. (2005) suggested that goalkeepers need a minimum of 1.3 seconds (1300 ms) to intercept the ball at the point furthest from the initial start position (2.90 m), and 0,61 seconds (610 ms) to intercept the ball at the point nearest the goalkeeper's initial position (0,33 m). They found that smaller right knee angles were related to greater left knee angles, signalling a greater likelihood that the goalkeeper would move to the right when he tried to block the kick. Smaller left knee angles were related to larger right knee angles, increasing the likelihood that the goalkeeper would dive to the left. There is a 98.2% probably that the goalkeeper will move in the direction opposite that of the knee that is more fully extended. Masters et al. (2006) showed that it is feasible for a goalkeeper to influence perception of area and consequently the direction of penalty kicks by standing marginally to one side or another of the goal-centre; the goalkeeper can then strategically dive to the side with greater area. The optimum displacement of the goalkeeper in real life is from 6 to 10 cm the penalty taker is unlikely to be mindful of a displacement in this range, but is at least 10% more likely to direct the penalty kick to the side with greater area than to the side with smaller area.

Another problem for goalkeeper is if the kicker hits the ball with right or left foot. Given that, the most team have penalty takers who are right footed (McMorris and Colenso 1996) and goalkeeper's experience when facing penalty kick is predominantly to right footed players, it is possible that anticipation of kicks taken by left footed players may not be as accurate. This was the hypothesis of McMorris and Colenso (1996) who found that professional goalkeepers anticipate right-footed penalties more accurately than left-footed penalties.

Researchers have reported extensive support for anticipatory expertise in sports using the occlusion paradigm (Salmela 1979; Abernethy 1987; Abernethy 1987). Two methods are used in the occlusion paradigm, the temporal occlusion which involves the performer viewing a dynamic sequence of events and progressively revealing more (or less) information about the unfolding action up to a point just after contact. Spatial occlusion involves selectively masking portions of the sequence during presentation (e.g. the arm or implement used to propel the target object). The aim is to determine the minimal information needed to make an accurate prediction about the outcome of the event (e.g. direction a ball). Generally, researchers have shown that athletes are able to make more accurate judgements when longer viewing times are made available (Salmela 1979; Williams and Burwitz 1993; Müller 2006) or when pertinent cues are maintained (Abernethy 1987; Abernethy 1987; Shim 2005). Researchers have also demonstrated that elite performers make more accurate predictions than novices and also make use of perceptual cues that novices do not perceive (Salmela 1979; Farrow 2003; Müller 2006).

Different studies have analyzed gaze behaviour of soccer goalkeeper founding different interest areas that are important to intercept the ball. One of the first was by Williams and Burwitz (1993) who compared expert and novice goalkeepers while they observed filmed sequences of five different players taking penalty kicks. The participants viewed the player’s preparatory stance, approach run and kicking action up to the point of occlusion and were required to indicate, using a pen and paper response, the corner of the goal in which the ball would be directed. Four occlusion periods were used: 120 and 40 ms before the players kicked the ball, at impact and 40 ms after impact. The expert goalkeepers performed better that the novices under the pre-impact viewing condition only. Most errors (62%) were associated with incorrect judgements about height, only 26% of errors were due to incorrect prediction about which side of the goal the ball was placed. Questionnaire responses revealed that, when trying to anticipate the correct side, information was obtained from; penalty taker's angle of run-up, leg approaching the ball, angle of the kicking foot and from the hips' flexion prior to ball contact. The hip position at impact was regarded as being particularly informative. For a right-footed kicker, the 'opening' of the hips suggested that the ball was about to be played to the goalkeeper's left, whereas a penalty played to the goalkeeper's right was characterised by a more 'closed' or central orientation of the penalty taker's hips relative to the goalkeeper. When attempting to anticipate ball height, the lean of the trunk at impact was the most informative cue. Penalty takers should note that these information cues are more pronounced when penalties are struck with the instep. Browder et al (1991) demonstrated that, when comparing a fast to a slow kick (ball speeds of 17.0 and 13.5 m/s, respectively), the pelvis shows greater rotational movement for the faster kick than for the slower kick (18° vs. 13°), suggesting the importance of this motion in the production of high speed kicks.

The zone of the shoulder, the kicking leg, between the ball and the non-kicking leg in the approach phase and in the kicking-swing phase was suggested by Kim & Lee (2006). Their results determined that elite players fixed their gaze at a certain point and made little gaze movement when they anticipated the ball direction successfully. This study found that elite goalkeepers, fixed their gaze on the zone between the ball and the non kicking leg, and mainly used information by fixating the kicking leg, the non kicking leg and the ball. They identified these cues as a visual pivot and used the parafovea to pick up relevant information from periphery.

Savelsbergh et al. (2002) investigated differences in informative cue between expert and novice goalkeepers. The expert goalkeepers used a search strategy involving fewer fixations of longer duration to fewer areas of the display than their novice counterparts. The novices spent longer fixating on the trunk, the arm and the hip regions as the penalty kick evolved, whereas the experts preferred to fixate the kicking leg, the non kicking leg and the ball areas and also the head region, particularly early on, although this may reflect a tendency to try and recognize facial characteristics early in the action sequence. Interestingly, both groups spent long periods fixating on "unclassified" areas of the display, this area was near to, but not on, the lower leg and the ball regions. This suggested that participants chose to anchor the fovea close to these key locations so that they could use the parafovea and visual periphery to pick up relevant information.

The placement of the supporting foot has received little attention in soccer. McLean & Tumilty (1993) reported foot placements in elite junior soccer players of 38 cm behind the ball centre, and 37cm to the side of the ball centre. Lees and Nolan (1998) reported that the supporting foot should be placed 5-10 cm to the side of the ball, but the anterior posterior positioning is equivocal, with authors suggesting a placement of 5-28 cm behind the ball (Hay 1985). It is likely that the anterior-posterior positioning is a function of the type of kicking performed and whether it is intended to keep the trajectory of the ball low or to make it goes high.

Franks and Harvey (1997) showed that the only response cue that was both reliable and time efficient was the placement of the non kicking foot. This was 80% reliable and allowed goalkeepers between 150 and 200 ms to react after detection. The position of the foot appears to dictate the direction of the shot. If the foot is directed toward the right, then the shot will be toward the right and similarly if the foot "points" to the left the shot is directed to the left. On the few occasions when the foot is pointing toward the centre of the goal two outcomes seem most likely. Either the ball will be driven directly at the goalkeeper or it will be sliced to the right. Reaction time in the order of 200-300 ms will not be fast enough for the goalkeeper to stop the penalty shot and must therefore be brought down to levels between 100 and 200 ms. The same results were obtained by Savelsbergh et al. (2005) which created a test film from the keepers' perspective, made a sailcloth in which there are 6 different target areas and the kicker has to hit one of them like real game. Average ball fly was 648 ms and mean ball velocity was 60 km/h. The successful experts were significantly more accurate in predicting the height and direction of the penalty kick, waited longer before initiating a response and spent longer periods of time fixating on the non kicking leg in comparison to the unsuccessful experts. The differences between successful and less successful expert performers in stopping a penalty are determined by a combination of when to initiate a response and attention to the non kicking leg. The successful expert goalkeepers employed a distinct anticipation strategy and initiated their actions relatively late in the run-up of the kicker. According to Franks and Hanvey (1997) the positioning of the non-kicking leg occurs at 200-250 ms prior to ball contact.

More recently (Dicks in press) found that soccer players used different gaze behaviours when responding to live kicks than when to videos or other observer conditions. Goalkeepers spent more time fixating the ball in comparison with the sum of all anatomical locations during the ISI (in-situ interception) condition while the opposite trend was observed for all other condition that concerned video verbal response and simulated joystick movements and three in situ conditions in which the goalkeepers produced a verbal response, a simplified body movement or an actual interceptive movement response. The most pronounced difference was that goalkeepers fixated earlier and for duration upon the ball location in the ISI condition in comparison with all other conditions. Gaze was most commonly directed towards the head or torso during the first 500 ms of the approach in all conditions. As the penalty taker run up evolved, there was an increased frequency of gaze fixations upon the kicking and non-kicking leg for all conditions except ISI.

The present study was designed to analyze, in a real-world situation, different variables that affect anticipatory movements by soccer goalkeepers during penalty kicks taken with the inside vs. instep foot in order to obtain reliable parameters for training soccer players. Differences in gaze behaviour are expected when the instep and inside of the foot are used because, when the kicker hits the ball to send it to the corner (left or right) he opens the knee, instead when the kicker hits the ball to send it on the center of the goal he doesn’t open the knee and hit the ball with instep kick. As Van der Kamp (2006) said: “*precise details pertaining to the control of the direction of the ball with an instep kick are not available*”. We expect that elite goalkeepers will be able to detect both cues, thus fixating the knee of the kicking leg or directly the non-kicking leg.

3.2 Methods

3.2.1 Participants

Seven (n = 7) intermediate level male with a mean age of 18.7 (SD = 2.4) years and seven (n =7) right-footed kickers with a mean age of 25.4 (SD = 4.7) years volunteered for the experiment. The kickers and goalkeepers, had at least varsity level soccer experience. All had normal or corrected to normal vision and gave their informed consent to participate in the study consistent with the guidelines of the Conjoint Health Research Ethics Board at the University of Calgary.

3.2.2 Apparatus

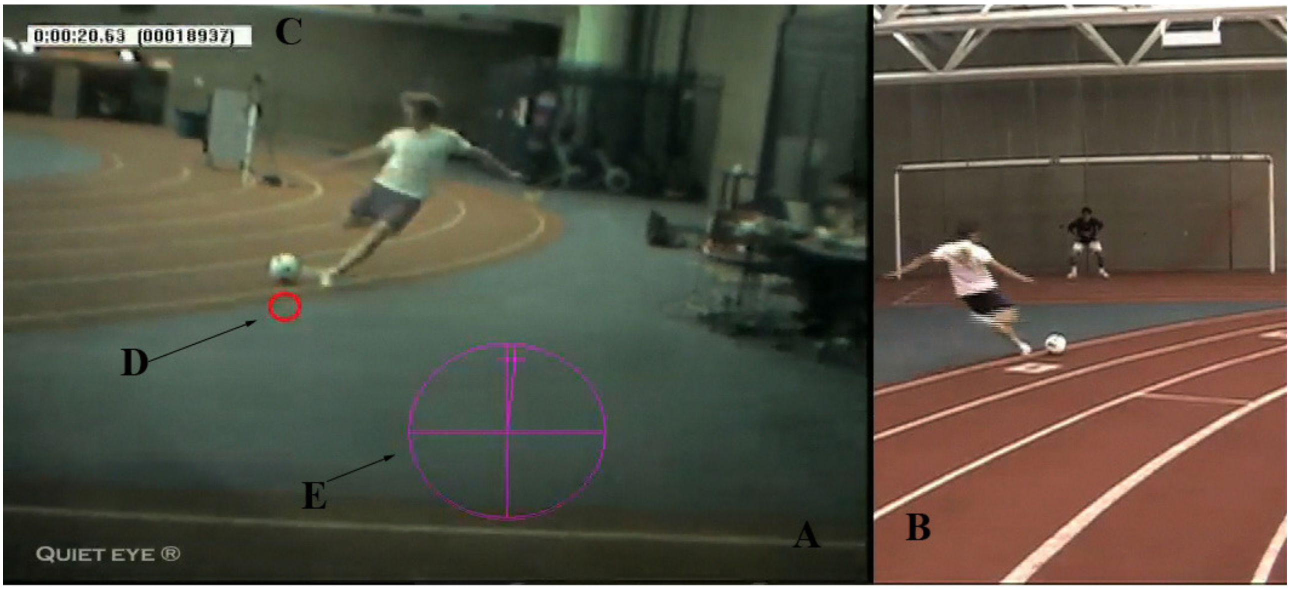


Figure 12. A frame of video recorded with the Vision-in-Action (VIA) system (Vickers 2007) showing the gaze image (A), the motor image (B) and the frame counter (C); also present in this frame are the gaze cursor (D) and the pupil indicator (E).

The vision-in-action (VIA) system (Vickers 1996; Vickers 2007) was used to collect the coupled gaze and motor behaviours of the goalkeepers. This system integrate input from a mobile eye tracking system (Applied Sciences Laboratories) with an external video of the goalkeeper's saving actions. The Mobile Eye is a head-mounted, monocular eye-tracking system that uses corneal reflection to measure eye-line-of-gaze with respect to the field of view with an accuracy of ± 1^{o} and precision of 0.5^{o} of visual angle. A frame of VIA data is shown in fig. 12 and shows the *gaze image* (A) of the goalkeeper, which was recorded by the scene camera mounted on the eye tracker. Superimposed on this image is a gaze circle, which indicated the goalkeeper's point of gaze with an accuracy of 1^{o} of visual angle (the diameter of the circle equalled 1 degree). The *motor image* (B) , that recorded the goalkeeper and kicker's motor sequences, was recorded by an external video camera (Fig. 12). The sample rate of the eye tracker and external video camera was 30 Hz (or 33.3 ms per frame). Synchronization of images A and B was carried out post-data collection using a commercial editing package, Final Cut Pro (Apple Corp).

3.2.3 Task

The goalkeepers took 30 penalty kicks on a synthetic pitch. The size of the goal (7.32 x 2.44 m) and the distance of the penalty spot from the goal (11 m) were in accordance with FIFA (2008) laws. Order of the kicks was randomly determined.

3.2.4 Procedure

Prior to beginning the experimental tasks the goalkeeper required about 20 minutes to stretch and warm-up. At the completion of the warm-up the goalkeeper was fitted with the eye tracker and calibrated to a nine-point grid. After calibration, the goalkeeper responded to 5 kicks to become accustomed to the eye tracker. A calibration check was conducted (on pitch) before each trial. The goalkeeper was required to fixate the ball placed in the scene to ensure that the system was accurate. When both the kicker and goalkeeper were ready, a verbal command ("Go!") was given to start the trial by the experimenter.

Participants were required to start their run-up at least 4 m behind the ball with an approach angle of between 10 and 30° (Williams 2002) and were required to take the penalty with instep or inside right-foot. The kickers were instructed to use a non-deceptive strategy in order to minimize any variability in the player's kicking action within and between conditions. Order of kicks was random so that an equal number of instep and inside foot kicks were attempted by each kicker. The trial ended when the goalkeeper either saved the ball or the ball entered the goal. The goalkeeper faced 15 consecutive shots followed by 5 minutes of rest and then ended the test with another 15 consecutive shots. Goalkeepers were naive to the requirements of the task, however the kickers were informed in order to encourage them to score as much goals as possible. A recorder kept track of the conditions and recorded the outcome (save, goal) of each trial. The gaze data was visible on a monitor and when necessary a recalibration was carried out by having the goalkeepers fixate the ball in the visuo-motor workspace.

None of the participants reported any detrimental effects of wearing the Mobile Eye on performance.

3.3 Dependent variables and analysis

Gaze and motor data were coded following procedures adapted for soccer from Panchuk and Vickers (2006) using Quiet Eye Solutions, a specialized software program developed to code coupled gaze and motor data (Quiet Eye Solutions, Inc.). Trial onset was held constant and occurred three seconds prior to the kicker ball-foot contact. Trial offset included ball flight time and occurred when the ball hit the keeper or passed the plane of the goal. Fixation was coded using definitions from the eye movement literature. A fixation was defined as fixations frequency, duration and location. Thirteen fixation locations were identified: ball, off ball (cursor is off the edge of the ball by from 1 to 3 degrees of visual angle), field far (the field between off-ball and field near), field near (the field near the goalkeeper, up to 5.5m from the goalkeeper), foot kicking leg, foot non-kicking leg, head, hips, knee kicking leg, knee non-kicking leg, run-up space (gaze that is between the kicker and the ball in the path of the run up to the ball), shoulders and another area called "other"(any other location).

Code-recode reliability was established using two independent coders. This facet of reliability is the degree to which different testers can achieve the same scores on the same subjects. The degree of objectivity (intertester reliability) can be established by having more than one tester gather data; then the scores are analyzed with intra-class correlation techniques to obtain an intertester reliability coefficient (Thomas and Nelson 2001). Gaze behaviour was analyzed in the same manner of judo data.

Search rate

This measure incorporate the mean number of fixation locations, mean number of visual fixations and the mean fixation duration per trial. A fixation was defined as the time when the eye remained stationary within 1° of visual angle for a period equal to, or greater than, 100 ms or tree video frames. Each search rate measure was analyzed separately using a two-way analysis of variance with outcome (goal/save) as a within-participant factors and foot contact (instep/inside) as between-participant factors.

Search Order

This variable was defined as the average frequency with which a combination of successive gaze behaviour was observed on each trial (i.e., fixations immediately prior to or following the current fixation). Initial analysis was performed descriptively using a series of transition matrices. Two variables were subsequently analyzed using separate two-way ANOVA with foot contact (instep/inside) and outcome (goal/save) as a between-participant factors and the variables were the number of transitions between all interest areas.

Perceptual Viewing Time

Percentage viewing time referred to the amount of time participants spent fixating various interest areas of the opponent when trying to anticipate ball direction. It was taken in account ten fixation locations: ball, off-ball, run-up space, foot-kicking leg, foot non-kicking leg, knee kicking leg, hips, shoulders, head and a further "other" category was used for data that did not fall into one of these classifications. Tree areas were excluded (field far, field near and knee non kicking leg because no data were found). The percentage viewing time data was analyzed using a repeated measure ANOVA in which fixation locations (10) and outcome (goal/save) were within-participant factors and foot-contact (instep/inside) a between-participant factors.

3.4 Soccer Results

Search rate

The mean score for each variable are presented in table 4. ANOVA analysis showed a significant main effect for the number of locations fixated across outcome (goal/save) ($F_{1, 23} = 52.05$; $p = .00$) but not for foot contact (instep/inside). Also number of fixations and mean fixation duration per trial were not significant. Table 4 indicates that participants spent more time fixating the areas in instep than inside kick (M = 683.33 vs. 586.08 ms) and in goal than in save situation (M = 680.47 vs. 588.94) (fig 13). Instep soccer kick showed a greater number of fixations (fig 14) per trial respect to inside kick (M = 5.73 vs. 5.38) and the same was for saved penalty kick versus scored penalty (M = 5.59 vs. 5.52). Finally, participants fixated on a great number of fixation locations per trial (fig 15) in scored that in saved penalties (M= 5.63 vs. 1.70) , p = .00 (table 4).

	Inside		Instep	
	Goal	Save	Goal	Save
Fixation Duration (ms)	632.59 ± 95.18	539.58 ± 58.83	728.35 ± 200.46	638.30 ± 147.79
Number of Fixations	5.46 ± 0.47	5.27 ± 0.49	5.50 ± 0.65	5.90 ± 0.59
Number of Fixation Locations	6.56 ± 0.43	1.91 ± 0.36	4.74 ± 0.63	1.49 ± 0.52

Table 4. Mean Fixation Duration and Mean Number of Fixations per trial in inside and in instep penalty kick across goal and save conditions (mean ± s).

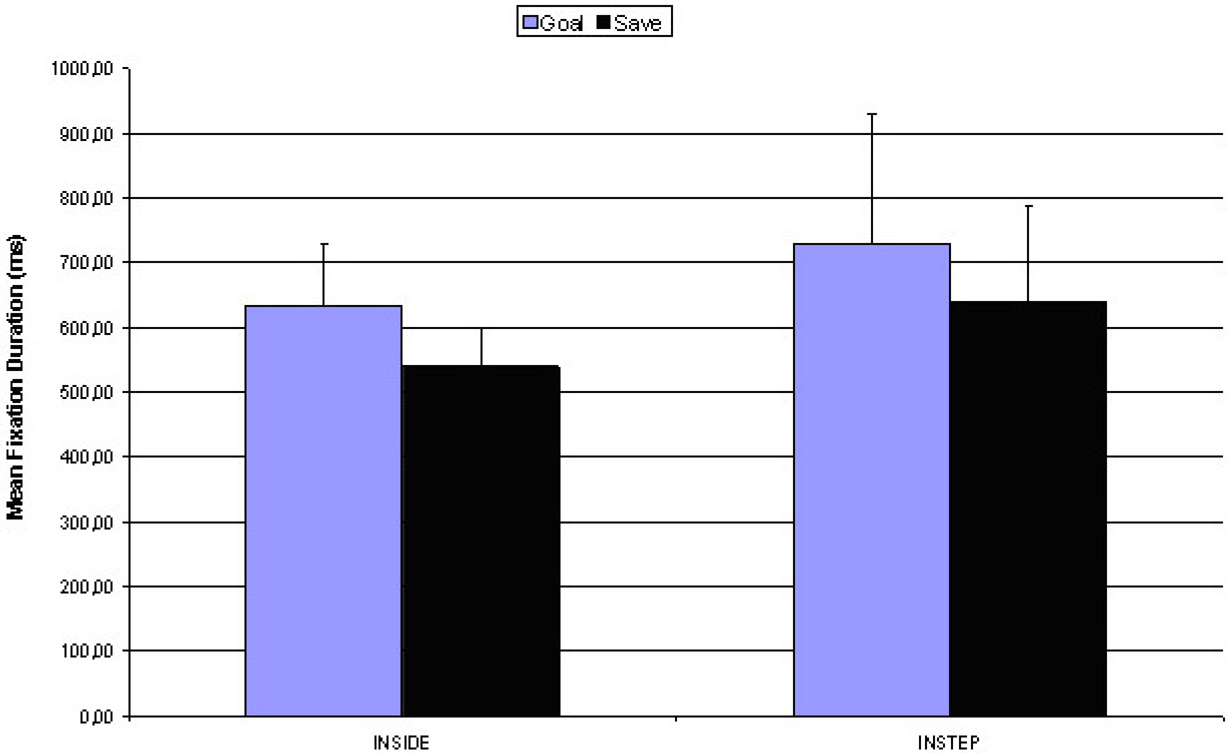


Figure 13. Mean (± se) fixation duration per trials in different conditions (inside/instep) across outcome (goal/save).

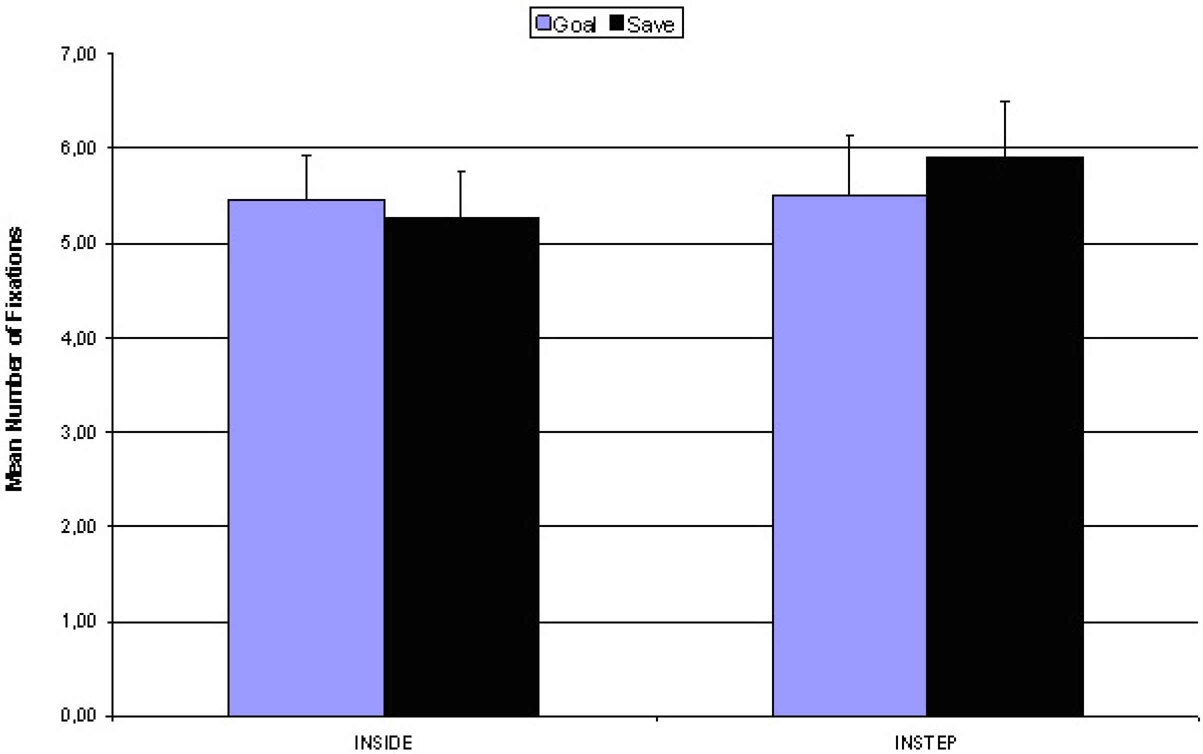


Figure 14. Mean (± se) number of fixations per trial in different conditions (inside/instep) across outcome (goal/save).

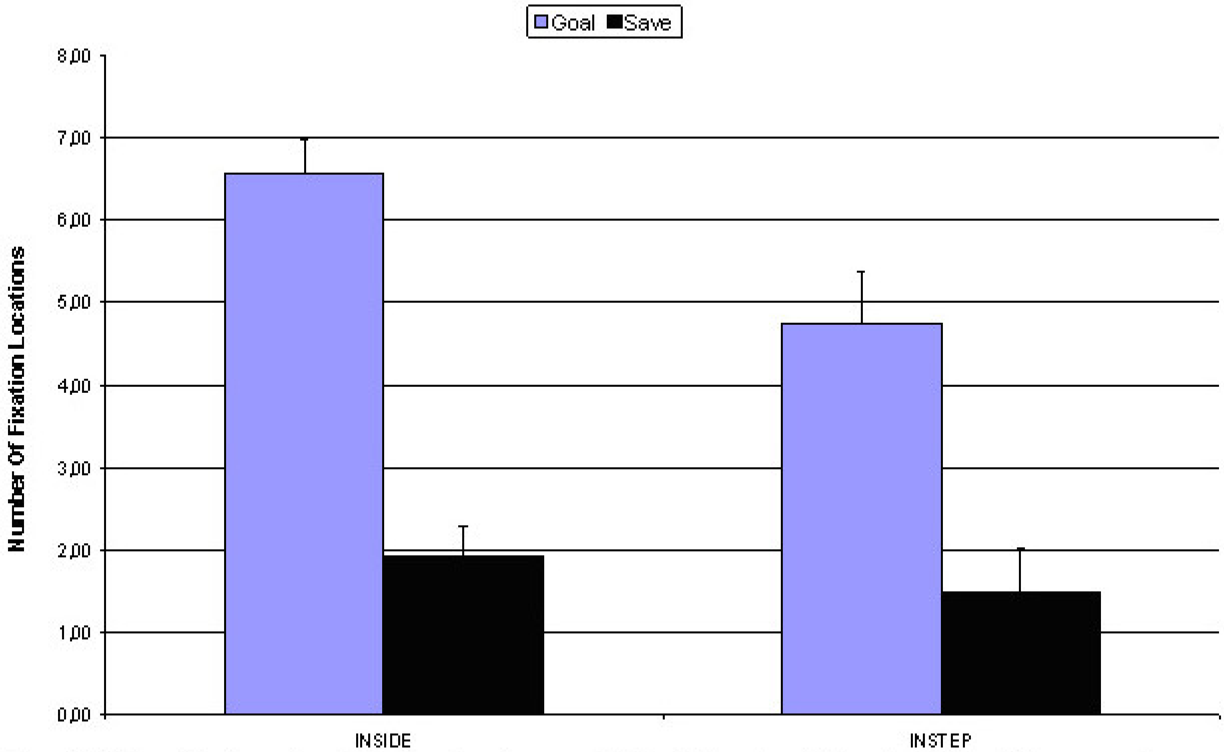


Figure 15. Mean (± se) number of fixation locations per trial in different conditions (inside/instep) across outcome (goal/save).

Search Order

The results showed significant differences in the number of transitions between all interest areas. Histograms (fig 16-17) (instep/inside) concerning connection between cues, provide a dynamic description of visual behaviour and complete the analysis carried out on different cues considered separately. Two-way ANOVA revealed significant differences in transition from ball to off-ball, to hips, to shoulders and to head (p = .00; .00; .03; .00 respectively), from off-ball to ball (p = .00), from run-up space to ball (p = .00), from foot kicking leg to ball (p = .02), from shoulders to ball and to head (p = .00; .00 respectively) and from head to ball (p = .02). Mean and standard error in search strategy as a results of foot contact and outcome are showed in table 5 and it indicate that the most gaze behaviour start and finish on ball interest areas. As highlighted in the table 5 Bonferroni post hoc test was used to multiple comparisons between foot contact (instep/inside) and outcome (goal/save). The asterisks reveal that instep-goal situation is the most different condition respect to other ones. Significant transitions were from run-up space and shoulders to ball and inside the off-ball areas (p < .00). Another interest observation is that a lot of transition start and finish in the same areas.

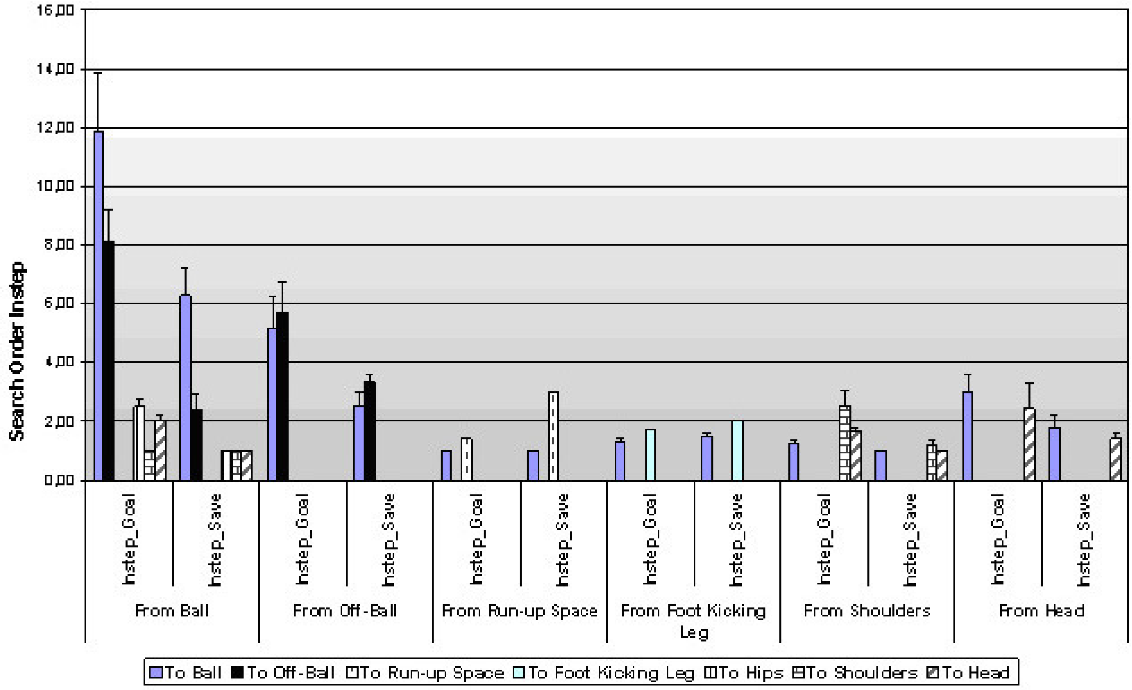


Figure 16. Representation of the visual search patterns employed by expert goalkeepers in instep foot-ball contact across scored and saved penalty kick.

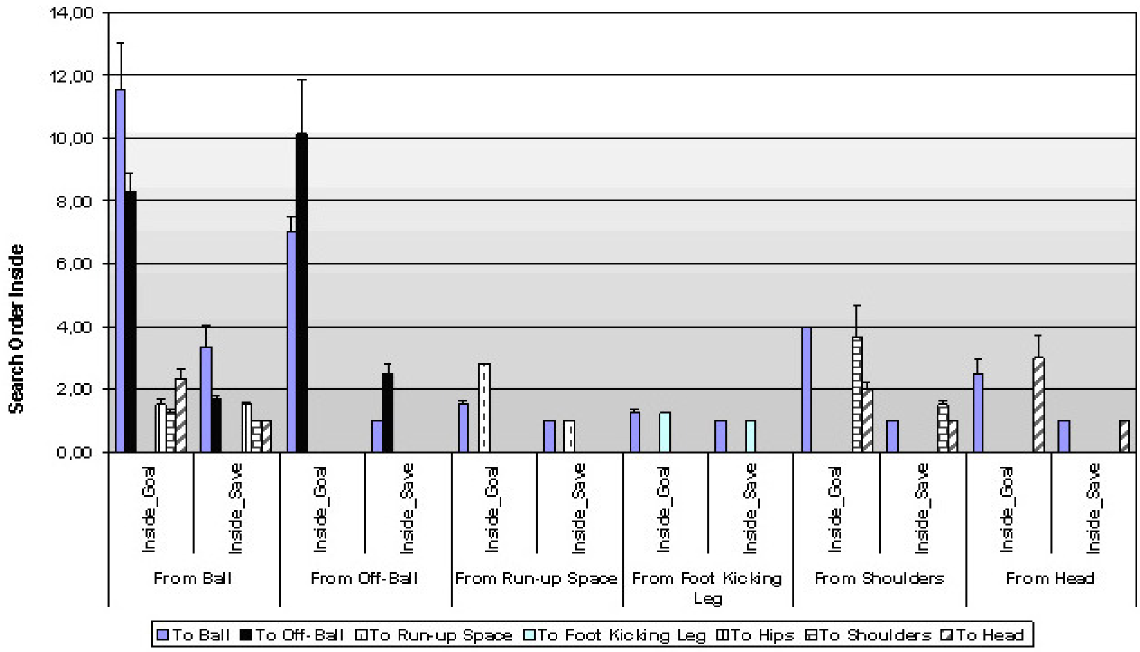


Figure 17. Representation of the visual search patterns employed by expert goalkeepers in inside foot-ball contact across scored and saved penalty kick.

		To Ball	To Off-Ball	To Run-up Space	To Foot Kicking Leg	To Hips	To Shoulders	To Head
From Ball	Instep_Goal	11.86 ± 1.99	8.14 ± 1.04	\	\	2.50 ± 0.28 *	1.00 ± 0.00	2.00 ± 0.19
	Inside_Goal	11.57 ± 1.45	8.29 ± 0.59	\	\	1.50 ± 0.16	1.25 ± 0.12	2.33 ± 0.29
	Instep_Save	6.29 ± 0.92	2.40 ± 0.55	\	\	1.00 ± 0.00	1.00 ± 0.00	1.00 ± 0.00
	Inside_Save	3.33 ± 0.72	1.67 ± 0.11	\	\	1.50 ± 0.09	1.00 ± 0.00	1.00 ± 0.00
From Off-Ball	Instep_Goal	5.17 ± 1.07	5.71 ± 1.01	\	\	\	\	\
	Inside_Goal	7.00 ± 0.50	10.14 ± 1.71 *	\	\	\	\	\
	Instep_Save	2.50 ± 0.48	3.33 ± 0.26	\	\	\	\	\
	Inside_Save	1.00 ± 0.00	2.50 ± 0.32	\	\	\	\	\
From Run-Up Space	Instep_Goal	1.00 ± 0.00	\	1.40 ± 0.15	\	\	\	\
	Inside_Goal	1.50 ± 0.13 *	\	2.80 ± 0.67	\	\	\	\
	Instep_Save	1.00 ± 0.00	\	3.00 ± 0.38	\	\	\	\
	Inside_Save	1.00 ± 0.00	\	1.00 ± 0.00	\	\	\	\
From Foot Kicking Leg	Instep_Goal	1.33 ± 0.11	\	\	1.75 ± 0.12	\	\	\
	Inside_Goal	1.25 ± 0.12	\	\	1.25 ± 0.12	\	\	\
	Instep_Save	1.50 ± 0.09	\	\	2.00 ± 0.19	\	\	\
	Inside_Save	1.00 ± 0.00	\	\	1.00 ± 0.00	\	\	\
From Shoulders	Instep_Goal	1.25 ± 0.12	\	\	\	\	2.50 ± 0.56	1.67 ± 0.11
	Inside_Goal	4.00 ± 0.00 *	\	\	\	\	3.67 ± 1.02	2.00 ± 0.22
	Instep_Save	1.00 ± 0.00	\	\	\	\	1.20 ± 0.14	1.00 ± 0.00
	Inside_Save	1.00 ± 0.00	\	\	\	\	1.50 ± 0.11	1.00 ± 0.00
From Head	Instep_Goal	3.00 ± 0.62	\	\	\	\	\	2.43 ± 0.84
	Inside_Goal	2.50 ± 0.48	\	\	\	\	\	3.00 ± 0.72
	Instep_Save	1.80 ± 0.40	\	\	\	\	\	1.40 ± 0.17
	Inside_Save	1.00 ± 0.00	\	\	\	\	\	1.00 ± 0.00

Table 5. Average (± se) frequency with which a combination of successive gaze behaviour was observed on each trial (* p<.00).

Perceptual Viewing Time

Mauchly's test indicated that the assumption of sphericity had been violated for repeated measures analysis of variance on the fixation locations main effect ($\chi 2 = 224.38$, $p = .00$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (epsilon = .19). A significant main effect was observed for outcome ($F_{1, 12} = 5.89$, $p = .03$), outcome x foot contact ($F_{1, 12} = 5.54$, $p = .03$) and location ($F_{1.7, 21,23} = 22.50$, $p = .00$). These differences are presented in table 6 and graphically in fig 18 where expert goalkeepers spend more time in save than in goal situation (M = 11.90 vs. 10.43) both in instep than inside penalty kick (p = .03). But in between-subject effects there were not a significant main effect (p= .26). Participants spend more time watching off ball, foot kicking leg, foot non kicking leg, knee kicking leg, hips and shoulders in save than goal situation although the differences were not significant.

	Inside		Instep	
	Goal	Save	Goal	Save
BALL	45.32 ± 10.45	53.04 ± 11.93	50.93 ± 10.45	42.28 ± 11.93
OFF-BALL	19.8 ± 4.09	26.47 ± 8.94	13.23 ± 4.09	27.03 ± 8.94
RUN-UP SPACE	5.09 ± 0.88	0.00 ± 0.19	1.43 ± 0.88	3.06 ± 0.19
FOOT KICKING LEG	0.92 ± 0.65	3.04 ± 0.50	3.46 ± 0.65	3.28 ± 0.50
FOOT NON KICKING LEG	1.26 ± 0.27	5.03 ± 0.21	1.14 ± 0.27	0.00 ± 0.21
KNEE KICKING LEG	3.42 ± 2.33	13.51 ± 1.83	8.4 ± 2.33	0.00 ± 1.83
HIPS	2.37 ± 0.49	4.87 ± 0.62	2.63 ± 0.49	2.87 ± 0.62
SHOULDERS	8.81 ± 3.28	11.02 ± 1.63	6.59 ± 3.28	8.64 ± 1.63
HEAD	12.02 ± 5.22	11.12 ± 2.77	12.62 ± 5.22	11.85 ± 2.77
OTHER	2.66 ± 1.18	2.51 ± 2.70	6.46 ± 1.18	8.30 ± 2.70

Table 6. Mean percentage (± se) of viewing time between instep and inside penalty kick across outcome (goal/save).

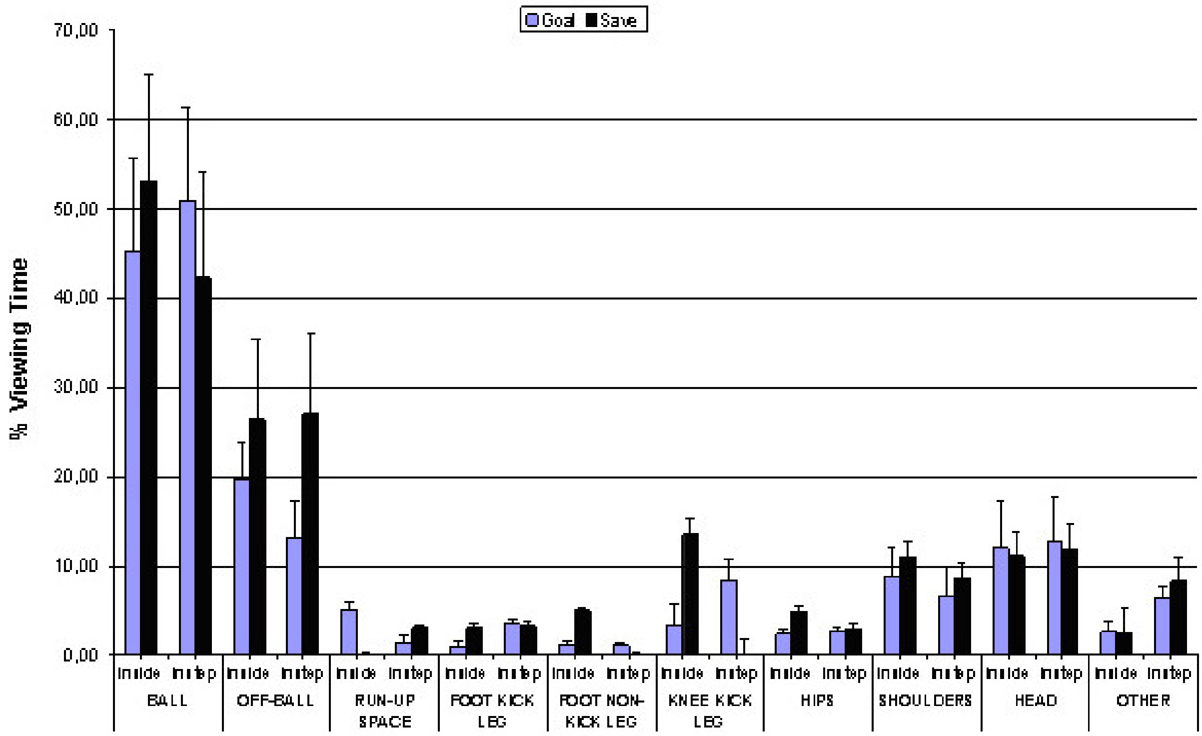


Figure 18. The percentage of time spent viewing each fixation locations in inside and in instep penalty kick across goal and save situations (mean ± se).

3.5 Soccer Discussion

The present study was designed to analyze, in a real-world situation, different variables that affect anticipatory movements by soccer goalkeepers during penalty kicks taken with the inside vs. instep foot in order to obtain reliable parameters for training soccer players. Although a large amount of research on soccer penalty kick has been published, no-one has researched the differences on performance between these two kinds of kick. The side foot is often used to make a controlled pass and the speed of the foot during this kick is less than for an instep kick (Lees and Nolan 1998).

All penalty takers were right footed players, and another problem for goalkeeper is if the kicker hits the ball with right or left foot. Given that the most team have penalty takers who are right footed (McMorris and Colenso 1996) and goalkeeper's experience when facing penalty kick is predominantly to right footed players, it is possible that anticipation of kicks taken by left footed players may not be as accurate. This was the hypothesis of McMorris and Colenso (1996) who found that professional goalkeepers anticipate right-footed penalties more accurately than left-footed penalties.

The results of the present study showed that expert goalkeepers spend more time gazing the inside than the instep penalty kick. But in scored penalty kick they spend more time in instep than inside. Different behaviour was observed in saved penalty kick where they spent more time in inside situation than in instep. In particular we can observe that in both foot-contact conditions participants look the foot of the non kicking leg and the knee of the kicking leg in saved penalty kick respect to other areas. This can be explained as important behaviour adopted from expert goalkeepers who try to anticipate the direction of the ball looking the foot of the supporting leg as confirmed by Franks and Harvey (1997) showed that the only response cue that was both reliable and time efficient was the placement of the non kicking foot. This was 80% reliable and allowed goalkeepers between 150 and 200 ms to react after detection. The position of the foot appears to dictate the direction of the shot. If the foot is directed toward the right, then the shot will be toward the right and similarly if the foot "points" to the left the shot is directed to the left. The same results was obtained by Savelsbergh et al. (2005). The successful experts spent longer periods of time fixating on the non kicking leg in comparison to the unsuccessful experts. The importance of the knee kicking leg maybe is correlated to the foot-contact because it is an important cue that goalkeepers can use to distinguish from instep to inside. In other words, when the kicker hits the ball to send it to the corner (left or right) he opens the knee, instead when the kicker hits the ball to send it on the center of the goal he doesn't open the knee and hit the ball with instep kick. As Van der Kamp (2006) said: "precise details pertaining to the control of the direction of the ball with an instep kick are not available". In our initial hypothesis we expected that elite goalkeepers will be able to detect both cues, thus fixating the knee of the kicking leg or directly the non-kicking leg. In Williams and Burwitz research (1993) in a right-footed kicker, the 'opening' of the hips suggested that the ball was about to be played to the goalkeeper's left, whereas a penalty played to the goalkeeper's right was characterised by a more 'closed' or central orientation of the penalty taker's hips relative to the goalkeeper. They found hips position as important cue like us, but we discovered it only in inside condition.

Number of fixations and mean fixation duration per trial were not significant, only fixation locations per trial was significant and greater in scored than in saved penalty kick. Participants spent more time fixating the areas in instep than inside kick and in goal than in save situation. Scored and saved instep soccer kick showed a greater number of fixations per trial respect to scored and saved inside kick respectively, it was the opposite in number of fixation locations. This kind of analysis is different from the other gaze control studies in sport where these two characteristics have been shown to be a feature of higher level of expertise. The non significant finding might be the result of the relatively small differences in goalkeepers experience between the two penalty conditions, small group size, and high standard deviation values.

The results of search order showed significant differences in the number of transition between all interest areas. Most gaze behaviour start and finish on ball interest areas, this can be hypothesized as participants chose to anchor the fovea close ball areas so that they could use the parafovea and visual periphery to pick up relevant information. The gaze strategy in all situations concerned transition from body cues to ball areas and vice versa, although in save situation the greatest mean was observed in transition started and finished in run-up space. This can confirm the supposition suggested before about the areas around the ball, enhanced also by Kim & Lee (2006) who found that elite goalkeepers, fixed their gaze on the zone between ball and non kicking leg, and mainly used information by fixating the kicking leg, the non kicking leg and the ball which they identified as a visual pivot, or more central location allowing peripheral locations to be viewed peripherally. Inside-goal situation is the most different condition compared to other ones as it was confirmed by multiple comparison analysis, the significant transitions were from run-up space and shoulders to ball and inside the off-ball areas. Finally, the most representative cues started from head, shoulder, hips, foot kicking leg and run up space and finished in ball interest areas, as discovered by Savelsbergh et al. (2002). His participants spent longer fixating on the kicking leg, the non kicking leg and the ball areas and also the head region. Head region, watched particularly early on, may reflect a tendency to try and recognize facial characteristics in the action sequence.

4. The Perceptual Representation of Near and Far Space

4.1. Introduction

The brain contains separate neural systems for representing, near or far space. Near or peripersonal space is roughly demarcated by the perimeter of arm's reach, while far or extrapersonal space extends beyond the sphere of potential motor behaviour.

The strongest evidence for distinct representation of near and far space in the human brain comes from studies of subjects with a well-known neuropsychological disorder called neglect (Husain 1996). In the most common form of neglect, the subject ignores an entire side, or hemifield, of egocentric space, usually the left side.

Studies found brain-damaged subjects who exhibited opposite types of neglect, one type involving left neglect in near but not far space, and the other involving left neglect in far but not near space (Halligan 1991; Cowey 1994). These findings constitute strong evidence that the brain contains separate neural systems for representing stimuli in peripersonal or extrapersonal space. Cowey et al (1999) suggested that the boundary between near and far sectors of space may not be represented as a rigid cut-off point but rather as a *continuum* across the zone corresponding roughly to the extent of arm's reach.

The important question is: "*why the brain has different systems for representing near and far space*"? It is possible to hypothesize why the brain contains different systems for representing near and far space. In particular, it is likely that these two systems have been designed by natural selection to solve fundamentally different kinds of computational problems involving motor control.

Near or peripersonal space is the arena in which the visuomotor control of arm and hand movements takes place, and this kind of behavioural control became increasingly important during primate and hominid evolution. In primates the frequent adoption of a sitting or upright posture enables the arms and hands to be used less for body support and more for manipulatory behaviours. This led hominids to become progressively more adapted to a variety of skilled actions. Selection pressures therefore caused the refinement of a set of brain mechanisms specialized for the visual guidance of manual behaviour in the peripersonal environment: stereo vision for determining the precise depth of objects in the near visual field; an attention system for guiding the hand to a fixated object when the hand cannot be directly viewed (Kemmerer 1999).

By comparison, far or extrapersonal space is the main arena in which visual search and object scanning and recognition take place, and these kinds of operations also became increasingly important during primate and hominid evolution. A voluntary saccadic eye movement system evolved to enable visual search and object scanning independent of head movements. This oculomotor system can be thought of as supporting the only kind of immediate action that can be taken toward objects in the distal field, namely foveation or "visual grasp" as well as part-whole analysis or "parsing", by means of sequentially fixating on different components of the object and thereby building up a complete visual representation of its structure (Kemmerer 1999).

4.2 Neural Substrates

Very little is known about the architecture of the near and far spatial systems in the human brain. It is possible that separate representation of near and far sectors of space are derived in part from an initially undifferentiated representation of the spatial environment that is anchored in head-centered coordinates (Rizzolatti 1997).

A large number of brain areas contribute to the representation of near space and more data are available regarding this system than the far system. In computational terms, one important function of the near system is to transform a single representation of peripersonal space in head-centered coordinates into multiple representations of peripersonal space in body-part-specific coordinates; the later representations can then be used to program movements, especially arm and hand movements directed toward or away from objects. Another function of this system is to visually monitor arm and hand actions relative to the face. As a reflection of these different purposes, the near system can be decomposed into several different functional-anatomical circuits that project from the parietal lobe: one for reaching, one for grasping and one for monitoring limb movements in relation to the face.

The reaching circuits includes at least two parietal areas, 7b and MIP (medial intraparietal sulcus). The grasping circuits is composed of a parieto-frontal pathway. Area AIP (anterior intraparietal sulcus) contains neurons that are activated during grasping actions as well as during passive fixation of objects. AIP projects to area F5 in the ventral premotor cortex of the frontal lobe, which is where the programming of hand movements takes place. The firing properties of neurons in this area are selective for different aspects of grasping behaviour – for example, different kinds of objects manipulation and types of grip (Rizzolatti 1988). Area VIP contains neurons that are driven largely by stimuli moving at certain speeds and in certain directions within the peripersonal environment.

The far system is well-adapted for using visual information to guide motor behaviour, however, the far system differs from the near system insofar as it is not designed for controlling arm, hand and head movements directed toward objects in the peripersonal environment, but it is instead designed for controlling saccadic eye movements directed mainly toward objects in the extrapersonal field of view. This system is composed of brain areas in both the parietal and the frontal lobe. Areas 7a and LIP (lateral intraparietal sulcus) contain neurons that respond primarily to visual inputs. Area 7a and LIP project to the portion of area 8 (frontal eye field) that is involved in programming voluntary saccadic eye movements, lesions in this area induce neglect that is much more severe for stimuli in far space than for stimuli in near space, exactly the opposite of lesions in areas 7b and F4 in the near space system (Kemmerer 1999). These findings therefore support the notion that the parietofrontal circuit extending from area 7a and LIP to area 8 is designed primarily for visual search and object scanning in the extrapersonal visual field.

Several general conclusions can be drawn about the functional-anatomical organization of the systems for representing near and far space. Both systems are evolutionarily designed for the visual guidance of motor control and are neurally implemented in parietofrontal circuits. But while the near system is geared toward the representation of peripersonal space in limb-centered and head centered coordinates, the far system is geared more toward the representation of extrapersonal space in gaze-centered coordinates. In other words, the near system represents space for purposes of manipulating or avoiding objects, whereas the far system represents space for "acquiring" and analyzing objects with the eyes.

4.3 Differences of acting in near versus far space: a Sport Approach

Although the experiments of this thesis were not specifically designed to compare near vs. far space analysis, nevertheless the results might be discussed on the light of the known physiological differences between the two conditions.

The analysis was done between expert judo fighters and expert soccer goalkeepers. From the point of view of judoists we used 20 defence trials (lapel plus sleeve), putting it together, on the other side we have chosen 20 trial also put it together (instep plus inside). Every trial was long 3 seconds and the analysis was the same used in experiment one and experiment two.

In these experiments (tab 7) was found that judoists spend a longer time fixating the opponent respect to soccer goalkeeper (M= 782 vs. 630 ms, respectively), the opposite was found in number of fixation per trial in which the greatest number of fixations was from soccer goalkeepers (M= 5,53 vs. 3,63) respect to expert judoists. In search order analysis (table 8) can be observe that the mean number of transitions that fall on the interest areas are much more in judo than soccer experiment.

	Fixation Duration (ms)	Number of Fixations	Search Order	% Viewing Time
E judoists	782.17 ± 35.63	3.63 ± 0.11	6.44 ± 0.31	26.04 ± 3.01
E goalkeepers	630.47 ± 38.03	5.53 ± 0.16	2.86 ± 0.17	12.80 ± 1.38

Table 7. Mean (± se) fixation duration, number of fixations, mean number of transitions fall on all interest areas (search order) and mean viewing time in all interest areas in expert (E) judoists and soccer goalkeepers.

	Judo Defence				
	To Lapel	To Sleeve	To Hand	To Face	To Other
From Lapel	14,78 ± 2,53	10,50 ± 1,62	6,75 ± 0,61	6,03 ± 1,09	7,26 ± 0,93
From Sleeve	7,00 ± 0,53	12,33 ± 1,62	3,00 ± 0,00	4,67 ± 0,32	5,03 ± 0,48
From Hand	5,67 ± 0,70	5,50 ± 0,52	5,83 ± 1,06	2,00 ± 0,00	5,00 ± 0,00
From Face	6,23 ± 0,50	5,20 ± 0,51	2,00 ± 0,00	13,93 ± 3,41	6,55 ± 0,68
From Other	7,47 ± 1,25	5,13 ± 0,71	1,00 ± 0,00	6,20 ± 0,83	5,90 ± 0,28
Total	**8,23 ± 0,76**	**7,73 ± 0,67**	**3,72 ± 0,41**	**6,56 ± 0,92**	**5,95 ± 0,28**

	Soccer						
	To Ball	To Off-Ball	To Run-up Space	To Foot Kicking Leg	To Hips	To Shoulders	To Head
From Ball	8,44 ± 1,04	6 ± 0,79	1,2 ± 0,13	1,22 ± 0,22	1,54 ± 0,24	1,08 ± 0,08	1,70 ± 0,33
From Off-Ball	4,59 ± 0,75	5,875 ± 0,86	1,67 ± 0,67	0,75 ± 0,25	3,00 ± 0,00	1,57 ± 0,30	1,40 ± 0,40
From Run-Up Space	1,20 ± 0,13	1,33 ± 0,33	2,15 ± 0,52	1,00 ± 0,00	1,00 ± 0,00	0,00 ± 0,00	1,00 ± 0,00
From Foot Kicking Leg	1,3 ± 0,15	1,33 ± 0,33	1,00 ± 0,00	1,54 ± 0,18	1,00 ± 0,00	1,33 ± 0,33	1,33 ± 0,33
From Shoulders	1,78 ± 0,43	1,25 ± 0,16	1,00 ± 0,00	1,33 ± 0,33	1,25 ± 0,25	2,42 ± 0,49	1,67 ± 0,24
From Head	2,28 ± 0,36	1,77 ± 0,43	1,25 ± 0,25	1,00 ± 0,00	1,00 ± 0,00	1,33 ± 0,33	2,16 ± 0,43
Total	**4,26 ± 0,46**	**4,30 ± 0,45**	**1,60 ± 0,23**	**1,24 ± 0,10**	**1,43 ± 0,16**	**1,77 ± 0,23**	**1,79 ± 0,20**

Table 8. Mean (± se) number of transitions between and within different interest areas in soccer and judo experts.

This may mean that watching a near object requires much more gaze behaviour with respect to watching a far object. In other words if one has to analyze a soccer kick he faces a far situation because more interest areas fall within his fovea and he doesn't need to move his eyes. Instead, fighting against a close opponent, one can see only few interest areas and he has to use parafoveal retina to recognize any attack and react to it. The percentage of time spent to see interest areas is much more in judo than in soccer situation (table 9) and it is a confirmation of the hypothesis.

Soccer		Judo	
Ball	47.70 ± 5.55	Face	34.14 ± 7.80
Off-Ball	21.02 ± 3.86	Jacket Skirt	0.00 ± 0.00
Field Far	1.79 ± 0.39	Lapel	43.11 ± 5.54
Field Near	2.11 ± 0.69	Legs	0.00 ± 0.00
Run-Up Space	3.08 ± 0.82	Sleeve	21.95 ± 3.82
Foot Kicking Leg	2.42 ± 0.49	Hand	6.29 ± 2.24
Foot Non-Kicking Leg	2.25 ± 0.62	Other	2.46 ± 0.67
Knee Kicking Leg	6.61 ± 2.87		
Knee Non-Kicking Leg	0.99 ± 0.48		
Hips	3.10 ± 0.50		
Shoulders	8.43 ± 1.76		
Head	12.04 ± 2.41		
Other	5.61 ± 1.43		
	Total		
Soccer	12.80 ± 1.38	Judo	26.04 ± 3.01

Table 9. Mean % (± se) viewing time in soccer and judo experts.

The comparison is an attempt to see if in these two kind of experiments there was distinctive gaze behaviour, given that judo situation comprised the near or peripersonal space while soccer goalkeepers concerned far or extrapersonal space. There are very few reports addressing this topic in sports. Some researchers have found interesting results in gaze behaviour studied when athletes aim at a far target (Vickers 1996; Williams 2002). A distinction is therefore made between aiming skills to near targets and those to far targets where the individual maintains control only to the point of release (basketball free throws).

Based on electrophysiological data in monkeys and neuropsychological observation in patients, it has been postulated that the dorsal and ventral processing streams are differentially involved in the neural representation of near and far space, respectively (Previc 1998). The dorsal and ventral streams which link the striate cortex to the posterior parietal lobe and inferotemporal cortex, respectively, have dedicated perceptual and attentional functions. The dorsal stream, specialized for spatial perception (i.e., “where”), apparently has a full representation of the visual field, including the far periphery, and may be responsible for higher attentional resolution and enhanced focused attention (e.g., discriminating targets from distractors; attentional tracking) in tasks performed in near space (in the lower visual field). In contrast, the ventral stream is reportedly specialized for perception and representation of objects and scenes (i.e., “what”) and is heavily biased toward central vision (particularly the fovea). The ventral stream provides an apparent visual search advantage in far space through spatial analysis, motion processing, depth processing, and more efficient saccadic eye movement and attentional shifting (Goodale 1992). In addition to the near and far space attentional biases related to the dorsal and ventral visual streams, orienting of attention is controlled by dorsal and ventral networks connecting the frontal and parietal lobes. The bilateral dorsal attention networks, linking the intraparietal sulcus and frontal eye field within each hemisphere, control the allocation of spatial attention and the selection of stimuli and response (endogenous orienting), while the right hemisphere ventral attention network, involving the temporoparietal junction and ventral frontal cortex, is concerned with target and reorienting to salient stimuli (exogenous orienting). Exogenous attention is controlled by external stimulus presentation and it is not under subjects’ control, instead, endogenous attention refers to directing attention under control of the individual, for example, when attention is being focused on the basis of instructions.

Abrams et al. (1990) have proposed three eye movement hypotheses that describe the coordination of the hand-gaze when aiming at near targets. In the **position-only hypothesis**, the eyes locate the target and remain fixed till completion of the movement. In this hypothesis information derived by fixation on the target is necessary to complete the movement accurately. In the **movement-only hypothesis** the eyes move 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 and was reported by Abrams et al. (1990) in a wrist rotation task where a cursor was directed to a target on a computer monitor. When people produce rapid aimed limb movements, spontaneously executed a saccade toward the target of their movements. The saccade is closely time locked to the initiation of the limb movement, although its order of occurrence does not seem crucial: Limb movement (wrist rotation) are equivalent whether they lead or follow an eye movement and the most participants tested began to move their eyes first on a majority of trials. Regardless of the relative onset of the eye and limb movements, the eyes almost always arrived at the target well before the limb did.

In Vickers's study (Vickers 1996) expert subjects were expected to fix the target through the preparation, impulse, and error correction phases, thereby supporting the position-only hypothesis. Near experts were expected to shift their gaze early in the movement followed by a fixation on the target during execution, thereby displaying the movement plus position strategy. During the key propulsion phase of the shooting action, fixation on the target did not occur; the target, the subject's hand, and the ball were not fixed during this time. Instead, the subject's gaze moved freely or they blinked, with both of these behaviour being most prevalent in the expert performers. In the free throw there appeared to be no final error correction phase as found when aiming at near target.

5. General Conclusions

From a psychological point of view, expert judoists use the covert orientation of attention which is the ability to allocate visual-spatial attention to different locations and to use diffuse attention (Posner 1980). From a psychophysiological point of view, experts' visual behaviour reveals a complementarities between foveal and peripheral vision. Our results on expert athletes in fact confirm that differences in visual behaviour, taking into account their level of expertise, appear mainly when the test presentation is continuous, last for a relatively long period of time and present a high level of uncertainty with regard to the chronology and the nature of events (Ripoll 1995).

Expert judoists performers “anchor” the fovea on central regions of the scene (lapel and face) while using peripheral vision to monitor opponents’ limb movements (Williams 1999). Further direction on the study could be the monitoring of anxiety and some physiological parameter to see if the hypothesis, suggested in the discussion, could be confirmed.

In summary, expert goalkeepers tend to spend more time in inside-save than instep-save penalty comparison that was opposite in scored penalty kick. In particular, participants looked foot non kicking leg and knee kicking leg in saved penalty kick respect to other areas. This is the first study that analyzes gaze behaviour of soccer goalkeepers in a real-sport task, further research is required to confirm or reject this hypothesis, maybe utilizing the occlusion criteria paradigm that was used in different laboratory studies (Williams and Burwitz 1993) with different occlusion periods before the players kicked the ball, at impact and after impact blinding the interest areas that were significant in this study.

8. References

Abernethy, B., & Russell, D. G. (1987). "Expert-novice differences in an applied selective attention task." Journal of Sport Psychology **9**: 326-345.

Abernethy, B., & Russell, D. G. (1987). "The relationship between expertise and visual search strategy in a racquet sport." Human Movement Science **6**: 283-319.

Abrams, R. A., Meyer, D.E., Kornblum, S. (1990). "Eye-Head Coordination: Oculomotor control in rapid aimed limb movements." Journal of Experimental Psychology: Human Perception and Performance **16**(2): 248-267.

Allard, F., Burnett, N. (1985). "Skill in sport." Canadian journal of psychology **39**: 294.

Bahill, A. T., Karnavas, W.J. (1993). "The perception of baseball's rising fastball and breaking curveball." Journal of Experimental Psychology: Human Perception and Performance **19**: 3.

Bahill, A. T., LaRitz, T. (1984). "Why can't batters keep their eyes on the ball?" American Scientist **72**(3): 249-253.

Bard, C., Fleury, M (1981). Considering eye movementa as a predictor of attainment. Vision and sport. I. M. Cockerill, MacGillvary, W.W. Cheltenham, Stanley Thornes**:** 28-41.

Bard, C., Fleury, M.L. (1976). "Analysis of visual search activity during sport problems situations." Journal of Human Movements studies **3**: 214.

Barlow, H., Blakemore, C.B., Pettigrew, J.D. (1967). "The neural mechanism of binocula depth perception " Journal of Physiology **193**: 327.

Berg, W. P., Killiam, S.M. (1995). "Size of the visual field in collegiate fast-pitch softball players and nonathletes." Perceptual motor skills **81**: 1307.

Bridgeman, B., Palca, J. (1980). "The role of microsaccades in high acuity observational tasks." Vision research **20**: 813-817.

Browder, K. D., C. L. Tant, et al. (1991). A three dimensional kinematic analysis of three kicking techniques in female players. . Biomechanics in Sport. Ames, IA, Iowa State University Press.**:** 95-100.

Carpenter, R. H. S. (1991). The visual origins of ocular motility. Eye Movements. R. H. S. Carpenter. London, MacMillan Press. **8:** 1-10.

Chase, W. G., Simon, H.A. (1973). "Perception in chess." Cognitive psychology **4**: 55.

Christenson G.N., W., A.M. (1988). "Visual skills of athletes versus nonathletes: development of a sports vision testing battery." Journal of the american optometric association **59**: 666.

Ciuffreda, K. J., Tannen, B. (1995). Eye movement basics for the clinicians. St. Louis, Mosby.

Cowey, A., Small, M., & Ellis, S. (1994). "Left-visuo spatial neglect can be worse in far than in near space." Neuropsychologia **32**: 1059-1066.

Cowey, A., Small, M., & Ellis, S. (1999). "No abrupt change in visual hemineglect from near to far space." Neuropsychologia **37**: 1-6.

Deshaies, P., Pargman, D. (1976). "Selected visual abilities of college football players." Perceptual motor skills **43**: 904.

Dicks, B. D. (in press). "Examination of gaze behaviors under in situ and video simulation task constraints reveals differences in the information used for perception and action." Attention, Perception & Psychophysics.

DiRusso, F., Pitzalis, S., Spinelli, D. (2003). "fixation stability and saccadic latency in elite shooters." Vision Research **43**: 1837.

Elmurr, P., Cornell, E., Heard, R. (1997). "Saccadic eye movements (part 2): the effects of practice on saccadic reaction time." International journal of sports vision **4**: 13.

Engbert, R., Kliegl, R. (2003). "Microsaccades uncover the orientation of covert attention." Vision research **43**: 1035-1045.

Epelboim, J., Kowler, E. (1993). "Slow control with eccentric targets: Evidence against a position-corrective model." Vision research **33**: 361-380.

Erickson, G. (2007). Sports Vision: vision care for the enhancement of sports performance. S.Louis, Butterworth-Heinemann Elsevier.

Farrow, D. A., B. (2003). "Do expertise and the degree of perception-action coupling affect natural anticipatory performance? ." Perception **32**: 1127-1139.

FIFA (2008). The penalty kick. The law of the game. Zurich, Federation Internationale de football association**:** 41-42.

Franks, I. M. and T. Harvey (1997). "Cues for goalkeepers: High-tech methods used to measure penalty shot response." Soccer Journal. **42**: 30-38.

Garland, D. J., Barry, J.R. (1990). "Sports expertise:the cognitive advantage." Perceptual motor skills **70**: 1299.

Goodale, M. A., Milner, A.D. (1992). "Separate visual pathways for perception and action." Trends in neurosciences **15**(1): 20-25.

Graydon, J., Bawden, M., Holder, T (1996). "The effects of binocular and monocular vision on a table tennis striking task under conditions of spatial-temporal uncertainty." International journal of sports vision **3**: 35.

Grossman, G. E., Leigh, R.J., Abel, L.A., Lanska, D.J., Thurston, S.E. (1988). "Frequency and velocity of rotational head perturbations during locomotion." Experimental Brain Research **70**: 470-476.

Hafed, Z. M., Clark, J.J. (2002). "Microsaccades as an overt measure of covert attention shifts." Vision research **42**: 2533-2545.

Halligan, P. W., & Marshall, J.C. (1991). "Left neglect for near but not for far space in man." Nature **350**: 498-500.

Harwood, M. R., Harris, C.M. (2002). "Time-optimality and the spectral overlap of saccadic eye movements." Annals of the New York Academy of Sciences **956**: 414-417.

Hay, J. G. (1985). The Biomechanics of Sports Techniques. Englewood Cliffs, NJ, Prentice-Hall.

Hofeldt, A. J., Hoefle, F.B. (1993). "Stereophotometric testing for Pulfrich's phenomenon in professional basketball players." Perceptual motor skills **77**: 407.

Husain, M., & Kennard, C. (1996). "Visual neglect associated with frontal lobe infarction." Journal of Neurology **243**: 652-657.

Isokawa, M. and A. Lees (1988). A biomechanical analysis of the instep kick motion in soccer. Science and Football. London, E & FN Spon**:** 449-455.

Kemmerer, D. (1999). ""Near" and "far" in language and perception." Cognition **73**: 35-63.

Kim, S. and S. Lee (2006). "Gaze behavior of elite soccer goalkeeper in successful penalty kick defense." International Journal of Applied Sports Sciences **18**(1): 96-110.

Kioumourtzoglou, E., Kourtessis, T., Michalopoulos, M. (1998). "Differences in several perceptual abilities between experts and novices in basketball, volleyball and water-polo." Perceptual motor skills **86**: 899.

Kowler, E. (1991). The stability of gaze and its implications for vision. Eye movements. R. H. S. Carpenter. London, MacMillan Press. **8:** 71-92.

Kuhn (1988). Penalty-kick strategies for shooters and goalkeepers. Science and Football. London, E & FN Spon**:** 489-492.

Kukla, D. A., Love, P.A., Sanet, R. (1993). "Contrast sensitivity function profiling: by sport and sport ability level." International journal of sports vision **1**: 25.

Land, M. F., & McLeod, P. (2000). "From eye movements to action: How batsmen hit the ball." Nature Neuroscience **3**.

Lees, A. and L. Nolan (1998). "The biomechanics of soccer: A review." Journal of Sports Sciences **16**: 211-234.

Leigh, R. J., Zee, D.S. (2006). The neurology of eye movements, Oxford University press.

Luhtanen, P. (1988). Kinematics and kinetics of maximal instep kicking in junior soccer players. Science and Football. London, E & FN Spon**:** 441-448.

Martinez-Conde, S., Macknik, S.L., Hubel, D.H. (2004). "The role of fixational eye movements in visual perception." Nature Reviews Neuroscience **5**: 229-240.

Masters, R. S. W., J. Van der Kamp, et al. (2006). "Imperceptibly off-center goalkeepers influence penalty kick direction in soccer." Phychological Science **18**(3): 222-223.

Matsumoto, Y., M. Ikai, et al. (1969). Studies on the visual fixation point of the referee during a judo match. Report 3, Kodokan.

Matsumoto Y., Ikai M., et al. (1969). Studies on the visual fixation point of judoists. Report 3, Kodokan.

Matsumoto Y., T., Y., Nakamura, R., Kawamura, T., Watanabe, A. (1972). A fundamental study on the distribution of attention in the visual field of judoists. Bulletin of the Association for the Scientific Studies on Judo. Kodokan. **Report 4**.

McLean, B. D. and D. M. Tumilty (1993). "Left-right asymmetry in two tipes of soccer kick." British Journal of Sports Medicine. **27**: 260-262.

McMorris, T. and S. Colenso (1996). "Anticipation of professional soccer goalkeepers when facing right- and left-footed penalty kicks." Perceptual and Motor Skills **82**: 931-934.

Milner, A. D., Goodale, M.A. (1995). The visual brain in action. Oxford, Oxford University Press.

Morya, E., R. Ranvaud, et al. (2003). "Dynamics of visual feedback in a laboratory simulation of a penalty kick." Journal of Sports Sciences **21**: 87-95.

Muller, J. (2003). Muller's elements of physiology. Bristol, Thoemmes.

Müller, S., Abernethy, B. & Farrow, D. (2006). "How do world-class cricket batsmen anticipate a bowler's intention? ." The Quarterly Journal of Experimental Psychology **59**(12): 2162-2168.

Panchuk, D. and J. N. Vickers (2006). "Gaze behavior of goaltenders under spatial-temporal constraints." Human Movement Science **25**: 733-752.

Pierantozzi, E., Nerozzi, E., Piras, A., Lubisco, A. (2008). Analysis of the fighting phase before the first grip in the finals of the judo world championship 2007. Advances in Judo Biomechanics Research: " Modern Evolution on Ancient Roots" A. Sacripanti, VDM Verlag Dr. Müller

Piras, A., Lobietti, R., Squatrito, S. (2010). "Study of saccadic eye movement dynamics in volleyball: Comparison among athletes and non athletes." Journal of Sports Medicine and Physical Fitness **In Press**.

Poggio, G. F., Talbot, W.H. (1981). "Mechanism of static and dynamic stereopsis in foveal cortex of rhesus monkey." Journal of Physiology **315**: 469.

Posner, M., I. (1980). "Orienting of Attention." Quarterly journal of experimental psychology **32**: 3-25.

Posner, M. I. (1980). "Orienting of attention." Quarterly journal of experimental psychology **32**: 3-25.

Posner, M. I., Raichle, M.E. (1994). Images of Mind. Oxford, W.A. Freeman and Company.

Previc, F. H. (1998). "The neuropsychology of 3-D space." Psychological Bulletin **124**: 123-164.

Regan, D. (1991). Binocular vision. London, Macmillan.

Regan, D., Beverly, K.I. (1978). "Looming detectors in the human visual pathway." Vision research **18**: 415.

Regan, D., Beverly, K.I., Cyander, M. (1979). "The visual perception of motion in depth." Scientific american **241**: 136.

Regan, D., Erkelens, C.J., Collewijn, H. (1986). "Necessary conditions for the perception of motion in depth." Investigative Ophthalmology & Visual Science **27**: 584.

Ripoll, H., Bard, C., Paillard, J. (1986). "Stabilization of the head and eyes on target as a factor in successful basketball shooting." Human Movement Sciences **5**: 47.

Ripoll, H., Bard, C., Paillard, J., Grosgeorge, B. (1982). Caracteristique de la centration de l'oeil et de la tete sur la cible et son role dans l'execution du tir en basketball. New paths to sport learning. T. Orlick, Partington, J.T., Salmela, J.H. Ottawa, Perceptives in Sport**:** 33-36.

Ripoll, H., Florence, P. (1988). "What does keeping one's eye on the ball mean?" Ergonomics **31**: 1647-1654.

Ripoll, H., Kerlirzin, Y., Stein, J.F., Reine, B. (1995). "Analysis of information processing, decision making and visual strategies in complex problem solving sport situations." Human Movement Science **14**(3): 325-349.

Ripoll, H., Papin , J.P., Guezennec, J.Y., Verdy, J.P. & Philip, M. (1985). "Analysis of visual scanning patternsof pistol shooters." SJournal of Sports Sciences **3**(2): 93-101.

Rizzolatti, G., Camarda, R., Fogassi, L., Gentilucci, M., Luppino, G., & Martelli, M. (1988). "Functional organization of area 6 in the macaque monkey. II. Area F5 and the control of distal movements." Experimental Brain Research **71**: 491-507.

Rizzolatti, G., Fadiga, L., Fogassi, L., & Gallese, V. (1997). "The space around us." Science **277**: 190-191.

Salmela, J. H. F., P. (1979). "Visual cues in ice hockey goaltending. ." Canadian Journal of Applied Sport Science **4**(1): 56-59.

Sanchez, F. J. N., A. O. Sicilia, et al. (2005). "Anticipation in soccer goalkeepers during penalty kicking." Int. J. Sport Psychol. **36**: 284-298.

Savelsbergh, G. J. P., J. Van der Kamp, et al. (2005). "Anticipation and visual search behavior in expert soccer goalkeepers." Ergonomics. **11**: 1686-1697.

Savelsbergh, G. J. P., Whiting, H.T.A. (1992). "The acquisition of catching under monocular and binocular conditions." Journal of Motor Behaviour **24**: 320.

Savelsbergh, G. J. P., A. M. Williams, et al. (2002). "Visual search, anticipation and expertise in soccer goalkeepers." Journal of Sports Sciences **20**: 279-287.

Shim, J., Miller, G. & Lutz, R. (2005). "Visual cues and information used to anticipate tennis ball shot and placement." Journal of Sport Behavior **28**(2): 186-200.

Singer, R. N., Williams, A.M., Frehlich, S.G., Janelle, C.M., Radlo, S.J., Barba, D.A., Bouchard, L.J. (1998). "New Frontiers in Visual Search: An Exploratory Study in Live Tennis Situation." Research Quarterly for Exercise and Sport **69**(3): 290-296.

Starkes, J. L. (1987). "Skill in field hockey: the nature of the cognitive advantage." Journal of sport psychology **9**: 146.

Steinman, R. M., Cunitz, R.J., Timberlake, G.T., Herman, M. (1967). "Voluntary control of microsaccades during maintained monocular fixation." Science **155**: 1577-1579.

Steinman, R. M., Cushman, W.B., Martins, A.J. (1982). "The precision of gaze: a review." Human Neurobiology **1**: 97.

Thomas, J. R. and J. K. Nelson (2001). Research methods in physical activity. Champaign, IL, Human Kinetics.

Tong, F. (2003). "Primary Visual Cortex and Visual Awarness." Nature Review Neuroscience **4**: 219-229.

Trachtman, J. N. (1973). "The relationship between ocular motilities and batting average in little leaguers." American Journal of Optometry and Archives of American Academy of Optometry **50**: 914.

Treisman, A. (1999). "Solutions to the binding problem." Neuron **24**: 105-110.

Treisman, A., Gelade, G. (1980). "A feature-integration theory of attention." Cognitive Phycology **12**: 97-136.

Turano, K. A., Geruschat, D.R., Baker, F.H. (2003). "Oculomotor strategies for the direction of gaze tested with a real-world activity." Vision research **43**: 333-346.

Tyler, C. W. (1991). Cyclopean vision. Binocular Vision. D. Regan. London, MacMillan Press: 38-74.

Van der Kamp, J. (2006). "A field simulation study of the effectiveness of penalty kick strategies in soccer: Late alteration of kick direction increase errors and reduce accuracy." Journal of Sports Sciences **24**(5): 467-477.

Vickers, J. N. (1992). "Gaze control in putting." Perception **21**: 117.

Vickers, J. N. (1996). "Control of visual attention during the basketball free throw." American journal of sports medicine **24**: S93-7.

Vickers, J. N. (1996). "Visual control when aiming at a far target." Journal of Experimental Psychology: Human Perception and Performance **22**(2): 342-354.

Vickers, J. N. (2007). Perception, cognition, and decision training: The quiet eye in action. Windsor, ON, Human Kinetics.

Vickers, J. N., Adolphe, R.M. (1997). "Gaze behaviour during a ball tracking and aiming skill." International journal of sports vision **4**: 18.

Von Hofsten, C. (1976). "The role of convergence in visual space perception." Vision research **16**: 193.

Wade, N. J., Tatler, B.W. (2005). The Moving Tablet of the Eye: The origins of modern eye movement research. Oxford, Oxford University Press.

Whittaker, S. G., Eaholtz, G. (1982). "Learning patterns of eye motions for foveal pursuit." Investigative ophthalmology & Visual Science **23**: 393.

Williams, A. M. and L. Burwitz (1993). Advance cue utilization in soccer. Science and Football. London, E & FN Spon**:** 239-243.

Williams, A. M., Griffiths, I.W. (2002). "A kinematic analysis of the prevalence of pre-impact cues in the football penalty kick." Journal of Sports Sciences **20**(1): 74.

Williams, A. M., Singer, R.A., Frehlich, S. (2002). "Quiet eye duration, expertise, and task complexity in a near and far aiming task." Journal of motor Behavior **34**: 197-207.

Williams, A. M., Ward, P., Knowles, J. M., Smeeton, N.J. (2002). "Anticipation Skill in a Real-World Task: Measurement, Training, and Transfer in Tennis." Journal of experimental Psychology: Applied **8**(4): 259-270.

Williams, A. M. a. E., D. (1999). "Anxiety, Expertise, and Visual Search Strategy in Karate." Journal of Sport & Exercise Psychology **21**(4): 362-375.

Williams, J. M., Thirer, J. (1976). "Vertical and Horizontal peripheral vision in male and female athletes and nonathletes." Research quarterly of the American Association for Health and Physical Education **46**: 200.

Wilson, T. A., Falkel, J. (2004). SportsVision: training for better performance. Champaign, IL, Human Kinetics.

Winterson, B. J., Collewijn, H. (1976). "Microsaccades during finely guided visuomotor tasks." Vision research **16**: 1387-1390.

Wurtz, R. H. (1996). "Vision for the control of movement." Investigative ophthalmology and vision science **11**: 2130-2145.

Wurtz, R. H., Mohler, C.W. (1976). "Organization of monkey superior culliculus: enhanced visual response of superficial layers cells." Journal of Neurophysiology **39**: 745-765.