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Vestibology

Saccades and driving

Saccadi e guida

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SUMMARY

Driving is not only a physical task, but is also a mental task. Visual inputs are indispensable in scanning the road, communicating with other road users and monitoring in-vehicle devices. The probability to detect an object while driving (conspicuity) is very important for assessment of driving effectiveness, and correct choice of information relevant to the safety of driving determines the efficiency of a driver. Accordingly, eye fixation and eye movements are essential for attention and choice in decision making. Saccades are the most used and effective means of maintaining a correct fixation while driving. In order to identify the features of the most predisposed subjects at high driving performances and those of the high-level sportsmen, we used a special tool called Visual Exploration Training System. We evaluated by saccade and attentional tests various groups of ordinary drivers, past professional racing drivers, professional truck drivers and professional athletes. Males have faster reaction time compared to females and an age below 30 seems to guarantee better precision of performance and accuracy in achieving all visual targets. The effect on physical activity and sports is confirmed. The performances of the Ferrari Driver Academy (FDA) selected students who were significantly better than those of a group of aspiring students and amateur racing drivers probably thanks to individual predisposition, training and so-called '*neural efficiency*'.

KEY WORDS: Saccades • Driving • Racecar driver • Eye-tracking • High-level sportsmen

RIASSUNTO

Guidare non è solo un compito fisico, ma anche mentale. Gli input visivi sono indispensabili per la scansione della strada, la comunicazione con gli altri utenti della strada e il monitoraggio dei dispositivi di bordo. La probabilità di rilevare un oggetto mentre si guida (conspicuity) è molto importante per la valutazione dell'efficacia della guida e la scelta corretta delle informazioni rilevanti per la sicurezza determina l'efficienza di un conducente. Di conseguenza la fissazione visiva e il movimento degli occhi sono essenziali per l'attenzione e la scelta nel prendere decisioni. I movimenti saccadici sono il mezzo più usato ed efficace per mantenere una corretta fissazione durante la guida. Per identificare le caratteristiche dei soggetti più predisposti alle alte prestazioni di guida e quelle degli atleti di alto livello, abbiamo utilizzato il Visual Exploration Training System. Abbiamo studiato con test saccadici e attentivi vari gruppi di conducenti ordinari, di piloti professionisti, di camionisti professionisti e di altri atleti professionisti. I maschi hanno un tempo di reazione più veloce rispetto alle femmine e l'età inferiore ai 30 anni sembra garantire una migliore precisione delle prestazioni e nel raggiungere tutti gli obiettivi visivi. L'effetto dell'attività fisica e lo sport sono confermati. Le performance degli allievi selezionati della Ferrari Driver Academy sono significativamente migliori, in particolare rispetto al gruppo di aspiranti studenti e piloti dilettanti, probabilmente grazie alla predisposizione individuale e sulla cosiddetta 'efficienza neurale' dovuta sia ad un utilizzo ridotto delle risorse che al miglioramento nell'elaborazione delle informazioni, grazie a una migliore comunicazione tra le aree del cervello correlate alle attività.

PAROLE CHIAVE: *Saccadi • Guida • Piloti sportivi • Eye-tracking • Sportivi di alto livello*

Introduction

Driving is not only a physical task, but is also a mental task.

Our behaviour while driving depends from various factors: external non-modifiable elements (e.g. weather), external modifiable elements (mechanical equipment) and those dependent on our body (physical characteristics, psychological and adaptive factors). We live in a multi-sensorial environment: visual information (such as objects, persons, animals, buildings, locations), acoustic information (like sounds, voices, noises), vestibular information from the labyrinths (like linear and angular acceleration, head position), proprioceptive information (body position) and tactile information (skin perception of posture and movement) are fundamental for adaptive programs to every environmental condition.

Many subjective cognitive processes, like attention, memory, learning, motivation, decision and psychological factors, are able to influence information processing and the ability to adapt quickly to modifications. Human errors such as misperception, information processing errors and

poor decision making are frequently identified as causes of accidents [1-5].
Visual inputs are indispensable in scanning the road, communicating with other road users and monitoring in-vehicle devices. The probability to detect an object while driving (conspicuity) is very important for assessment of driving effectiveness, and correct choice of information relevant to the safety of driving determines efficiency of a driver.
Accordingly, eye fixation and eye movements are essential for attention and choice in decision making [6-9].
The main goal of eye movements is to maintain foveal control of the most important visual target in every static or dynamic condition, but drivers need to acquire relevant information using both central and peripheral vision, the so-called useful field of view (UFOV).
Various eye movements are used to perceive information in driving: smooth pursuit (SP), opticokinetic reflex (OKR), vestibulo-oculomotor reflex (VOR), vergence movements and saccadic movements (SM). These various systems are closely connected to control of the head (eye-head coordination mechanism) and total body movements (posture and gait control).
The eyes are never really fixed, because physiological micro-movement is continuous and has a nature of low-amplitude (< 1') and high-frequency vibrations (50-100 Hz).
SM constitute the vast majority of ocular movements.
Saccadic Reaction Time (RT) exhibits temporal variability that is largely accounted for by the time necessary for visuo-motor and motor neurons to reach a specific threshold. The velocity is proportional to movement amplitude and reaches 900°/sec in humans. The saccade-generating system cannot respond to subsequent changes in the position of the target during eye movement and a second saccade must be made to correct the error. Any shift of gaze larger than about 20°-30° is accompanied by a head movement (so-called eye-head coordination). The head is moving at least 20-50 msec later and the vestibulo-ocular-reflex (VOR) causes the eyes to roll back in the head to keep gaze on the target.
SM may be reflexed or voluntary, peripherally-visually guided or centrally guided, and can be of various kinds. With regards to driving, the most important kind of saccades are the pro-saccades (reflexive saccade triggered exogenously by the appearance of a peripheral stimulus, or by the disappearance of a fixation stimulus), the scanning saccades (triggered endogenously for the purpose of exploring the visual environment), the anti-saccades (the eyes move away from the visual onset toward another direction), the memory guided saccade (the eyes move toward a remembered point, with no visual stimulus) and the predictive saccades (the eyes are kept on an object moving in a temporally and/or spatially predictive manner; saccades often coincide with or anticipate the predictable movement of an object).
Voluntary saccades are much more frequent in everyday life. A simple visually guided saccadic eye movement requires at least two mental processes: target selection and motor preparation. These processes are carried out by a network of cortical and subcortical structures [10 11]. The frontal eye fields, parietal eye field, the motion-sensitive area (MT/V5), the precuneus (V6), and the angular and the cingulate gyri were more activated in reflexive saccades than in voluntary saccades. No significant difference in activation was found in the cerebellum. Working memory may be involved in anticipatory drifts [12] and different cortical resources may be recruited when prediction is utilised, resulting in reduced latency, increased peak velocity and anticipatory movements. The cerebellum is crucial for synchronising saccades with learned or planned temporal events and the cerebellar vermis IV/V is involved in temporal prediction for saccadic movements. Usually antisaccadic responses show an increased latency and number of errors compared to prosaccadic response and the antisaccadic task also allows evaluation of the capacity to inhibit reflexive saccades and produce voluntary saccades. Its neuronal related network is still discussed [13-15]. To explore our environment, we make on average three saccades per second. Most of these saccades are of small amplitude (< 10° of visual angle) and in conjunction with head and or trunk movements [16]. Saccade motor control is highly stereotyped and automatised. Its long-term maintenance is served by an oculomotor learning process called saccadic adaptation which has to monitor success after the saccade and learn from observed errors in order to fine-tune planning parameters for future saccades [17]. The ability to generate antisaccades in the direction away from a new visual stimulus is fundamental in order to maintain an adequate level of attention. The antisaccade requires the capacity to inhibit a reflexive saccadic response in favour of complex volitional behaviour [18-22]. Saccadic movements can be trained and within half an hour healthy subjects become able to progressively improve saccadic control [23-27]. Activity in the inferior premotor cortex is significantly modulated and decreased during the progress of learning. Saccadic movements involve a problem of visual perception. During each, the visual scene sweeps across the retina with high-speed motion with inevitable blurring of the image, as the retina is sweeping the visual field. Object positions in retinal coordinates change, the entire visual image is not updated and humans become effectively blind, but usually we are not aware of this blur during eye movement. We do not perceive very fast disturbing motion or jumps of the

visual scene because there is a mechanism that "cuts off" the processing of retinal images when it becomes blurred. This lack of perception or omission is linked to a phenomenon called masking or saccadic suppression [28], which reduces the impact of retinal motion during the saccade on the visual system. This phenomenon is characterised by the inability to detect changes in the location of a target when the change occurs immediately before, during, or shortly after the saccade (120 msec). Because saccadic suppression starts before the actual onset of the saccade, it cannot be triggered by retinal motion and must be centrally activated by the brain. In this way, the cognitive individual system is able to reconstruct, "in real time", all the details of the retina caught in a glimpse, but not yet focused, through a "filling in" process. For this reason, the spatial reconstruction of the environment that surrounds us takes effect on a central level by comparing memorised past experiences [29]. However, each scene contains many different objects, few of which are relevant to behaviour at any given moment. Therefore, attentional mechanisms are also needed to select relevant objects. For this reason, the entire visual image is not updated during each saccade and large sudden changes in a visual scene can go undetected (change blindness).

Since the 1980s many authors have understood the important role of vision in driving and have measured eye movements, in daily practice, in sports, on heavy vehicles, at intersections without traffic lights, or in search of parking spaces, and have evaluated the effect of central de-structuring of eye movements due to alcohol intake [30]. There is evidence that the pattern of eye movements of the driver depends on the number of objects and on the complexity of the landscape [31 32] and on anticipation, which in turn depends on experience, and which can modify the reaction times. OKR is important while driving curves and at night, when solicitation of the peripheral retina is given by curbs, or, for instance, billboards, trees or tribunes. Too many optokinetic stimulations can be dangerous because of the large number of provoked saccadic phases. The angular VOR (from semicircular canals) makes a fundamental contribution to the maintenance of dynamic visual acuity while moving the head on horizontal and vertical planes. The linear VOR (from otolithic macular receptors) is very important during linear accelerations and decelerations. Unfortunately, the role of the substitutional SM which are typical of vestibular loss patient and which are able to increase the risk of saccadic visual suppression and blindness has not been evaluated.

However, saccades are the most widely used and effective means of maintaining a correct fixation while driving and the frequency of blinking, and saccade characteristics are a parameter to determine the level of fatigue and of attention [33]. In the task of driving, saccades can be frequent and can be shorter than 200 msec.

Typically, drivers tend to fixate straight ahead when driving, usually towards the location where the vehicle will be in the next few seconds, at least on straight and undemanding roads. Drivers may adopt different search strategies when they need to perceive objects located in front of and behind their own car by using the rear and side mirrors or when they drive on a straight road (stable driving), and mainly perceive objects located in front of their own car with few mirror glances. The reflexions in the outside rear view mirror images, passing through double-gazed windows of the car, may provoke misperceptions. When approaching an intersection, drivers made repeated saccadic gaze movements; after entering the intersection, saccadic gaze movements are directed in the direction of turning. One of the most complex visual tasks when driving is exiting a multistory car park, which involves the scanning of hundreds of parked vehicles with an average fixation time of approximately 100 msec. The total time spent fixating on a likely hazardous vehicle is longer for people in the driving-only condition than for those talking on a mobile phone with less exploring saccades.

It can easily be argued that not looking in the right place almost certainly guarantees that drivers will not react to the risk appropriately. Common sense suggests that drivers should ''keep their eyes on the road'' and ''look where they are going.'' During navigation, a driver tends to choose a target point in the field of view, allowing him/her to anticipate direction of travel of the vehicle. This tendency can cause 2 types of conflict: emergence of a number of points that can be "target points" in the same visual task, or occurrence of a number of elements that could be important for driving, but related with a variety of other visual tasks, as pedestrian detection or visual control of navigation system. Car drivers can employ various visual strategies. The tangent point strategy is based on the use of the tangent point (TP). This is a point on the lane edge on the inside of the curve where the line of sight is tangential to the lane edge, and corresponds to the point in the driver's visual field where the visual orientation of the projection of the edge-line is reversed. The TP at a specific moment in time coincides with the apex point of a corner. The "gaze-sampling strategy" proposes to fixate points on the future path and measure the curvature of optic flow vectors, which can inform drivers whether they over- or under-steer and drivers direct their gaze on their future path, approximately 1 to 2 sec ahead of the vehicle [34]. In general, the TP condition is preferred, and previewing the road curvature by tracking a distant point contributes to the stability of steering [35]. During daytime driving, visual distractions, such as billboards located on the roadside of a highway, increase the frequency of errors. Older people need more fixation than younger ones to follow the same scene, as well as more fixation to recognise the scene in circumstances of poor visibility (fog, rain, etc.). Furthermore, older people respond more slowly than younger people, they are less accurate in capturing scenes viewed while driving and make smaller saccades than young drivers [36]. The literature suggests that expert athletes do not differ from non-experts in elementary abilities such as visual acuity, colour vision, or peripheral response time [37], but the former respond faster and more accurately to task-specific cues than non-experts [38 39]. However, despite the extensive body of knowledge on the technological aspects of racecars, comparatively little is known about the motor, perceptual and cognitive skills of athlete performance in motorsports [40 41]. Knowledge of these skills may aid in designing training methods for racing drivers and improve driver-vehicle interfaces for not only motorsport applications, but also road vehicles [42 43]. Both professional and naïve drivers may share the common knowledge necessary for ordinary road driving but driving a racing-car implies a number of additional skills, from the use of different controls to the management of braking and rapid accelerations.

It is well established that practice is a prerequisite for achieving high levels of performance [44]. Many studies have examined the effects of driving experience on eye movements using driving settings [45 46]. During stable driving, eye movements are less variable in trained drivers than in untrained drivers [47], and by varying driving conditions the difference becomes more evident. Experienced drivers seem to rely less on foveal vision and more on peripheral vision for steering control. Experienced or safer drivers seem to collect more information of the scene and to be able to move their locus of attention quicker than novices [46]. They also direct their gaze further ahead than novices. Horizontal scanning can be different. Experienced drivers tend to exhibit a wider horizontal search strategy with shorter eye-movement distances and longer fixation durations. On a dual-carriageway road, horizontal variances of fixation positions seem to be larger and fixation durations seem to be shorter in the experienced group than in the novice group; on a rural road experienced drivers seem to have smaller variances of fixation positions and longer fixation durations than novice drivers. Expert drivers are significantly more likely to gaze at areas of the roadway that contain information relevant to the reduction of risks than untrained drivers [46-48]. Their visual search depends on expectancy or anticipation skills based on experience. Therefore, the trained drivers may anticipate the locations where potential dangerous events and relevant objects are likely to appear. Those with better attentional function, as measured by avoidance of objects, exhibit faster and larger saccades when driving.

Advanced age hardly affects older drivers' ability to perceive hazards [49]. Novice drivers check the road more and estimate uninfluenced targets. They prioritise fixating on points on the road which aid steering, for example, "future path" points [50] or fixate closer to the vehicle to maintain lane position. They also look more at side pavements for possible pedestrians stepping out, inspecting slippery roads more often for adjoining traffic or look around for possible undertaking or overtaking vehicles in more demanding situations. This type of visual behaviour is important because wider scanning may result in more peripheral hazards.

In simulated driving there are fewer significant differences in a spatial distribution of fixation points. The differences in visual strategy seem to be linked not only to experience (i.e., how long someone has driven), but also to expertise in a particular field (policemen, truck drivers, racing drivers). Through practice and experience, task performance improves when actions become more automated and there is less of a requirement for conscious intervention [51 52]. With driving, it may be the case that through experience, fewer conscious resources are required to control the vehicle as driving skill becomes automatic and this frees up resources to allocate visual attention to other parts of the scene. At the tactical level, racing drivers show a different gaze strategy, adjusting their gaze as they drive through the corner and choose different driving lines and optimise their driving lines to increase corner exit speeds. However, racing drivers drive statistically significantly lower best lap times than non-racing drivers not only thanks to eye movements, but also to different eye-head coordination. The driver directs his gaze at a horizontal offset from the TP, and this offset is different for each corner, illustrating that the TP itself is not the main area of visual attention while driving through corners, but also with strong correlation between head rotation and the vehicle's rotational speed approximately one second later. The eyes-in-head angle remains relatively constant throughout the lap with large differences in the head yaw angle for racing drivers compared to non-racing drivers. Racing drivers turn their head nearly twice as often as non-racing drivers while cornering. Racing drivers also steer their head more into corners than non-racing drivers and vary their gaze direction as a function of traveled distance, whereas non-racing drivers keep a more constant gaze location, close to the vicinity of the TP. As racing drivers enter a corner, they direct their gaze away from the TP towards the outside of the corner, and as they progress through the corner they move their gaze towards the TP and beyond the TP. As the racing drivers exit the corner, they direct their gaze again towards the outside of the corner and subsequently look again towards the TP.

Brain functional studies have begun to indicate that skill acquisition in motor or cognitive domains may be associated with both increased or decreased response in task-related regions [53-59]. These findings suggest that neural efficiency may be associated with a greater automaticity and a reduced attentive load during task execution compared to 'ordinary' individuals [60 61].

Contextual cueing is a concept in psychology that refers to the manner in which the human brain gathers information from visual elements and their surroundings. It is defined as an attentional guidance or facilitation effect derived from past experiences of (mostly hidden) regularities of the (mainly visual) world. In other words, visual attention can be guided by incidentally acquired knowledge about spatial invariants. The attention decides to select or ignore the visual targets. Recent evidence collected in various highly skilled populations suggests that exceptional abilities, such as elite athletes, professional dancers, archers, divers and musicians, may be associated with specific changes in the morphological and functional architecture of the brain [56 59 62-78].

Skills and expertise are accompanied by relevant brain functional modifications even in drivers, and a distinct brain functional organisation emerges even during relatively simple visuo-motor tasks. Just 2 hours of practice with a driving simulator are sufficient to induce structural changes [79 80]. Indeed, recent fMR studies [81 82] showed both quantitative and qualitative differences between professional and naïve drivers. During the motor reaction, both naïve and professional drivers recruited similarly distributed networks (bilateral visual occipital, posterior temporal and parietal cortex, sensorimotor, motor and premotor areas, insula, striatum, cerebellum, cingulate, middle and inferior frontal cortex, prefrontal and precentral cortex, precuneus, parahippocampus, thalamus, lentiform nucleus), which include areas devoted to visuo-spatial processing, motor control and executive functions. However, comparative evaluation shows significant differences. Skilled car drivers are characterised by: reduced brain cortical activation and reinforced connectivity measures between task-relevant areas, consistent functional recruitment of driving-related brain regions (including vigilance, visuo-spatial monitoring, navigation, action preparation and motor control), increased grey matter density in basal ganglia, sensory-motor cortex, inferior frontal gyrus, retrosplenial cortex, fusiform/lingual gyrus and parahippocampus. Naïve car drivers are characterised by consistent modulation of brain response mostly limited to visual brain areas, and to regions devoted to spatial information processing, greater and more extensive response in supplementary motor area, left middle frontal and precentral cortex, bilateral inferior parietal lobule, right superior parietal, and postcentral cortex, cerebellum, and bilateral striatum and greater recruitment of task-related brain areas, including sensorimotor, parietal and prefrontal regions.

Materials and methods

In order to identify the features of the most predisposed subjects with high driving performances and those of high-level sportsmen, we used a special tool called Visual Exploration Training System (VET by SVEP) which consists in: personal computer (PC), eye-tracking system (120 Hz frequency analysis) and a new specific software by SVEP, according to the literature on the subject [30].

We examined 174 subjects:

- group 1 (FDA): 6 Ferrari Driver Academy (FDA) students; 6 males (M) aged 15 to 20 years (mean 17.2 ± 2.17);
- group 2 (ARD): 20 FDA aspiring students and amateur racing drivers; 19 M and 1 females (F) aged 14 to 27 years (mean 22.07 ± 5.23);
- group 3 (PRD): 7 past professional racing drivers; 7 M aged 36 to 55 years (mean 42.83 ± 7.13);
- group 4 (BVP): 35 professional basket and volley ball players (Italian top league); 22 M and 13 F aged 19 to 32 years (mean 23.43 ± 5.27);
- group 5 (ORD): 87 ordinary road drivers; 58 M and 29 F, aged 15 to 53 years (mean 33.92 ± 10.16);
- group 6 (PTD): 19 professional truck drivers; 19 M aged 35 to 47 years (mean 41.35 ± 4.73).

Both FDA-selected students and FDA-aspiring students as well as amateur racing drivers had prior experience in go-kart races and/or international high level races with different types of cars.

No participant had any history of balance disorder or asymmetric deficits of auditory or visual function. None was taking any medication.

Subjects were seating in front of a monitor wearing the eye-tracking system.

Two tests were performed.

In the first test (saccade test; ST), the subject had to fix a target point that appeared randomly on the monitor in 31 different positions in 23 sec.

We evaluated:

1. average start time (msec) of ocular movements, defined as the interval of time between the presentation of the stimulus appearance and start of appropriate response in the subject (RT);

2. target reaching time (msec) with 80% accuracy (TRT);
3. average percentage of accuracy in achieving all targets (AP1).

In this way we evaluated the ability to produce repeated saccades for random stimuli maintaining a high level of attention.

In the second test (attentional test; AT), the subject had to maintain fixation on a target point that appeared randomly on the monitor in 50 different positions in 50 sec even during the recurrent appearance of new distracting images (car, humans, animals, road-signals). The distractive images progressively increased in number (from 1 to 4) and type every 10 sec.

A possible saccade towards the distracting image requires a corrective antisaccade, which is more difficult to perform compared to a prosaccadic task. Given the greater difficulty of this task with respect to prosaccadic tasks, heightened control is needed for its success.

We evaluated:

1. number of centred target points or precision of performance (PP);
2. number of saccades not directed towards the target point or attention deficit index (ADI);
3. average percentage of accuracy in achieving all targets (AP2).

The study was developed according to Declaration of Helsinki for Ethical Principles for Medical Research Involving Human Subjects of World Medical Association (WMA). All participants were volunteers and were informed about the study procedures and risks involved. All participants retained the right to withdraw from the study at any moment.

Results

Average start time (RT) for the series of 31 random reflexive saccades was shorter in FDA and in BVP (Table I). Target reaching time with 80% accuracy (TRT) was shorter in FDA, ARD and BVP. The average percentage of accuracy in achieving all targets (API) was higher in FDA, ARD and BVP. The highest number of centred target points or rather precision of performance in AT(PP) was in FDA and the lowest was in PTD.

Average percentage of accuracy in achieving all targets (AP2) was higher in FDA, ARD, PRD and BVP.

In AT, there were no significant differences between groups regarding the number of saccades not directed towards the right target point or attention deficit index (ADI).

The subjects aged less than 30 years (Table II) showed significantly better values for the target reaching time, with 80% accuracy (TRT) in ST and for the number of centred target points (PP) and for average percentage of accuracy in achieving all targets (AP2) in AT.

Table I. Mean and sd of the various parameters in ST and AT in various groups and significant differences (p t-test) between ordinary road drivers (ORD) and other groups.

	RT (msec)	TRT (msec)	AP1	PP (N)	ADI (N)	AP2
FDA	238.0 - sd 32.2	337.5 - sd 7.7	74.8 - sd 1.0	50.5 - sd 0.7	39.3 - sd 10.3	69.0 - sd 3.5
ARD	268.3 - sd 31.3	380.0 - sd 29.6	65.9 - sd 7.7	44.0 - sd 4.6	50,3 - sd 32.5	65.2 - sd 3.5
PRD	257.0 - sd 35.8	410.7 - sd 28.0	64.4 - sd 5.5	44.8 - sd 3.1	37,7 - sd 5.2	66.5 - sd 3.1
BVP	252.4 - sd 24.6	339.7 - sd 26.3	70.2 - sd 5.9	45.6 - sd 4.4	48.9 - sd 14.7	67.6 - sd 4.6
ORD	285.7 - sd 39.4	423.7 - sd 39.0	61.5 - sd 8.2	45.0 - sd 5.9	45.8 - sd 21.3	61.0 - sd 7.0
PTD	299.1 - sd 31.1	423.7 - sd 25.8	62.7 - sd 6.2	42.9 - sd 4.1	54.8 - sd 17.9	63.2 - sd 4.4
ORD/FDA	0.0047	0.0000	0.0002	0.0001		0.0069
ORD/ARD		0.0000	0.0309	0.0002		0.0106
ORD/PRD				0.0033		0.0428
ORD/BVP	0.0000	0.0000	0.0000			0.0000
ORD/PTD				0.0001		

Table II. Mean and sd of the various parameters in ST and AT of ordinary road drivers groups (ORD) aged less (29 cases) or more (58 cases) than 30 years.

	RT (msec)	TRT (msec)	AP1	PP (N)	ADI (n)	AP2
ORD < 30 y	284.55 - sd 36.39	367.11 - sd 42.76	61.5 - sd 8.2	48 - sd 5.89	40.62 - sd 25.17	64.8 - sd 5.16
ORD > 30 y	284.11 - sd 38.20	387.45 - sd 35.22	61.6 - sd 8.3	43,38 - sd 5.11	48.66 - sd 18.37	58.8 - sd 7.04
t-test		0.0205		0.0006		0.0001

In ordinary road drivers, there were differences between males and females. RT was slightly longer in females than in males (Table III). The number of saccades not directed towards the target point, i.e. the attention deficit index (ADI) was significantly higher in females and was associated with a lower average percentage of accuracy in achieving all targets (AP2).
This likely indicates a greater number of antisaccades in order to achieve all the correct targets.
The difference in number of saccades not directed towards the target point (ADI) was more significant in subjects aged less than 30 years: males made many fewer exploring saccades than females (Table IV). However, in this range of age the average accuracy in achieving all targets (AP2) was greater in females.
There were significant differences between ordinary road drivers and sports subjects (Table I). The average start time (RT) was shorter in FDA and in BVP.
Target reaching time with 80% accuracy (TRT) was shorter in FDA, ARD and BVP.
In ST, average percentage of accuracy in achieving all targets (API) was higher in FDA, ARD and BVP and in AT (AP2) in FDA, ARD, PRD and BVP.
Both males (Table V) and females among professional basket and volley ball players showed better performance in the tests, and the female disadvantage was almost completely reduced by practice. The number of saccades not directed towards the target point (ADI) in AT was higher in females.
A probable difference also emerges due to individual predisposition. Indeed, in our tests the performances of FDA-selected students were significantly better than those of the group of aspiring students and amateur racing drivers (ARD) (Table VI).

Discussion

The level of attention and collaboration was high in all groups. Indeed, in the AT there were no significant differences between groups regarding the number of saccades not directed towards the right target point or attention deficit index (ADI).

Table III. Mean and sd values of the various parameters in ST and AT in 58 males (M) and 29 females (F) of ordinary road drivers groups (ORD).

	RT (msec)	TRT (msec)	AP1	PP (NJ)	ADI (N)	AP2
F ORD	294.17- sd 39.19	381.13 - sd 42.24	62.0 - sd 9.9	46.18 - sd 3.40	52.5 - sd 25.66	59.0 - sd 8.11
M ORD	277.88 - sd 34.76	378.31 - sd 35.45	61.5 - sd 7.3	44.74- sd 6.05	40.76 - sd 15.90	62.5 - sd 5.72
t-test	0.0516				0.0102	0.0222

Table IV. Mean and sd of the various parameters in ST and AT in 21 males (M) and 8 females (F) of ordinary road drivers groups (ORD) aged less than 30 years.

	RT (msec)	TRT (msec)	AP1	PP (n)	ADI (N)	AP2
F ORD < 30 y	278.46 - sd 41.12	358.0 - sd 41.15	67.7 - sd 7.1	47.71 - sd 2.45	64.37 - sd 37.59	68.6 - sd 5.61
M ORD < 30 y	283.75 - sd 24.59	366.0 - sd 19.69	63.6 - sd 3.0	48.09 - sd 6.67	31.57 - sd 8.99	63.2 - sd 4.3
t-test			0.0349		0.0007	0.0098

Table V. Mean and sd of the various parameters in ST and AT in 58 males (M) ordinary road drivers (ORD) and 22 of professional players group (BVP) and in 29 females (F) ordinary road drivers and 13 of professional players group (BVP).

	RT (msec)	TRT (msec)	AP1	PP (N)	ADI (N)	AP2
M ORD	277.88 - sd 34.76	378.31- sd 35.45	61.5 - sd 7.3	44.74 - sd 6.05	40.76 - sd 15.90	62.5 - sd 5.72
M BPV	252.2 - sd 27.3	345.2 - sd 26.2	69.1 - sd 6.2	45.9 - sd 3.8	44.9 - sd 10.7	67.2 - sd 4.4
t-test M BPV/ORD	0.0026	0.0002	0.0000			0.0008
F ORD	294.17 - sd 39.19	381.13 - sd 42.24	62.0 - sd 9.9	46.18 - sd 3.40	52.5 - sd 25.66	59.0 - sd 8.11
F BPV	252.8 - sd 20.1	330.3 - sd 24.5	72.1- sd 5.0	45.4 - sd 5.3	54.6 - sd 18.0	68.4 - sd 4.8
t-test F BPV/ORD	0.0009	0.0002	0.0033			0.0004
F BPV	252.8 - sd 20.1	330.3 - sd 24.5	72.1 - sd 5.0	45.4 - sd 5.3	54.6 - sd 18.0	68.4 - sd 4.8
M BPV	252.2 - sd 27.3	345.2 - sd 26.2	69.1 - sd 6.2	45.9 - sd 3.8	44.9 - sd 10.7	67.2 - sd 4.4
t-test M/F BVP					0.0429	

Table VI. Mean and sd of various parameters in ST and AT in males (M) aged less than 30 years: 6 of Ferrari Driver Academy (FDA), 21 ordinary road drivers (ORD) and 19 aspiring students and amateur racing drivers (ARD).

	RT (msec)	TRT (msec)	AP1	PP (N)	ADI (n°)	AP2
FDA	238.0 - sd 32.2	337.5 - sd 7.7	74.8 - sd 1.0	50.5 - sd 0.7	39.3 - sd 10.3	69.0 - sd 3.5
ARD	268.3 - sd 31.3	380.0 - sd 29.6	65.9 - sd 7.7	44.0 - sd 4.6	50.3 - sd 32.5	65.2- sd 3.5
t-test FDA/ARD	0.0047	0.0000	0.0002	0.0025	0.0005	0.0069

Usually the mean reaction time to detect visual stimuli and to produce a reactive saccade is approximately 180–200 msec. Reaction time shortens with age through childhood and gradually lengthens during adulthood; it also depends on attention and inter-individual variability is evident [83]. However, the values remained stable in the age range of our study. Probably in our examination conditions RT in ST (Table I) was higher depending on the particular conditions of examination. In fact, we evaluated the average time for a long series of 31 random reflexive saccades. In agreement with the literature, in our study males had faster RT as compared to females. The age below 30 seems to guarantee better target reaching time (TRT), precision of performance (PP) and accuracy in achieving all targets (AP2). The effect of physical activity and doing sports on improving RT and accuracy in achieving all visual targets is confirmed.

The performances of females professional players are better compared with female ordinary road drivers and in our study the female disadvantage was almost completely reduced by practice [84-87]. The performances of professional truck drivers were similar to those of ordinary road drivers, but were also characterised by lower precision of performance in the ST. These performances are significantly worse compared with those of racing drivers of the same age. Likely this is related to the problem of driving tasks. In driving, many tasks are performed and drivers may adopt different search strategies depending on the current driving task. For example, when drivers are passing, they need to perceive objects located in front of and behind their own car by using rear and side mirrors in preparation for maneuvering. In contrast, when drivers drive on a straight road (stable driving), they perceive mainly objects located in front of their own car with few mirror glances. Large vehicles only have side mirrors and therefore require different visual control strategies. In fact, it has been shown that the number of gaze movements was significantly greater in drivers of large vehicles. The amplitude of eye movements is significantly broader when driving large vehicles (truck, bus) than during driving a small car.

Finally, the performances of FDA-selected students were significantly better than those of the group of aspiring students and amateur racing drivers probably thanks to individual predisposition based on so-called '*neural efficiency*', which postulates more efficient cortical functioning based on both a reduced utilisation of resources and an improvement in information processing, thanks to a better communication between task-related brain areas. Indeed, selected populations of individuals achieve very high levels of skills and performance in fields ranging from arts to sport activities as a consequence of intensive training and, probably, of some genetic predisposition [72]. However, the role of genetic predisposition and/or of acquired experience is not yet clear.

Conclusions

Both professional and naïve drivers may share the common knowledge necessary for ordinary road driving, but naïve individuals simply watch the race, while professional drivers imagine themselves to race.

In order to improve both safety and performances during daily or sports driving, it is important "what and where to look". Visual environmental control requires that foveal vision is maintained on specific targets (reference objects, trajectory points) and experience aimed at creating specific neuronal networks able to satisfy the most appropriate eye-test-body motor control strategy.

Indeed, the sensory-motor decision processes interact via functional information-processing loops in the brain to produce complex, adaptive behaviours [88]. To achieve this goal, it is necessary to maintain adequate levels of visual attention even in the presence of distracting targets, reduce saccadic movements (with relative blindness and possible loss of environmental information from sections of the route that increase with increasing speed) and train the ability to perform eventual corrective antisaccades.

These abilities are essential for any high-level sporting activity, particularly for drivers. Athletic men and women acquire these performances with experience and training. The acquired attentional capacity tends to remain high even over time, mostly in racing drivers. Women generally show lower level performances, but they can significantly improve with training. The gaze is considered a good method of evaluation for assessment of attention while driving [89] and a correct strategy of visual control of the environment through saccadic and anti-saccadic movements adapted to the situation is of fundamental importance in sport and driving. Our easy-to-use diagnostic method seems to be able to identify the most predisposed subjects at high driving performances and thus those to be submitted to specific training [45] to improve the function of saccadic exploration and safety in driving.

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Conflict of interest statement

None declared.

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