

# **ECEM 10**



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**Book of Abstracts**

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The Book of Abstracts contains the abstracts of papers presented at the tenth European Conference on Eye Movements (ECEM 10). The conference covers many aspects of the oculomotor system: neurophysiology, behavioural studies, modelling, information processing, applications, measuring techniques. ECEM 10 is held from 23 to 25 September, 1999 at Utrecht University, The Netherlands.

The programme committee, consisting of J.A.M. van Gisbergen, J. van der Steen, A.H. Wertheim, E.J. Nijhof and C.J. Erkelens composed the programme and defined a number of themes according to which the oral sessions were organised. The committee scheduled six invited lectures related to the themes.

All abstracts were reviewed by the Scientific Committee consisting of W. Becker, B. Fischer, J.M. Findlay, A.G. Gale, J.A.M. van Gisbergen, R. Groner, D. Heller, K. Koga, G. d'Ydewalle and D. Zambarbieri. The accepted abstracts were divided into oral and poster presentations following the preferences of the authors and scientific committee.

P.W. Schiphorst compiled the electronically received abstracts into a pleasantly readable book of abstracts. The abstracts are organised in three groups: invited lectures, oral and poster contributions. The abstracts of the oral presentations are grouped by session. The abstracts of the invited lectures and the oral presentations are ordered according to the programme. The abstracts of the poster presentations are ordered alphabetically by the name of the first author.

In combination with the programme booklet the abstracts provide information which may help to select sessions and posters of interest and to prepare questions to be asked in the discussions.

## The human vestibulo-ocular response to transient head rotations

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Even though the vestibulo-ocular reflex (VOR) to head rotation has a long tradition of research, several elementary properties of the VOR are not yet well known. Its role in gaze-stabilisation is well recognised, but properties such as latency and gain in response to brief, transient disturbances of head position have been under-investigated. The very short basic pathway of the VOR (only 3 neurones) suggests a role especially in the compensation of such fast, transient head movements, which cannot be adequately dealt with by visually mediated eye movements. Despite this, and to a large extent due to technical limitations, the emphasis in VOR research has been on sustained rotations or oscillations of the head, especially in human subjects. Recently, there has been a trend to study the VOR with transients and for this purpose we have introduced a head-helmet, driven transiently by reactive forces. This work has revealed a number of interesting and partly unexpected properties. Brief, well-controlled head rotations with an initially approximately constant acceleration ( $\sim 1000 \text{ deg/s}^2$ ) were imposed on healthy subjects. Binocular eye movements were recorded with scleral coils in a magnetic field and analysed for a period of  $\sim 100$  ms after the start of the head pulse. Averaging procedures were used to reduce noise. In the first period after the start of the head movement ( $\sim 10$  ms), eye movements were, unexpectedly, typically anti-compensatory, with peak velocities of a few  $\text{deg/s}$  and zero-latency. This component is interpreted as purely mechanical, and probably due to the eccentric rotation of the orbit around a head-centred axis (with linear forces acting on the orbital contents). Active, compensatory eye movement started after a VOR latency of  $\sim 8$  ms, according to estimates that took into account the anti-compensatory phase. Statistical analysis showed a highly significantly shorter delay (by  $\sim 1$  ms) of the contralateral vs. the ipsilateral eye (relative to the direction of head rotation), in agreement with the known shortest synaptic pathways, that involve 1 extra neurone (the interneurone in the abducens nucleus). The moment-to-moment VOR gain ( $G$ ) was calculated as

$$\frac{V_{\text{eye}}(t)}{V_{\text{head}}(t - \text{latency})}.$$

The time course of  $G$  was very sensitive to the duration of the latency; our surprisingly short latency estimates yielded the most simple, monotonous build-up of gain after the anti-compensatory phase, without implausible undershoots (for too short latencies) or overshoots (for too long latencies). Effects of the distance of a visual target (a larger VOR gain for a near target, as necessitated by the eccentric rotation of the eye) appeared 20 - 30 ms after the start of the active VOR. Responses in darkness and with a distant target were identical.

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## **Saccades and scanpaths: models of cognitive processing**

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Several cognitive processes, which include attention, spatial working memory and response inhibition, are involved in the generation of a saccade. Appropriate manipulation of the behavioural paradigm in which an isolated saccade is required allows analysis of these individual processes. Applying these paradigms to subjects with focal structural or neurochemical lesions and during brain imaging, has made it possible to develop a provisional functional neuro-anatomical brain network for saccadic generation, which will be described.

The analysis of sequences of saccades, called scanpaths, undertaken during the performance of specific behavioural tasks can also provide valuable insights into the cognitive processes involved, and their disturbance in patients with neurological disease. Analysis of the scanpaths made during the performance of standard neuropsychological tasks, such as cancellation and the Tower of London planning task in patients with parietal lobe lesions and Parkinson's disease, can be used to provide evidence for specific cognitive deficits. As an example, recent studies of these patients will be described which have revealed impairments in spatial working memory.

## **Eye movements and cognition**

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A variety of cognitive tasks have been studied by using eye movement data. Reading, problem solving and visual search are familiar examples. The approaches used in such cognitively-oriented eye movement research are as varied as the tasks, but they can be divided into two major categories: (i) varying the high-level parameters of the task to find out how perceptual and cognitive factors influence eye movement patterns, and (ii) using eye movement data as a protocol to gain insights about the underlying cognitive process. I will discuss some recent insights that eye movements have provided in the study of cognitive processing and theoretical issues inherent in modelling eye movement data.

## **The ecological validity of laboratory experiments on the saccadic system**

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Scientific research proceeds by investigating manageable problems and frequently this involves choosing to research simple situations. This approach is always subject to the criticism that results may not be of general applicability. In this talk, I shall consider the validity of this criticism in relation to work on the saccadic system.

The most frequent use of saccades is to scan around the visual environment. However much work on the saccadic system investigates saccadic orienting to simple targets which appear suddenly. The onset visual transient of such targets will preferentially stimulate the magnocellular pathways of the visual system. Onset visual transients are recognised to have a special attentional status and also appear to have automatic and inescapable access to the saccadic system, as shown clearly in the remote distracter effect (Walker et al, 1997). Another feature of the processing of onset transients is the spatial integration demonstrated by the global effect (Findlay, 1982). Although originally found in a situation without onset transients (Coren and Hoenig, 1972), the effect has a less robust status in saccade control during the scanning of static scenes.

Visual search offers a way of investigating display scanning in a controlled situation. A typical search experiment requires subjects to search for a pre-specified target amidst a number of distracter elements. Experimental work on visual search (Findlay, 1997; Belky and Motter, 1998) has identified two factors which affect saccade landing position both of the first saccade after the display appears and of subsequent saccades. The first factor is visual similarity to the target, reflecting the operation of the search selection set adopted by the subject. The second is spatial proximity to the current fixation location. These factors are likely to be dominant ones in many scanning situations. This is illustrated by a recent study of scanpaths through a set of randomly positioned objects.

Belky E.J. and Motter B.C. (1998). The guidance of eye movements during active visual search. *Vision Research*, **38**, 1805-1818.

Coren S. and Hoenig P. (1972). Effect of non-target stimuli on the length of voluntary saccades. *Perceptual and Motor Skills*, **34**, 499-508.

Findlay J.M. (1982). Global processing for saccadic eye movements. *Vision Research*, **22**, 1033-1045.

Findlay J.M. (1997). Saccade target selection in visual search. *Vision Research*, **37**, 617-631.

Walker R., Deubel H., Schneider W.X. and Findlay J.M. (1997). The effect of remote distractors on saccade programming: evidence for an extended fixation zone. *Journal of Neurophysiology*, **78**, 1108-1119.

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## The generation of antisaccades: development and dyslexia

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Saccade control has at least 3 components: fixation holds the eyes in place, reflexes take the eyes automatically from one stimulus to the next, and voluntary control allows one to look at things by conscious decisions. This contribution concentrates on 4 aspects of the voluntary component as tested by the original antisaccade task introduced by Hallett (1978): antisaccade performance of adults, development with age, antisaccades in dyslexia, effects of daily practice.

With a gap condition (fixation point switched off before stimulus onset) adult healthy subjects cannot perform this task without producing certain numbers of erratic prosaccades (about 15%). Valid spatial precues increase the error rate and half of the errors remain unconscious.

The variables describing antisaccade performance (error rate, reaction time, correction rate, and correction time) varied strongly with age until age 18 y and beyond age 40 - 50 y, while those describing the prosaccades were pretty much developed at age 8 - 9 y (300 subjects).

Saccade performance of 400 dyslexics was compared with that of 100 normally reading children (age 7 to 18 y, subdivided in 4 age groups). Group mean values of the error rate from antisaccade task were significantly different at all ages except for the youngest age group. Up to 50% of the dyslexic children depending on age produced significantly more errors in the antisaccade task than the controls. High error rates may occur because of weak fixation or because of deficits in the voluntary control. Reaction and correction times did not differentiate between groups.

We also tested 300 controls and 370 dyslexics by 3 dynamic orientation detection tasks: one required stationary fixation, the other prosaccades, and the third saccades against the direction of a distracter. Subjects between age 10 y and 40 y performed these tasks easily above 85 - 95% correct. The performance dropped to percent correct values around 65% at age 8 y or at ages above 60 y. On average dyslexic children performed below the level of the age matched controls in particular in the distracter task.

In order to improve saccade control of the dyslexics we gave them a selection of the 3 visual task for daily practice. After 3 to 6 weeks of practice the children were retested (N = 78): most of them had improved their saccadic behaviour. In particular the error rate decreased by 20% and the correction rate increased by 13% on average.

This study shows that the different components of saccade control develop differently with age, voluntary control being fully developed only around age 18 y. A large percentage of dyslexics exhibit developmental deficits of their vol-

untary not of their reflexive control component. These oculomotor and visual deficits may be considered as a consequence of a deficit in the magnocellular system serving the dorsal route. Daily practice helps the children to overcome the optomotor deficits and hopefully forms the basis for a better learning of reading and spelling skills in the future.

### **Binocular co-ordination: Can the Hering-Helmholtz controversy be resolved?**

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More than a century ago, Helmholtz and Hering proposed conflicting hypotheses about how binocular co-ordination of eye movements was achieved. Helmholtz proposed that each eye is controlled independently and that binocular co-ordination is a learned behaviour. Hering proposed that both eyes are innervated by common conjugate and vergence commands that yoke their movements (Hering's Law of Equal Innervation). Neurophysiological evidence has, until recently, provided apparent support for Hering's hypothesis. Recent studies suggest, however, that Helmholtz' hypothesis should be reconsidered. For example, we have reported that premotor medium lead burst neurones in the paramedian pontine reticular formation (PPRF) encode monocular commands for right or left eye movements, not conjugate eye movement commands as was previously assumed. We have also shown that many abducens motoneurones are not monocular, as previously assumed, but binocular, and exhibit discharge activity related to movements of either eye. The premotor data suggest that Helmholtz may have been correct in assuming a degree of independent neural control of each eye. The motoneurone data, however, suggest a novel reinterpretation of Hering's Law that may provide a way to reconcile their conflicting hypotheses.

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## Experimental analysis of a competitive timing model of antisaccade performance in humans

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The antisaccade task requires making saccades in the direction opposite to a peripherally-flashed cue. We examine the predictions of a functional-neuroanatomical model that emphasises the timing of competing saccade programs for determining whether one makes a reflexive error or an antisaccade. As the number of on-line parameters for programming an antisaccade increases, antisaccade programming slows, which shifts timing dynamics further in favour of the competing reflexive saccade. Our earlier work partially supported this model: decreasing the number of parameters for on-line antisaccade programming improved performance. Decreasing uncertainty in the number of possible cue locations (from 2 to 1) led to near perfect performance. In contrast, increasing the number of possible cue locations from two to four did not affect error rate when cues were positioned along a single axis. We hypothesise that this result was obtained because increases in amplitude related antisaccade programming parameters may not have resulted in increased processing time, but that increases in direction related parameters would require more processing time and result in higher error rates.

We have conducted four studies with a total of 90 neurologically normal undergraduates. Eye movements were recorded using an infrared corneal reflection eye tracker recording at 180 Hz (ISCAN model RK-426). All antisaccade trials consisted of the same temporal sequence of events, although location of specific antisaccade cues varied between the different studies. Trials began with subjects fixating a central fixation point that remained for 1000 - 3000 ms. At fixation point offset, a peripheral cue consisting of a two degree square white box appeared for 400 ms. This cue signalled the participant to make an eye movement to the location on the screen opposite to the cue. Eye movement direction, amplitude, and latency were recorded using an automated system.

The results support the hypothesis that on-line programming of saccadic amplitude does not increase the timing needed for antisaccade programming, but that increasing the possible directions of antisaccades increases reflexive responding. In study 1, errors in a 2-location antisaccade task went from 25% when the cue direction varied, to 4% when possible cues varied in amplitude only. In study 2, when saccade direction varied, errors increased from 25% to 45% in a 2- versus 4-location antisaccade task. In study 3, we rule out the possible alternative hypothesis that the 2- versus 4-location effect we obtained in study 2 was due to the increased difficulty of making antisaccades along two visual axes in the 4-location condition, as opposed to only one axis in the 2-location condition. In study 4, we demonstrate that none of the findings in the previous three studies were attributable to the effects of practice, fatigue, or or-

der. The results of all four studies are examined in the context of the competitive timing model as well as recent neurophysiological findings.

### **Reflexive saccades are not preceded by shifts of visual attention: Evidence from an antisaccade task**

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In recent years, ample evidence has accumulated suggesting that a shift of visual attention precedes every saccade directed to a visual target. We here provide evidence that this obligatory coupling between attention and eye movement programming may not be the case for involuntary, reflexive saccades.

In an antisaccade task, subjects produce up to 20% of involuntary, reflexive prosaccade errors to the stimulus. Interestingly, they do not recognise more than half of these errors and their corrections. An explanation for this misperception could be that attention is shifted in the direction of the voluntarily planned saccade as instructed by the task while on error trials the involuntary, reflexive saccade is made without a corresponding attention shift. We tested this hypothesis in a dual-task paradigm in which subjects had to perform antisaccades triggered by the presentation of a visual stimulus that appeared to the right or to the left of a central fixation. Also, they had to discriminate between target letters ("E" and mirror-"E") which were presented for short durations before the eye movement either at the stimulus position or on the side opposite to the stimulus (i.e., at the instructed saccade goal). Additionally, subjects pressed a button when they thought that they had made an erroneous prosaccade.

The data show that for the correct, voluntary antisaccades discrimination performance is indeed best at the position of the saccade goal, confirming the earlier findings. This is not true for the involuntary, unperceived prosaccade errors, however. In these cases discrimination performance is better on the side where the subject was instructed to look than on the side where the subject actually looked, suggesting that the programming of these reflexive saccades do not require visual attention.

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## **Role of primate frontal eye field in preparation and execution of pro-saccades and anti-saccades**

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Diversity in behavioural responses to a sensory stimulus have been attributed to variations in preparatory set. Previous studies have identified neural correlates for set-related activity for saccadic eye movements in the superior colliculus (SC) in primates, but its origin remained unknown. Here, we investigated whether the frontal eye field (FEF) could be one source of the set-related activity of SC neurones. We recorded the activity of single neurones in the FEF while monkeys performed a task in which they either had to look toward a visual stimulus (pro-saccade) or away from the stimulus (anti-saccade) depending on the colour of the initial fixation point. The focus of this study were FEF neurones that displayed saccade activity. In many experiments, neurones projecting to the SC were identified with antidromic stimulation techniques. Like in the SC, the level of prestimulus activity of FEF neurones was task-dependent, correlated with the reaction time of the forthcoming saccade, and predicted performance in the anti-saccade task. Like SC neurones, FEF neurones displayed lower stimulus-related and saccade-related activity for anti-saccades compared with pro-saccades. These results provide direct evidence that the descending pathway from the FEF to the SC carries preparatory set-related activity for pro-saccades and anti-saccades. Like in the SC, the task to suppress the prepotent response to look towards a flashed visual stimulus is associated in the FEF with a decrease of preparatory saccade-related activity.

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## **Antisaccade control during working memory operations: Evidence for a dissociation of storage and active manipulation**

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The successful execution of an antisaccade implies an executive operation, namely the inhibition of an erroneous prosaccade towards the abruptly appearing saccade cue. We tested in a series of experiments how this inhibition process interferes with operations involved in working memory. The basic dual task paradigm consists of an antisaccade that had to be performed in temporal overlap with another working memory task. In Experiment 1, the antisaccade had to be carried out during the retention interval of a verbal Sternberg working memory task that required to memorise a varying number of auditorily presented letters. The addition of a working memory task increased the number of erroneous prosaccade significantly (general dual task cost). However, the number of letters to be retained did not influence the number of prosaccades. Experiment 2 used a visual spatial working memory task in which Phillips patterns of a varying complexity had to be retained. Again, the complexity of the patterns did not influence the number of erroneous prosaccades. So, the degree and complexity of working memory storage did not interact with antisaccade control.

The next two experiments used working memory operations implying the active manipulations of material. In Experiment 3, the working memory task consists of simple mental arithmetic operations of varying complexity (+1 or -1 vs. +3 or -3) performed in temporal overlap with an antisaccade task. The number of erroneous prosaccade increased with the complexity of the mental operation. In Experiment 4, we manipulated the SOA between the tone signal for specifying the arithmetic operation (+3 or -3) and the antisaccade cue. The results show a time-dependent monotonic increase of erroneous prosaccades from 0 to 600 ms and afterwards a monotonic decrease from 600 to 1200 ms. We conclude from all four experiments that antisaccade control - the executive operation of inhibition - does not depend on the degree and complexity of working memory storage but it does depend on the complexity of and temporal overlap with simple mental arithmetic operations.

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## **Saccadic peak velocity as an indicator of cognitive processing demand**

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The purpose of the present study is to replicate and extend earlier experiments on saccade velocity in a forced choice reaction paradigm. As we have shown in a series of previous studies, saccadic peak velocity varies with task variables like post-saccadic demand, knowledge of results, foreperiod duration and time on task (App and Debus, 1998). These results can be accounted for in terms of cognitive-energetic models of information processing assuming that at least two different energetic resources are involved, a basal arousal/activation system and a superordinate energetic mechanism, referred to as effort (Sanders, 1998).

In our initial experiments subjects were asked to execute a target saccade towards an imperative stimulus in the periphery (left or right) and a return saccade after the manual response back to the center of the screen. The distance between the centre of the screen as a departure and arrival point and the location of the target was always 12 deg. Due to a postsaccadic choice reaction task (a fast respond to a specific key as a function of a numerical stimulus), target saccades were always carried out under high processing demand. In contrast, return saccades were either carried out in a low demand condition, i.e. when subjects only had to wait for the beginning of the next trial, or in a high demand condition, when a further choice reaction after the return saccade was required. Eye movements were recorded using an electro-oculogram (EOG). Saccadic peak velocities were adjusted mathematically with respect to the amplitudes according to a procedure suggested by Becker (1989). As a key result of several experiments, saccadic peak velocity was found to be higher for saccades under high demand conditions as compared to those under low demand conditions.

The present study, while applying the same experimental logic, differs in several respects. Saccade parameters are now measured using a very accurate infrared reflection technique, allowing for a better control of amplitude variation. New experimental conditions were added, including the use of the peripheral target positions as starting and ending points of saccades under high and low demand conditions. This allows for a dissociation of task-induced velocity variations from differences due to centrifugal vs. centripetal movement directions (Colleijn, Erkelens & Steinman, 1988). Another potential confounding factor in our earlier experiments was the predictability of saccade direction, as the direction of target saccades was unpredictable whereas return saccades were always aimed at the central location. In the adapted paradigm, conditions with both predictable and unpredictable target and return saccade directions were included. Across all variations, a significantly higher peak velocity for saccades in high-demand conditions emerged as the central result. In sum, our experiments provide firm evidence for a systematic variation of saccade veloc-

ity with cognitive processing demand. Within the framework of cognitive-energetic models of information processing this parameter can hence be seen as a good candidate for a sensitive and specific indicator of mental effort.

## **Saccades and fixations for remembered targets**

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With a pair of continuously-visible, widely-separated targets (20 deg to 40 deg), saccadic refixation from one to the other usually involves two steps: an initial large saccade, which somewhat undershoots the target, followed at short latency by a second, smaller same-direction saccade, commonly referred to as a "correction" saccade. A seemingly obvious interpretation of this phenomenon would be that intervening visual stimuli show that the initial saccade had not fully accomplished its intended purpose and requires correction. This interpretation, however, stumbles over the finding that large-magnitude refixations made in complete darkness often also involve similar double-saccades (Becker and Fuchs, 1969, *Vision Research*, **9**: 1247-1258; see also Carpenter, 1988, *Movement of the Eyes* [Second Edition]. Pion, London, pp. 83-86).

New experiments show that refixations to the remembered locations of currently masked targets at modest eccentricity (7 deg or 14 deg) also typically involve similar two-step movements, even when the initial saccade ends on target location and would not require correction. The usual result was a final fixational overshoot: In 5 of 6 test series, total change in eye orientation significantly exceeded that required by the originally seen target by 1 deg to 4 deg. Even when the new target was located diagonally upward, was then masked, and the refixation task required an initial purely vertical saccade, followed by a horizontal saccade, the second, horizontal saccade was followed at short latency by a third "correction" saccade in the same direction, again producing horizontal fixational overshoot.

The average amplitudes of the second saccades of such two-step refixations for remembered targets were similar for targets at 14 deg eccentricity and at 7 deg; the proportionality proposed by Becker and Fuchs (1969; *ibid.*) for larger saccades was not evident. For a given target spacing, however, second-saccade amplitude depended very strongly on the variable magnitude of the initial saccade, on a test-by-test basis: Larger initial saccades were consistently associated with smaller second saccades ( $p < 0.001$  in all 6 data sets).

Such results suggest that the location of a new target may be initially encoded as the muscular-activity or -tension co-ordinates of the desired endpoint (conceivably as an expected "corollary discharge"); and that this encoded value persists after the completion of the initial saccade, so as to provide a reference for evaluation of the initial-saccade error, for amplitude scaling of a "correction" saccade. Since the double saccades typically produced final target overshoot,

the hypothesised remembered reference value must be assumed to be subject to degradation, either by occurrence of the initial saccade itself or by the passage of time.

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## **Extra-retinal information about eye orientation is just as good for vergence as for version**

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When judging where an object is relative to ourselves, we are better at judging its direction than its distance. In a way this is obvious from the geometry of binocular vision. Is this the only reason for us being better at judging direction than distance?

To find out we asked subjects to align two vertical lines (length 1.9 deg; vertical separation 9.1 deg) both laterally and in depth. To make sure that they had to use extra-retinal information about the orientation of their eyes to perform the task, the lines were presented sequentially. Subjects determined which was visible by directing their gaze at it. The switch between the two targets took place during the vertical saccade that shifted their gaze.

Individual subjects made systematic errors, but these were not consistent across subjects. The variable errors, when expressed in centimetres, were much larger for distance than for direction, and this asymmetry increased with viewing distance (as is to be expected from the geometry). When expressed as angles, the standard deviations were no larger for distance than for direction, and were similar at all viewing distances.

We conclude that the resolution of extra-retinal information about the orientation of our eyes is no different for vergence and version. The difference in accuracy between judgements of distance and direction arises when eye orientation is translated into physical distance, or when the subject's performance is influenced by factors other than the resolution of eye orientation.

## **The eye movement-based relational manipulation effect: Evidence for detailed representations of the world**

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In previous work, we have shown that eye movement monitoring may be used as an indirect measure of on-line changes in the processing of a stimulus as a result of prior exposure. The pattern of eye movements to various regions of a repeated stimulus provides information about the viewer's memory representation of that item without requiring any verbal reports or explicit memory judgements from the subject. In the current work, we again used eye movement measures to inform us about the nature of representation of the changing world by having subjects view new scenes, repeated scenes, and previously viewed but manipulated scenes. The "change blindness" literature has suggested that

people form sparse, incomplete representations of the world, as evidenced by their poor explicit reports of changes that occur in previously viewed displays. The current work instead used indirect measures, derived from eye movement monitoring, to explore just how rich or detailed viewers' representation of the world might be. The central measure in this work was the extent to which subjects' eye movements were attracted to the "critical region" of scenes in which manipulations occurred, rather than whether or not they could report that any changes had occurred.

Subjects were presented with a series of real-world scenes on a colour monitor. In one experiment they were required to answer a relational yes/no question concerning two objects within the scene while the scene remained on the screen. In another experiment they were to just study the scenes in order to remember them. Some scenes (and the questions) were repeated across blocks; other scenes appeared only once. In a final block, half of the repeated scenes underwent a manipulation (addition or deletion of an object; left-right or right-left movement of an object's position).

Across repetitions of the scenes, the "eye movement-based memory effect" was observed; prior exposure to the scenes produced a change in on-line processing, replicating our earlier work. For scenes that were manipulated in a final block, a "relational manipulation effect" was seen in the eye movements: subjects directed an increased proportion of their total fixations to the critical region which had been manipulated compared to other subjects' viewing of the same region when no manipulation had ever occurred.

In the current study, detailed representations of many scenes needed to be maintained over time in order for the relational manipulation effect to be observed in the final block. These results suggest that we do form and maintain detailed representations of the world; so much, in fact, that when the world changes, our eye movements are directed toward the exact location of that change.

### **Illusory velocity perception produced by active and passive head rotation, investigated by means of a head mounted display**

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An object moving at constant speed produces different perceptions of velocity dependent on the eye movement state (fixation or smooth pursuit).

Koga and Groner (1990) and Koga, Groner, Bischof and Groner (1998) studied the modulating effects of pursuit eye movement on the perception of motion. Under certain conditions, the moving target pursued by the eye was perceived

as motionless, however in other conditions the target was perceived as a moving object even when it was stationary.

The present experiment is an attempt to compare the modifying effects of motion perception under dynamic environmental conditions such as active and passive head movement. When a moving target is shown to a subject on a head mounted display either in lateral or longitudinal direction during either lateral or longitudinal head rotation, the subject reports the perception of an unstable (non-veridical) target movement such as slow or fast motion of a stimulus moving at constant speed. In the case of active head rotation, voluntary head rotation produces compensatory eye movements (=VOR), and the slow phase of compensatory eye movement is synchronised to the direction of the target motion, thus making perceived velocity of the target slower (c.f. Koga & Groner, 1997, 1998).

Passive head/body rotation was also introduced by the horizontal or vertical rotation of a chair driven by an external motor. The same results were observed in the passive head/body movement condition as in the condition of active head rotation. This result implies that the compensatory eye movements driven by either active or passive head movements directly modify the perception of the target's motion, and the findings indicate that the retinal displacement of the target during body rotation leads to the impression of an unstable external world.

### **The functional field of view for collision perception in real-time animation systems**

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In recent years, the realisation has been growing within the computer graphics community of the advantages to be gained by using knowledge of human perception. We maintain that an extension of this approach to a study of human visual perception of dynamic scenes would be very beneficial in solving some of the problems of real-time animation systems. In interactive animation applications such as Virtual Reality (VR) or games, it cannot be predicted in advance how a user or the entities in a virtual world will behave, so the animation must be created in real-time. As the number of independently moving objects in the scene increases, the computational load also increases. Possible scenarios include crowd simulations or avalanches of rocks, where large numbers of homogeneous entities move around a virtual world in real-time. There are many bottlenecks in such systems, collision detection being a major one. A trade-off between detection accuracy and speed is necessary to achieve a high and constant frame-rate. The disadvantage of this approach is that objects may be perceived

to be interacting in an unrealistic manner, repulsing each other at a distance, or interpenetrating. The analysis of visual perception of collision events enables a prioritisation of potential collisions to process within a given frame of an animation, hence reducing the negative impact of detection accuracy degradation.

To determine the functional field of view for the perception of collisions, we carried out 3 experiments with 12 participants. Filled white circles of 1 deg diameter presented on a black background served as stimuli. Subjects were asked to detect collisions (no gap between two circles) versus repulsions with minimal gap sizes of 0.1 or 0.4 deg. In experiment 1, we examined detection performance in a static display as a function of 3 levels of eccentricity, 4 directions of offset and 8 regions (up-left, right-down etc.). Experiments 2 and 3 used a dynamic situation with targets moving at a speed of 2.9 deg per second. In experiment 2 we added distracters that were different in colour from the colliding entities, and in experiment 3 we added distracters which were identical to the colliding entities (the "real-world" scenario).

In all three experiments, performance was found to be determined by eccentricity and separation of the colliding entities. In experiments 2 and 3, most subjects achieved maximum detection rates when collisions occurred at locations above the current fixation. The number of distracters significantly affected performance when the distracters were visually similar to the colliding entities (experiment 3), but not when the distracters were different (experiment 2).

Based on the results of these experiments, a plausible model of human visual perception of collisions was developed. In a real-time animation of large numbers of homogeneous three-dimensional objects, this model was used both to schedule collision processing, and as a metric to measure perceived collision inaccuracy. This system is currently being extended to include an eye movement contingent regime of prioritising collisions.

## **Saccadic eye movement and compression of visual space**

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The influence of saccadic eye movements on the perception of visual space has been investigated in several studies. Many of them showed an anticipatory shift in the perceived position of a stimulus that was flashed immediately before, during or after a saccadic eye movement. Recent studies have revealed that these mislocalisations depend on the spatial position of the stimulus. Ross et al. (1997, *Nature*, **386**: 598-601) showed that stimuli which were presented in a spatial position before the saccade target were systematically 'shifted' in the direction of the saccade. However, when the stimuli were presented behind the target, they were mislocated in a direction opposite to the saccadic eye movement. Ross et al. (1997) interpret this as a 'compression' of visual space around the target of the impending saccade. By contrast, another group (Cai et al., 1997,

*Nature*, **386**: 601-604) found a shift but not a compression of visual space. In this contribution we propose a resolution of this discrepancy by showing that the saccadic eye movement only leads to a compression of visual space when a visual reference frame is present.

We instructed subjects to make horizontal saccades from left to right in a dimly lit room. A vertical bar was flashed at four different spatial positions around the saccade target. At different times we presented an on-screen ruler as a frame of visual reference. Subjects indicated the perceived position of the stimulus with a computer cursor.

Our results show a clear mislocalisation of perisaccadically presented stimuli. The largest mislocalisations are observed at the start of a saccade and depend on stimulus position. The presence of the visual reference has a large influence on the compression. When the reference is present during the whole trial we observe a large compression towards the end of the saccade. Even when the ruler appears at the same time as the stimulus-onset and remains visible immediately after the end of the saccadic eye movement, the compression is still large. But, when the visual reference disappears with stimulus-onset or temporarily disappears during the saccade, only little compression is observed.

We conclude that the compression of the visual space is due to the interaction of an extraretinal signal with visual information present during the saccade. This explains the differences in the studies mentioned above. While visual references were present during the experiments of Ross et al. (1997), they disappeared before the onset of the saccade in the study of Cai et al. (1997). Moreover based on the findings that the maximum of the shift appeared at the beginning of the saccade and the maximum of the compression at the end of the saccade, we conclude that different mechanisms are responsible for these phenomena.

### **Implicit transsaccadic memory for saccade source and target**

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When observers make a saccade from one object to another, saccade-contingent displacements of the object to which the eyes were sent (the target) or the object that served as launch site (the source) are hard to detect, whereas changes in the objects' depth orientation are readily noticed. Changes in the target's position and orientation are not detected more accurately than changes in the source. We report on a test of the hypothesis that, in contrast to what these findings suggest, transsaccadic coding of target position is in fact accurate, but the information is unavailable to conscious perception, because the visual system assumes the world remains stable. Deubel et al. (Vision Research, 1996) demonstrated that, by briefly blanking the saccade target during and just after the saccade, the default assumption of a stable visual world is invalidated and saccade-contingent displacements are relatively easy to detect. We test the hy-

pothesis of an implicit transsaccadic advantage for the target over the source, by examining the effects of blanking on the detectability of source vs. target changes.

## **Re-examination of temporal and spatial properties of eye movement in reading Japanese text**

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The authors have obtained SMI's Eye Link System recently after using NAC's EMR 5 and 7 that run at 30 Hz and EMR 6 at 600 Hz for years. The arrival of a new generation eye-movement recorder, whose sampling speed is over one order of magnitude greater than the 30 Hz recorder, has led us to a new horizon and new understanding about the eye movement properties in reading.

We conducted a series of four experiments using Eye Link System to re-examine the threshold parameters of eye movement in reading Japanese text. In the first experiment we displayed scrolling 8 sets of Japanese words of the same lengths (2 to 8 characters) at a speed of 7 deg/s, and measured the average number of characters the subjects recognised at one fixation. In this experiment the subjects perceived displayed characters during smooth pursuit and then their eyes jumped to the next information area. By measuring the pursuit property, we learned that an average of three characters were perceived at one fixation.

In the second experiment, to obtain the minimum time necessary for recognising words (2 to 5 characters in length) and found that a fixation of 28 - 70 ms was necessary to recognise a meaningful word of within three characters, which is identical with the result of Perfetti, C. A., and Bell, L (1991).

In the third experiment, we examined the range of effective visual field by displaying simple sentences in Japanese using the window method with six different sizes (1 deg x 1 through 6 deg) by measuring the average amount of saccadic distance in reading the sentences. The result of this experiment was that the average distance of saccadic jumps with window sizes of 5 deg or more equals to that with no visual field limitation, which suggests that reading will not be much affected by a window whose size is 5 deg or larger.

In the fourth experiment, the subjects were instructed to read five grammatically correct Japanese sentences and five grammatically incorrect sentences (about 20 characters long each), which were masked at each fixation point with a moving window (1 x 4 deg) after 84 through 265 ms (7 different delays with an increment of 14 ms) since the onset of each fixation. The text materials were not understandable when they were displayed less than 70 ms. From this experiment, it was found that loci and fixation duration were not affected by the masking conditions, while on the other hand understanding of the text materials was greatly influenced by them. To understand grammatically correct sentences correctly, at least an average presentation duration of 224 ms was neces-

sary, whereas grammatically incorrect sentences failed to be understood even with the presentation duration of 252 ms.

## **Inhibitory neighbourhood effects in visual word recognition**

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The influence of orthographic neighbour primes on visual word recognition was investigated in three experiments. In each experiment, target words were primed by either a higher frequency neighbour (HFN) or a higher frequency unrelated word (HFU), and the critical letter position at which the HFN prime differed from the target word was exhaustively manipulated.

Experiment 1 used a masked foveal priming paradigm. Lexical decisions to the target word were found to be inhibited by HFN vs. HFU primes, regardless of critical letter position. In experiment 2, the same items were used in a parafoveal preview paradigm in which the prime was presented in the parafovea rather than in the fovea, and replaced by the target word during the participant's eye movement to the location of the prime. Here, the effect of the HFN prime on lexical decisions to the target word was facilitative when the critical letter position was word internal, but inhibitory when the critical letter position was initial or final. Exploratory analyses indicated that the prime effect was modulated by the proximity of the initial fixation on the target word to the critical letter position, and suggested that the different profile of priming effects observed in experiments 1 and 2 was due to increased lateral masking of internal prime letters under parafoveal conditions of presentation. In experiment 3, a more natural parafoveal preview paradigm was used in which the target words were placed in sentence contexts and the participant's task was simply to read each sentence for comprehension. Although the overall effect of the preview manipulation on target word fixation time was null, more detailed examination of the data, in which launch site, landing site, and proximity of the initial target word fixation to the critical letter were taken into account, provided clear evidence of inhibitory HFN prime effects on target word gaze duration.

These findings demonstrate that orthographically related parafoveal previews can inhibit target word recognition. More generally, the results support the view that competitive neighbourhood processes are involved in visual word recognition, and suggest that a word's competitiveness is modulated both by its frequency and by the efficiency with which its disambiguating information is processed (a) prior to fixation, and (b) upon being fixated.

## **Do ophthalmokinesis and reading develop in parallel?**

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This study investigated the relationship between eye movements development and reading performance in Primary school children (7 - 9 y).

Eye movements are the best reflectors of reading performance, as reading and eye movements development follow parallel paths and usually one can be predicted from the other (Gilbert, 1953; Pavlidis, 1990). Eye movement characteristics correlate highly with reading skill and, therefore, provide a reliable, and objective method for the evaluation of reading efficiency and for the diagnosis of reading and attentional difficulties (Pavlidis, 1990).

Reading skills develop gradually, improving in precision and speed over the first 2 - 3 years of schooling and are clearly reflected in the pattern and characteristics of the reader's eye movements. About two-thirds of the total development of readers' eye movements, occurring between the first grade and college level, is reported to be achieved by the 9<sup>th</sup> year of age. The number of fixations is a better index of reading skills than the duration of fixations (Taylor, Franckenpohl, & Pette, 1960).

**Methodology:** The subjects for this study were 120 first, second and third grade pupils taken from 3 public primary schools from the city of Thessaloniki, Greece. Their age ranged from 7 to 9 years of age and they represented the whole reading spectrum. The fully automated portable infrared OKG<sup>®</sup> photoelectric system developed by Prof. Pavlidis was used for automated eye movement data collection and analysis. All recordings took place at the schools we visited.

They were tested for their cognitive and their reading-writing abilities using the following tests:

1. Raven.
2. Word Recognition Reading tests, three texts (two appropriate for their grade and one two grades above).
3. Single Word Writing tests, three texts (same as in Reading).
4. Eye Movements recording during reading and non-reading tasks (Pavlidis Test).

**Reading tasks:** The children's saccadic and pursuit eye movements were recorded while they read on the monitor the above mentioned texts. Their comprehension, speed and accuracy of reading were analysed.

**Non-reading tasks:** While the children follow with their eyes sequentially illuminated light spots or a slowly moving light spot on a computer monitor, their eye movements were synchronously recorded. These tasks are independent of

any linguistic, high level information processing requirements and are not influenced by memory, emotional factors or intelligence. The saccadic task simulated the reading process by replacing words with simultaneously and equidistantly presented light spots. (Pavlidis, 1981, 1990).

Results: The results show a high degree of correlation between ophthalmokinesis and reading performance.

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### **Associations and dissociations of attention and eye movements in a letter identification paradigm**

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Relations between visual attention and eye movements have been studied in a number of recent experiment using dual task paradigms (e.g. Hoffman & Subramaniam 1995, Kowler et al. 1995, Deubel & Schneider 1996). In these studies participants were asked to execute a saccade to an eccentric target while performing a concurrent identification task. Results indicated close functional relations between attention and saccade generation. We present a series of letter recognition experiments that differ from prior studies in one critical aspect: the execution of saccades was not suggested and participants were not aware of making any saccades.

In four experiments a paradigm was used where triplets of letters are presented for 50 ms at an eccentricity of 4 or 7 deg to the left or right of a central fixation point. Participants were asked to identify either the central or the peripheral letter while ignoring the other two letters. Trials with only one critical stimulus served as a baseline. Subjects made saccades toward the target letters in over 80% of all trials although the stimuli had disappeared a long time before the eyes arrived. These saccades were clearly goal-directed, had normal latencies and exhibited the typical saccadic undershoot tendency. The presence of proximal vs. distal distracters (two letters at 1 and 2 deg distance relative to the target) increased vs. decreased mean saccade amplitude by about 0.5 deg. Latency had virtually no effect on this "global effect", but at longer presentation durations (up to 500 ms) it was much more pronounced.

There was a clear relation between saccade amplitude and recognition performance. Successful letter identification was associated with saccades that had amplitudes more similar to those of single target control trials. This replicates the basic finding of a tight coupling between saccades and visual attention and shows that such effects are not restricted to explicit dual-task paradigms. At the same time there were also results that point to dissociations of saccade target specification and letter recognition. Saccade amplitudes toward single letter targets were modulated by the relative position of distracters (proximal vs. distal) during letter triplet trials within the same block. In contrast, no comparable inter-trial effects were found with respect to identification performance. Proximal and distal distracters led to very similar extents of saccade amplitude modification, yet there was a marked asymmetry in the extent of the related reduction of recognition performance.

Our results can be well accounted for within a theoretical framework assuming that saccade target selection (selection for action) and perceptual identification (selection for recognition) initially share a common representation but are subsequently processed in different processing streams. Implications of these considerations for saccade target selection and word recognition in reading and other complex tasks will be discussed.

### **Information is obtained from both the left and the right of fixation during word recognition**

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One central issue in the study of eye-movements in reading deals with how readers can co-ordinate eye-movements with text comprehension in reading. According to one type of model, readers shift a "spotlight" of attention from one word to the next in a discrete, unidirectional manner. This spotlight of attention is focused on a single word at a time, until its recognition is achieved. Once this occurs, attention shifts to the next word in the text. The focus of attention doesn't need to coincide with fixation location-- occasionally, the eye may move ahead of attention. When this occurs, properties of the attended stimulus that is now to the left of fixation may affect the viewing of the fixated (i.e., target) word. Conversely, attention may shift to the next word before the eyes move to it. When this occurs, readers may take less time processing the next word when it is subsequently fixated (i.e., there will be a preview benefit).

The current experiment examined attentional processes during fixation in reading by manipulating the availability of lexical information both to the left and to the right of fixation. A critical sequence of pre-target, target, and post-target words (e.g., steaming bath water) were embedded in sentences. Eye-movement-contingent-display changes were used to manipulate the visibility of pre- and post-target words while the target was fixated (all target words were

shown as their base forms). Four versions of each three-word sequence were constructed: one in which the pre-target word was shown unchanged (e.g., steaming), one in which the pre-target was replaced with a sequence of dissimilar letters (e.g., gocvqhdf), one in which the post-target word was shown intact (e.g., water), and one in which the post-target word was replaced with a string of dissimilar letters (e.g., cevyf).

The results showed that information to the left and right of fixation had an effect on processing the target word. Readers' first fixation and gaze durations showed that they fixated longer on the target word when the word to the left of fixation consisted of a dissimilar letter string than when it consisted of the base word. Readers also fixated longer on the target word when information to the right of the target consisted of a dissimilar letter string as compared to when it consisted of a base word. Notably, when readers were denied lexical information to the left of fixation, there was no decrement in the preview benefit on the post-target word, suggesting that readers obtained information both to the left and the right of the fixated target. These data are difficult to reconcile with word-size spotlight conceptions of visuo-spatial attention. In effect, they favour a gradient conception, according to which the allocation of attention is not limited to one word at a time.

## **Responses to repeated presentations of single cycle sinusoids show link between anticipatory ocular pursuit and prediction in sinusoidal pursuit**

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Repeated presentation of constant velocity target motion stimuli has been shown to allow build-up of anticipatory smooth pursuit prior to target onset. These anticipatory movements confer a temporal advantage on the pursuit response that largely compensates for time delays in visual feedback. Although it is likely that this would account for the reduced phase errors in sinusoidal pursuit, this has never been demonstrated experimentally. Here, we examine changes in eye movement that occur when a single cycle sinusoid is repeatedly presented to determine if phase error compensation can be demonstrated. During each presentation the target appeared at centre, moved right and returned to centre with a single cycle sinusoidal velocity profile. In experiment I peak displacement and frequency of motion remained constant for a sequence of 5 - 7 presentations. Five peak displacements (4 - 20 deg) and four stimulus frequencies (0.4 - 1.6 Hz) were examined. The target disappeared between each presentation for a randomised interval of 1.2 - 2.8 s. In experiment II, the number of presentations in each sequence was randomised and peak velocity changed unexpectedly between sequences. In both experiments head-fixed subjects tracked target motion, then held fixation on a separate central target until an audio cue, occurring 480 ms before target onset, allowed preparation for the next stimulus. Eye movements were monitored by infrared oculography. Six normal subjects participated with local ethical committee approval.

In experiment I subjects reacted to the first presentation of each sequence with a latency of 100 - 150 ms that persisted as a phase error throughout the first response. But in response to the second presentation they compensated for most of that phase error by generating anticipatory eye movement prior to onset as well as an anticipatory return to centre. In the steady state (mean of responses 3 - 5) subjects matched target motion with negligible phase error at 0.4 Hz, the eye following the target very smoothly and closely throughout its trajectory. Although some phase error persisted at higher frequencies (1.25 & 1.6 Hz) the values were comparable to those of continuous sinusoidal pursuit. In a second part of experiment I, subjects were instructed to fixate, rather than pursue, during the first presentation. They were then still able to make a phase compensated predictive response to the 2nd presentation showing that it was not necessary to make a motor response, only to view the target motion. The strength of prediction was revealed in experiment II, where, for example, an unexpected decrease in target velocity from 80 - 32 deg/s at 1.25 Hz resulted in an inappropriate smooth pursuit response well in excess of target velocity (peak velocity 50 deg/s) that persisted for the first half cycle of the stimulus (i.e. 400 ms).

These results provide support for the hypothesis that prediction in sinusoidal pursuit is carried out by storing information derived from prior visual input and subsequently reproducing it as an anticipatory pre-programmed trajectory that allows phase errors to be reduced even for single cycles of a sinusoidal stimulus.

### **Further evidence for a short-term store used in predictive ocular pursuit and its dependency upon timing information**

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Previous experiments have indicated that repeated, transient motion stimuli may charge an internal store which is subsequently released to generate predictive ocular pursuit. But evidence indicates that the store may decay, as evinced by the observation that increasing the interval between stimuli causes a decrease in anticipatory eye velocity (Wells and Barnes, 1998, *Exp. Brain Res.*, **120**: 129-133). In the current experiment we assessed whether this effect was due to a true decay or to a failure to build up the store. We also assessed the effect of auditory timing information on anticipatory ocular pursuit. Human subjects were seated with head fixed and viewed a moving target on a screen at 1.5 m. Eye movements were recorded by infrared reflection. The target was exposed for 480 ms as it moved with a constant velocity ( $50^\circ/\text{s}$ ) ramp to the right. Ramps were presented in pairs, each preceded by an audio cue at cue times (CT) of 300, 600 or 1100 ms before target onset. Average interstimulus interval within each pair was 2.4 s (randomised from 1.8 - 3.0 s). Each pair was separated by a gap of either 7.2 s or 14.4 s, during which the subjects heard either 2 or 5 audio cues respectively, but saw no visual stimulus. During this gap, subjects were instructed to reproduce the eye movements each time there was an audio cue. Eight combinations, each comprising 2 ramps and a gap, were presented consecutively. All conditions which presented in a balanced, randomised design. 6 subjects participated with local ethics committee approval.

Anticipation was assessed by measurement of smooth eye velocity (V100) 100 ms after target onset (i.e. before the effects of visual processing). The difference between the 1st V100 of each pair and the 2nd V100 of the previous pair was used to assess the decay of the store. There was a significant decrease in V100 when the gap time was 14.4 s (e.g. from  $25.0 - 19.6^\circ/\text{s}$  for CT = 600 ms, ANOVA  $p < 0.001$ ) but a much smaller decrease when the gap was 7.2 s (e.g. from  $25.8 - 23.4^\circ/\text{s}$  for CT = 600 ms,  $p = 0.161$ ). V100 for the 2nd response of each pair was similar ( $p > 0.05$ ) regardless of gap time, suggesting that presentation of the second ramp allowed the store to be charged to a similar level. Optimum values of V100 were obtained for CT = 600 ms, with a significant decline for CT = 300 ms ( $p < 0.001$ ) and CT = 1100 ms ( $p < 0.001$ ).

The results confirm that the internal store does indeed decay, though over a longer period than implicated previously. The apparent decay found earlier (Wells and Barnes, 1998) was probably attributable to reduced build-up of the store when there were long gaps between single ramp stimuli. The data also show a strong effect of CT on V100, which was optimal for CT = 600 ms.

### **Accuracy of visual tracking during pseudorandom two-dimensional target motion**

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It is well established that errors associated with visual tracking of a target moving in a predetermined way are significantly lower than those recorded in an unpredictable paradigm. This observation has been validated in numerous studies on tracking ability of subjects involved in one-dimensional tasks.

A study was conducted to investigate whether subject's performance will be equally degraded by removal of the natural predicting ability when the task is extended to two dimensions. Gaze point locations were transduced using pupil centre/corneal reflection technique. The target trajectory was generated using combination of multiple arcs obtained through intersection of circles of varying location and radius. To avoid generation of saccades as much as possible, an algorithm was used to control the trajectory so that the target moved smoothly and did not bounce from the boundaries of the screen. Target velocity was varied from 5 deg/s to 15 deg/s. Tracking error was obtained by subtracting target position from eye position measured at the same instance, and subsequently splitting this difference into two components: tangent component (the component along the movement direction) and its orthogonal counterpart. The mean value of tangent component was found to increase proportionally to target velocity, whereas its standard deviation remained at the same level.

These findings provide an interesting contrast to those reported in our earlier study for the case of predictable target motion in two dimensions where negligible change in the mean tangent error with increasing target velocity was accompanied by proportional increase in standard deviation. We discuss whether such a reverse in the roles between the mean tangent error and its standard deviation could be attributed to removal of directional cue for the saccadic system by making the target move unpredictably; the saccadic system thus seems to be deprived of its corrective function which does not allow performance of the pursuit system to be boosted in traditional way.

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## **Cortical areas activated by pursuit eye movements: influence of target and background motion. A fMRI study**

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The cortical areas activated by smooth pursuit eye movements can be studied with functional magnetic resonance imaging (fMRI). Recently, we developed a new technique for recording eye movements simultaneously with fMRI. There is no interference between fMRI and eye movement signals and the temporal and spatial resolution of the latter is very good (Kimmig et al., 1999, *Exp. Brain Res.*, in press). In this study we investigated the influence of target and background motion as well as eye movements on the cortical activity, especially the motion sensitive area V5/V5A.

Data were obtained from 8 healthy human subjects. Eye movements were measured with an infrared light reflection technique and a newly developed fibre optic system (spatial resolution 0.2 deg; temporal resolution 1 kHz). fMRI data were obtained with a 1.5 T Siemens Vision scanner (EPI, 16-24 planes, FOV 256x256, 128x128 voxels). Visual stimuli were created on a VSG graphics board and shown in back-projection with an LCD-projector. We compared fixation periods (OFF) with activation periods (ON) of 30 s length each. The stimulus consisted of sinusoidal movements in the horizontal plane (peak velocity 20 deg/s; frequency 0.3 Hz; amplitude  $\pm 10$  deg). In a first series of experiments (i) a red target dot moved across a stationary random dot background, (ii) dot and background moved together, (iii) the dot remained stationary while the background moved. Subjects task was to pursue or fixate the target dot. In a control experiment the background was replaced by a second single dot. In another experiment we controlled subjects attention by asking them to make a button press after random dimming of the target dot.

We found activation in the primary visual cortex V1, in the motion sensitive area V5/V5A, in parietal cortex (area 7), the precuneus, and little activation in the frontal eye fields (area 6) and the supplementary eye fields. Dot motion with ocular pursuit as well as background motion with fixating eyes yielded similar activation of area V5/V5A. The activation in V5/V5A was strongest if during pursuit target and background moved together (i.e. minimal retinal slip). Pursuit of the dot with a stationary single dot background resulted in some activation. Fixation of a stationary dot while a second one moved across the retina evoked no significant activation in V5/V5A. The subjects' attention, as defined by the subsidiary dimming task, did not substantially alter the results.

We conclude that retinal and extraretinal information activates area V5/V5A. The extraretinal signal seems to produce a stronger activation than the retinal information.

## **Initiation of smooth pursuit eye movements in the absence of retinal image motion**

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Movement of an object usually can be detected by the displacement of the retinal image. In order to reveal the basic mechanisms of visual motion processing, other types of motion irrespective of retinal image motion have been introduced, so called non-Fourier motion or second order motion. It was earlier shown that human subjects not only do perceive second order motion but can also direct their eyes towards objects defined by second order motion. However, the contribution of second order motion to the very earliest component of smooth pursuit eye movements is not clear yet. Therefore, we decided to compare pursuit initiation elicited by stimuli containing or lacking, respectively, retinal image motion.

The eye movements of five healthy human subjects were measured with an infrared eye tracker (0.2 deg spatial resolution). The occurrence of pursuit initiation prior to the initial saccade was determined by a velocity threshold based on standard deviation. Initial eye acceleration was calculated by linear regression of eye velocity. The off-line analysis was exclusively performed on single trials. Stimuli consisted of bars (0.65 x 1.7 deg or 2.6 x 1.7 deg) moving in front of a dynamic noise background. For the first-order-motion stimuli, the bar consisted of a random-dot pattern. In case of the second order (drift-balanced) stimuli, the bar defined an area, in which random dots remained stationary. Any target moved at two different speeds (4.15 deg/s or 8.3 deg/s) in either horizontal direction.

Although the second order stimulus did not provide any retinal image motion, pursuit initiation was observed in 61% of all trials (contrasted to trials with post-saccadic pursuit only, grand average of 5 subjects, 1600 trials each, all conditions). Out of these, 74% showed pursuit initiation in direction of the target. In contrast, pursuit initiation elicited by Fourier motion stimuli was detected in 82% of all trials, and 89% of these trials showed initiation in the direction of target movement. These differences in pursuit initiation due to first and second order stimuli were statistically significant ( $p < 0.001$ , confidence interval). The initial acceleration elicited by second order motion (39 deg/s<sup>2</sup>) was significantly ( $p < 0.001$ , t-test) reduced compared with the acceleration elicited by first order motion (52 deg/s<sup>2</sup>). The pursuit onset latency due to second order motion (192 ms) was also significantly larger as the latency due to first order motion (173 ms). Interestingly, initial acceleration was a function of target velocity only in case of first order motion, but not in case of second order motion.

There are two conclusions that can be drawn from our results: First, second order motion stimuli can initiate smooth pursuit eye movements, although there

was no retinal image motion correlated with object motion. Second, initial eye acceleration did only reflect target velocity in case of first order motion. This suggests that there might be two different motion detection mechanism underlying the initiation of smooth pursuit eye movements.

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## **Disparity sensitivity in the macaque Ventral IntraParietal area (VIP)**

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The macaque ventral intraparietal area VIP was originally defined as the MT projection zone in the fundus of the intraparietalis sulcus. Most neurones are sensitive for the direction and speed of visual stimulus motion. In addition, many neurones are multimodal, i.e., they respond not only to visual, but also to tactile and vestibular stimulation. Even more interestingly, most neurones are directionally selective with matching preferred directions in all three modalities. Recent anatomical findings could show distinct projections between parietal and premotor cortex, and especially connections between area VIP and a region of premotor cortex controlling head movements. Therefore, a specific function of area VIP could be to guide movements, based on multimodal sensory input, in order to head for objects of interest in near extrapersonal space. This functional role would require a representation of 'near' and/or 'far', i.e. depth information, at the level of single cells in this area. There exist several cues to infer depth information from visual images: e.g. horizontal disparity, texture gradients, and motion parallax. In our present study we therefore were interested in the question whether neurones in area VIP reveal disparity sensitivity and whether this, if existent, would match the functional hypothesis of representing near extrapersonal space.

We recorded single unit activity of neurones from area VIP of one awake behaving monkey (*M. mulatta*) during expose to large field stereoscopic stimuli. The monkey was seated in a primate chair with the head fixed facing a 90 deg by 90 deg projection screen at a distance of 48 cm. Visual stimuli as well as a central fixation target were back-projected onto this screen. The animal was given liquid rewards for keeping both eyes within an electronically defined ( $\pm 1$  deg) window, centred on the central fixation target. Directional selectivity was assessed by moving a random dot pattern (covering the whole tangent screen at all instances) along a circular pathway. Sensitivity of neurones to horizontal disparity was assessed by presenting these moving images stereoscopically to the two eyes by means of a LCD shutter goggle synchronised with the stimulus generator (Silicon Graphics workstation). During an individual trial, stimuli had one of seven different disparity values ranging from 3 deg uncrossed (far) to 3 deg crossed (near) disparity in 1 deg steps. Different disparity values were presented across trials in pseudo-randomised order.

More than 70 percent of the cells revealed a direction specific response to movement of a large field random dot pattern. Sixty percent of these cells revealed a statistically significant tuning for the horizontal disparity of the stimulus ( $p < 0.05$ , distribution free ANOVA). Neurones usually were broadly tuned to disparity with a large majority of them ( $> 80\%$ ) tuned for 'near' stimuli.

Thus, our findings are in agreement with the functional role of area VIP for the encoding of movement in near extrapersonal space.

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## **A c-FOS study reveals the coactivation of the optokinetic nuclei of the rat following oblique motion stimulations**

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Optokinetic nystagmus (OKN) is a gaze stabilising reflex elicited by displacement of the whole surround induced by self-motion of the animal. Depending on the motion, the resulting retinal slip signal will activate direction selective ganglion cells which in turn are connected to specifically committed subcortical visual nuclei. Thus, the nucleus of the optic tract (NOT) and the dorsal terminal nucleus (DTN) of the accessory optic system (AOS) are critically involved in handling the horizontal optokinetic signal, whereas the medial terminal nucleus (MTN) and the lateral terminal nucleus (LTN) of the AOS are considered essential along the vertical optokinetic route. Furthermore, the optokinetic nuclei are arranged in such a way that robust inhibitory pathways are connecting to each other. Reciprocal inhibition between the two has been invoked as a mechanism to be used for silencing one nucleus when the other is working, thus improving oculomotor performance. Definitively, it seems that gaze stabilisation mechanisms carried out by the OKN should be grounded on a strong segregation of directional motion detection and processing. However, unitary recordings have shown that some cells in the optokinetic nuclei responded even for a broader range of stimulus directions than those considered strictly specific.

For addressing the real consistency of these electrophysiological findings we investigated whether and to what extent an optokinetic nucleus (i.e. NOT), besides its own directional competence (i.e. horizontal), might be involved in oculomotor responses arising from surrounding motion directions progressively shifted from its best fit. For our aim we applied the c-FOS immunoreactivity method and inspected for labelled cells in the optokinetic nuclei of Long Evans rats stimulated for 1 hour with computer generated square wave gratings (0.2 cycles/deg and 80% contrast) moving at 2 deg/s on a monitor subtending a visual field of about 103 x 81 deg. Eight different motion directions, shifted 45 deg from each other, were presented to binocularly viewing animals.

Following each stimulation in any oblique direction we found several c-FOS positive cells in the horizontal (NOT and DTN) as well as in the vertical optokinetic nuclei (MTN and LTN). Conversely, c-FOS labelling resulted limited to its proper committed nucleus when the stimulus was moving merely horizontally or vertically.

It seems likely, therefore, that different modalities of cross-talk might take place between optokinetic nuclei: a strong mutual inhibition or a complete independence. Considering oculomotor behaviour, reciprocal inhibition allows at the best an OKN either in a vertical or horizontal straight direction. On the contrary, independence following functional disconnection between optokinetic nuclei appears to be the condition for which each of them could become self-governing, assuring the simultaneous excitation of NOT and MTN. In conclusion, concurrent activation of nuclei displaced along the horizontal and vertical optokinetic pathway should represent the neuronal counterpart of a suitable oculomotor reflex occurring in the natural environment when the head position of the animal and its motion features can induce a visual world displacement in any direction, very often in directions different from those merely orthogonal.

### **Rapid neuronal plasticity shapes saccadic reaction times**

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The consolidation of motor skills necessitates long-lasting changes in the nervous system. Such plasticity has been documented in motor systems after training and long-term adaptation. However, there has been no demonstration of immediate use-related changes that may reflect the processes underlying the gradual improvement of motor performance. To address this issue, we explored the changes in performance (reaction time) of three rhesus monkeys trained to perform the gap saccade paradigm. Simultaneously, we recorded the preparatory activity of saccade-related neurones in the superior colliculus while the monkey made saccades to targets that were presented with equal probability either within or opposite the response field of the neurone. This preparatory activity predicted the ensuing reaction time of saccades directed into a neurone's response field. Similar to sequential effects observed in human manual responses, each monkey displayed reaction times to target locations that were organised in a sequential pattern, becoming progressively shorter with each preceding compatible movement and longer with each preceding incompatible movement. This sequential pattern of performance modification was associated with changes in neuronal preparatory activity of similar magnitude and configuration. The sequential patterns displayed by both behaviour and neuronal activity was immediate, progressive, and reversible which suggests that motor signal properties are continuously shaped by use-related experience and the resultant changes can be regarded as a precursor for the adaptation of motor behaviour.

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## **Saccade accuracy and timed perturbation of the cerebellar output signals from the caudal fastigial nucleus**

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Dysfunction of the medio-dorsal region of cerebellum severely impairs the accuracy of saccades. The caudal fastigial nucleus (cFN) is the output nucleus by which this cerebellar region influences the brainstem saccadic generator. In the head-restrained monkey, its inactivation by local injection of muscimol impairs all saccades: the horizontal component of ipsiversive saccades is hypermetric whereas it is hypometric for contraversive ones. Interestingly, for upward target eccentricities, saccades are also biased horizontally towards the injected side.

The sustained pharmacological effect of muscimol does not allow a distinction between horizontal biases resulting from perturbations of signals during saccade preparation and biases introduced during saccade execution. To determine the critical period during which an impaired activity in cFN alters saccade accuracy, a more transient technique is necessary. We tested in three monkeys the effect of low-frequency electrical microstimulation of the cFN on the accuracy of saccades towards a transient visual target (100 ms).

Low frequency electrical microstimulation (100 Hz during 100 or 200 ms) biases goal-directed saccades towards the ipsilateral side, like muscimol injection does. When applied during the latency period of a vertical saccade, it does not significantly affect the accuracy. However, when applied during the saccade, it biases its trajectory towards the stimulated side with a magnitude increasing with saccade duration.

The muscimol-like effect of the low-frequency microstimulation suggests that such a microstimulation inhibits cFN activity by recruiting the inhibitory afferents from the cerebellar vermis (axons of Purkinje cells). Low-frequency microstimulation of cFN must be applied during the saccade to bias its trajectory. These data suggest that the horizontal bias observed during muscimol inactivation of cFN results from an impairment in the intrasaccadic activity of fastigial neurones.

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## **Neural correlates of Inhibition Of Return (IOR) in the monkey superior colliculus**

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Inhibition of return (IOR) is a phenomenon whereby subjects are slower in responding to targets presented at previously cued locations. A number of studies have suggested that the superior colliculus is a necessary neural structure for the generation of IOR. Our goal was to test this proposal by recording the extracellular activity of visual- and saccade-related neurones in the superior colliculus while monkeys performed two versions of an inhibition of return paradigm. In both paradigms visual stimuli were presented in the following sequence: a central location, a peripheral location, the central location, and a final peripheral location. In the saccade-saccade paradigm, a stimulus was stepped between locations and the monkey was required to follow it with saccades. In the stimulus-saccade paradigm, the central fixation point, which required constant visual fixation, remained illuminated throughout the paradigm until the presentation of the final saccadic target. In the saccade-saccade paradigm, the final SRT was slowest when the two peripheral targets were presented in opposite locations and this was correlated with reduced motor-preparatory activity in the SC. In the stimulus-saccade paradigm, final SRT was slowest when the first stimulus was presented at the same location as the final saccadic target (i.e., IOR) and this was correlated with reduced visual-related activity in the SC. These findings suggest that oculomotor and visual history influence SRT's through motor preparation and visual processing, respectively, at the level of the SC. Whether these neural correlates originate in the SC or originate elsewhere and are merely reflected in the SC is currently being investigated.

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## Manipulating signals for pursuit initiation: A comparison of the effects of microstimulation in visual area MT with movement of the background on a step-ramp tracking task

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In order to probe the mechanisms of signal processing for pursuit eye movements, we manipulated motion signals in two different ways while rhesus monkeys performed a step-ramp visual tracking task. The task required that the monkey first foveated a small square (0.17 deg), after which a target spot (0.6 deg diameter) appeared in the peripheral visual field and moved away in one of several possible directions and speeds. On half of the trials we altered the motion signal during the first 200 ms of target motion. We used the scleral search coil technique to measure eye position and velocity, and compared these measures for trials with and without altered motion.

In the first set of experiments, we applied brief (~200 ms) trains of biphasic current pulses to physiologically characterised sites within visual area MT. We analysed the average eye velocity during the first 20 - 60 ms from the endpoint of the saccade to the target and found that the pattern of effects were well fit by a vector-averaging model in which the velocity of the eye movement on stimulated trials is a weighted average of the target velocity due to the visual stimulus and of an “electrical velocity” induced by microstimulation (Groh, Born & Newsome, 1997, *J. Neurosci.*, **17**: 4312-4330). We also found that sites with different centre-surround properties yielded different effects on tracking behaviour: stimulation at sites selective for local motion usually shifted smooth pursuit in the preferred direction of the neurones at the site, whereas stimulation at sites responsive to wide-field motion tended to shift pursuit in the opposite direction. We hypothesised that activating these wide-field sites mimicked background motion thus inducing an illusion of target motion in the opposite direction.

To test this hypothesis, we examined the effects of real motion of a random dot background on the same step-ramp task. These experiments were formally identical to the microstimulation experiments described above, the sole difference being the substitution of a 200 ms period of background motion for the period of microstimulation. Each background motion experiment was designed to match a particular microstimulation experiment for which we obtained a significant result at a wide-field motion site in MT. Thus the location of target onset matched the co-ordinates of the corresponding MT receptive field, and the direction and speed of background motion matched the preferred direction and speed of the neurones at the same site. We performed an identical analysis on

these data and found that background motion reliably produced an effect on pursuit initiation in the direction opposite to that of the background.

Thus the effect of real background motion on pursuit initiation was similar to that observed for microstimulation at wide-field motion sites within MT. This suggests that the conversion of background motion to a target-related signal in the opposite direction happens downstream from MT. A likely neural substrate for such a conversion is area MST, where single neurones that reverse their preferred directions for wide-field and local motion have been described (Komatsu & Wurtz, 1988, *J. Neurophysiol.*, **60**: 621-643).

## **The planning of successive saccades in reading: Evidence from visually-guided and memorised saccades**

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To direct gaze and to read what we see, spatial information about where words begin and end must be transformed into a motor plan. Saccade programming, however, requires a transformation from this retinal frame of reference into a motor frame appropriate for the eye.

When a reader plans two successive saccades, the motor movement to achieve the second target is different from the earlier retinal location of the stimulus. In order to program accurately the second saccade, the saccadic system has to update it with the new eye position. Interestingly, we found that the selection of a second word as the target for the second saccade produces an appropriate transformation of the motor plan and a recalculation of the second movement with respect to the current position of the second target word. Consequently, the eyes land left of the centre of the second word. However, when the second saccade is directed within the first word, this saccade was shown to be invariant with respect to the current eye position. In this latter case, the saccade is coded in motor space co-ordinates and the signal for the saccadic system is a command to move the eyes by a certain distance in the orbit.

These results were observed for (1) visually-guided saccades (2) visually-guided saccades after target displacement (3) memory-guided saccades which are executed towards an internally-represented memorised location of the targets.

These findings have important implications for models of oculomotor control during reading. They emphasise different metrics for the control of intra- and inter-word saccades.

### **Determinants of eyes' landing position in words during reading**

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The place where the eyes first fixate in a word during continuous reading, called the preferred landing position (PLP), is usually located halfway between the beginning and the middle of the word (McConkie, Kerr, Reddix, & Zola, 1988, *Vision Research*, **28**: 1107-1118; Vitu, O'Regan, & Mittau, 1990, *Perception & Psychophysics*, **10**: 375-378). Several attempts to explain this finding have been proposed, namely: hemispheric specialisation, aiming error, lexical constraint, and reading habits.

The main goal of the present series of experiments was to test the validity of these various explanations and to propose a mechanism that might account for the off-centre location of the PLP. Five eye-movement experiments were conducted using a lexical decision task (Experiment 1) and a stimulus bisection task where subjects were required to move their eyes to the location they estimated to be the centre of the stimuli (Experiments 2-5). The type of stimulus -- linguistic (words and non-words) vs. non-linguistic (strings of sharps, dotted lines, and solid lines) -- and the stimulus presentation side (left vs. right) were manipulated.

Our results do seem to support an interpretation in terms of attentional factors governed by reading habits. One can even go further in this interpretation and propose a possible mechanism of PLP off-centeredness based on the visual scanning of discrete stimuli. It seems that what is important in the saccade computation process is the discrete vs. continuous quality of the stimuli. These findings support the idea that the landing position in a stimulus is determined by an eye-guiding mechanism based on a perceptual low-level pre-processing step that detects the presence or absence of spaces between the characters. If the stimuli turn out to be discrete, subjects take the direction of visual exploration into account and attempt to land at the beginning of the stimulus, in preparation for subsequent left-to-right visual scanning. If the stimuli turn out to be continuous, a left-to-right strategy is not implemented and the left/right landing position distribution is symmetrical. In this case, a low-level strategy is used and subjects aim for the midpoint.

## **A representational component to the "preferred viewing position" in reading**

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**Background:** Current research on word perception and reading focuses on temporal aspects of behaviour (eye fixation times, naming latencies etc.) and tends to ignore spatial information processing despite the fact that reading is a spatial activity. One systematic aspect of spatial behaviour in reading is the "preferred viewing position" (PVP) of initial fixations to the left of the word's centre. This fixation bias increases above 2 char with long words. To account for it, different hypotheses have been put forth (attentional bias, oculomotor strategy, information distribution), all of which assume that VERIDICAL word length enters into a resource-limited computation of saccade amplitudes. In conflict with this assumption, there is a failure to accurately determine word centre even under unlimited viewing conditions in a word bisection task.

**Method:** Subjects determined the perceived middle of visually presented words and lines on a computer screen with a 1 pixel wide vertical bisection line that was controlled by a mouse. Stimuli were presented at random locations until

response (typically 3 - 4 s). As in the neuropsychological line bisection task, the direction of error indicates an over-representation of the length of this side. Visual stimulus attributes (word length, letter spacing, red letter) and lexical aspects (word frequency, word class, number of morphemes and syllables, grapheme-phoneme mapping, pseudowords, nonwords, ease of lexical access) as well as response factors (mouse, keyboard, pointing, concurrent articulation) were manipulated.

Main results: There was a systematic bisection bias toward the beginning of words that increased with word length, just as the PVP effect in reading. It is, however, of smaller size (up to 1 char). This word bisection error was not predictable from line bisection performance and did not vary with response mode, ruling out a simple visuo-motor account. Bias depended on number of characters but not on physical word length and was unaffected by an attention manipulation, suggesting that it reflects higher-level lexical processing. In agreement with this, word bisection bias was sensitive to manipulations of lexical access (stronger bias in a second language; positive bias with a typo near the word's end). Finally, perceived word centre depended on phoneme distribution, even under concurrent articulation conditions.

Interpretation: These results have implications for our understanding of eye movement control in reading: Word length is represented functionally, not veridically. This suggests a representational contribution to eye movement control in reading. The phoneme compensation effect further argues for obligatory activation of phonology in word recognition and demonstrates how analyses of spatial performance can add to our understanding of reading.

## **Processing difficulty hypothesis of saccade computation in reading**

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Most current models of eye movement control during reading posit that the landing positions in words are primarily governed by low-level factors such as the launch site of the saccade and the length of the targeted word. Higher-level cognitive processes are typically not assigned any significant role. However, according to the processing difficulty hypothesis put forth by Hyönä (1995, *JEP: HPP*, **21**: 68-81), momentary fluctuations in processing load are assumed to be capable of influencing the saccade trajectory. Specifically, the hypothesis predicts that a relatively shorter saccade will ensue when the foveal or parafoveal load is high in comparison to when it is low.

Data will be presented that lend support for the hypothesis. The data come from 3 experiments, which examined the processing of long two-noun compounds words (e.g. carwash) in reading Finnish. In the first experiment, the

frequency of the initial constituent was manipulated, in the second the frequency of the second constituent was varied, and in the third the frequency of the whole word was manipulated. The constituent frequency manipulation reliably influenced the within-word saccade computation. When the initial compound word constituent was of low-frequency, the second fixation landed closer to the beginning of the word, in comparison to the case when the initial constituent was of high-frequency. An analogous pattern was observed in the experiment, where the frequency of the second constituent was varied. These data are consistent with the processing difficulty hypothesis in suggesting that both foveal and parafoveal load are capable of influencing the trajectory of in-traword saccades. It was further showed that the incoming saccade was affected by the frequency of the initial constituent - a finding consistent with the view that also interword saccades are potentially influenced by processing difficulty. There were two effects that were predicted by the processing difficulty hypothesis, but which did not occur: first, there was no effect of second constituent frequency on the length of the exit saccade, and second, whole-word frequency was not found to influence saccade computation. A modified version of the processing difficulty hypothesis will be proposed that reconciles the observed findings.

### **Parafoveal words influence concurrent foveal processing**

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A central assumption of many current models of eye movement control in reading is that word recognition and visual attention are intimately linked. Attention is shifted from a word to a neighbouring word in a serial fashion. Eye movements typically (although not necessarily) follow these shifts of attention. Information secured from a parafoveal view of a given word secures a processing gain when that word is directly fixated (the 'preview effect'), but the serial nature of attention-switching precludes concurrent effects. That is, from this theoretical perspective, properties of a parafoveal word cannot influence current foveal processing. Our paper briefly reviews evidence from several sources which questions this assumption. Parafoveal-on-foveal effects have recently been reported in a numbers of tasks, from isolated word recognition to continuous text processing. The results of an experiment will then be reported in which subjects read strings of five words looking for (rare) instances of articles of clothing. The length, frequency and initial constraint of the third and fourth words in a string (targets) were manipulated. In experimental items, the second word was invariably a short four-letter word and while this was fixated the first target word was pattern-masked.

First fixation duration and gaze on the first target word varied systematically as a function of properties of the unfixated second target word. As in previous studies (Kennedy, 1999), the direction of this modulation was inverted, with shorter foveal times (and lower refixation rates) associated with more difficult parafoveal targets. The present data also comment on the interaction between properties of a foveal target and its parafoveal neighbour. Overall, the results cannot be accommodated by a model of eye movement control in which attention is deployed in a serial sequential fashion. The data are more consistent with the notion of parallel processing, distributed over a region larger than a single word.

Kennedy, A. (1999). Parafoveal Processing in Word Recognition. *Quarterly Journal of Experimental Psychology*. In press.

### **The influence of low-level visuo-motor factors on saccade length in reading**

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In reading, the eyes move with saccades of variable sizes that land at various locations in the words and sometimes lead the eyes to skip one or several words. As shown in a large number of studies, the variability in landing sites and skipping rate is only slightly related to the necessities of ongoing processing, and mostly results from low-level visuo-motor constraints associated with saccadic programming (see Brysbaert & Vitu, 1998 for a review). Particularly, one factor that contributes largely to this variability is the launch site or how far from the beginning of a word the eyes are launched from: the further the eyes from the beginning of a word, the more likely the eyes land towards the very-beginning of the word (McConkie, Kerr, Reddix, Zola, & Jacobs, 1988). This finding that does not seem to result from visual acuity constraints, was originally interpreted in terms of a range effect (Kapoula, 1985). An alternative account proposed by Vitu (1991) consists in assuming that the launch site effect results from a centre-of-gravity effect (Findlay, 1981), or the influence of the characters that belong to the fixated word and that might prevent the eyes from landing at the centre of the word (that is supposed to be the aimed-for location).

To distinguish between both accounts, a series of experiments was conducted that tested separately the effects of both the eccentricity of a peripheral target and the initial eye fixation location in a meaningless letter string, on the initial saccade landing site. The peripheral target was either an isolated letter, or a letter in string, or a word. Preliminary results indicate that independently of target eccentricity, the initial fixation position has a strong influence on where the eyes land: the closer the eyes from the beginning of the starting letter string,

the more likely the eyes undershoot the peripheral target. Results are interpreted in favour of a centre-of-gravity account for the launch site effect. Implications for models of eye movements in reading and more generally saccadic programming will be discussed.

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Findlay, J.M., 1981, Spatial and temporal factors in the predictive generation of saccadic eye movements. *Vision Research*, **21** : 347-354.

Kapoula, Z., 1985, Evidence for a range effect in the saccadic system. *Vision Research*, **25**: 1155-1157.

McConkie, G.W., Kerr, P.W., Reddix, M.D. & Zola D., 1988, Eye movement control during reading: I. The location of initial eye fixations on words. *Vision Research*, **28**(10): 1107-1118.

Vitu, F., 1991, Against the existence of a range effect during reading. *Vision Research*, **31** (11): 2009-2015.

## **Stimulus competition in saccadic programming I: Experimental technique and landing sites of the first saccades**

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It is a common belief that saccades can be initiated by two different sources of information: (1) Stimulus driven ("bottom-up processing") and (2) Concept driven ("top-down processing"). Most research involves only one of these two sources of information, although -- since only one saccade can be initiated at one moment of time -- the saccadic system must co-ordinate the two sources of information for every single saccade.

We have developed an experimental technique for comparing the influence of the respective sources of information. The stimuli are presented within a circular window (4 deg diameter). In the condition of stimulus driven processing (1) eight competing stimuli are exposed for 1500 ms in a circular arrangement around the fixation cross. This is followed by a briefly presented target stimulus in the centre of the display. Observers have to decide whether the target stimulus was identical with one of the immediately preceding stimuli.

In the concept driven condition (2), the target stimulus is presented in each trial prior to the display of the test stimulus. The underlying assumption of this technique is that the priming with a target produces a top-down processing of subsequent test stimuli. By balancing the stimuli over the 8 spatial positions and recording eye movements at each trial, it is possible to make independent comparisons of the relative salience of the stimuli as well as of the preferred spatial position.

We report three experiments where the latencies and landing sites of the first saccades were recorded by means of a Dual-Purkinje-Image Eye Tracker and compared between the condition of top-down and bottom-up processing. Using a screen with a background of medium luminance, the stimuli varied in spatial frequency content (low-pass filtering and high-pass filtering), two levels of luminance (positive and negative) and of contrast, resulting in 8 stimuli per display. It is demonstrated that some of the stimulus characteristics (contrast and spatial frequency) play a prominent role in bottom up processing, but no effect of luminance was observed. Surprisingly, no effect of top-down processing could be demonstrated in the first experiment. However, by introducing stimulus content as an independent variable, resulted in additional top down processing. This effect could be increased by presenting the same target over a whole block of consecutive trials.

## **Stimulus competition in saccadic programming II: Analysis of the scanpath**

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The experimental paradigm of our research is described in detail in the presentation of Groner et al. (Stimulus competition in saccadic programming I : Experimental technique and landing sites of the first saccades). There, with respect to the direction of attention, it was distinguished between (1) stimulus driven processing (= bottom up) where salient aspects of the stimulus attract attention, and (2) expectancy driven processing (top-down) where the observer is attending to those aspects of the stimulus which are related to his or her expectation. We investigated the relative influence of the two aspects by varying (i) the salient features of the stimulus - by varying the content of the images, spatial frequency content of the stimuli, and contrast - as well as (ii) the search intention of the observer - by instructing them to decide whether the target is within the search display or not. It is demonstrated that the saccadic eye movements are, in part, controlled by stimuli with high spatial frequency and high contrast (bottom up processing). The saccades are also controlled, in part, by the search for the target: In fact, the relatively most probable landing position of any fixation is a hit, i.e. the fixated stimulus matches the target perfectly (top down processing). Nevertheless, the interaction of both processes is not clear. The probability of a hit in the first fixation is only about 25% (expecting 12.5% at random), whereas it is higher in the second fixation. This result is in contradiction with the assumption of immediate processing, and we will try to resolve this problem by models of delayed or parallel processing. To evaluate the extent of peripheral processing, a control experiment was run where the observers were asked to fixate the centre of the screen, suppressing any saccades, and to decide whether the target was present or not.

### **Influence of attentional capture on oculomotor control**

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We make rapid eye movements to examine the world around us. Before an eye movement is made, attention is covertly shifted to the location of the object of interest. The eye typically will land at the position at which attention is directed. Previous research has shown that when searching for a colour singleton, top-down control cannot prevent attentional capture by an abrupt visual onset (see e.g., Theeuwes, 1994, *Journal of Experimental Psychology: Human Perception & Performance*, **20**: 799-806).

In the present study we used a visual search task in which observers were required to make a voluntary, goal-directed saccade to a colour singleton target. In half of the trials, simultaneously with the presentation of the colour singleton target, a new object presented with an abrupt onset appeared somewhere in the display. The visual onset was never relevant for the task. The question addressed was whether the appearance of the new, yet irrelevant onset would disrupt the planning and execution of the goal-directed saccade towards the singleton target.

The results show that the goal-directed eye movement towards the colour singleton was disrupted by the appearance of the visual onset. In many instances, before the eye reached the singleton target, it started moving in the direction of the onset. The eye often landed for a very short period of time (25 - 150 ms) near the onset. The results provide evidence that top-down control can neither entirely prevent attentional capture by visual onsets, nor can it prevent the eye to start moving in the direction of the onset. The results suggests parallel programming of two saccades: one voluntary goal-directed eye movement toward the colour singleton target and one stimulus-driven eye movement reflexively elicited by the appearance of the visual onset. In line with the claims regarding the parallel programming of two saccades, there is neurophysiological evidence that there are two parallel pathways involved in the generation of saccades: a subcortical pathway depending on the superior colliculus, and a cortical pathway depending on the frontal eye field (e.g. Schall, 1995, *Review in the Neurosciences*, 6: 63-85) Presumably, the superior colliculus is involved in producing the reflexive movements while the frontal eye field may be involved in the goal-directed eye movements.

## **Effect of transcranial magnetic stimulation of the parietal area on the latency of saccades, vergence and combined eye movements**

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Transcranial Magnetic Stimulation (TMS) of the posterior parietal cortex increases the latency of memory-guided saccades (Müri et al., 1996), as well as of visually-guided saccades (Müri et al., personal communication). Animal studies (Gnadt and Mays, 1995) show that the parietal area is also involved in vergence and combined saccade and vergence movements. This study examines in normal humans by means of the TMS the role of parietal cortex for saccades, vergence and combined movements. Single-pulse magnet stimulation (MegaStim 200) was applied on the right posterior parietal cortex of nine subjects; the stimulator output was set at 80% of the motor threshold. The targets of visually-guided eye movements were 6 LED's, one lit at a time. Three LED's were placed one at the centre and two at  $\pm 20^\circ$  at a distance of 20 cm from the subject; the other three LED's were placed at a distance of 150 cm (at the centre and  $\pm 20^\circ$ ). The target LED was switched on 200 ms after extinction of the central LED (gap interval, aiming to produce short latencies). The TMS was applied 80 ms after the target LED was switched on. Each type of eye movement was repeated 10 times. Blocks with no TMS were also performed. Eye movements were recorded binocularly with the IRIS device. For pure saccades, ipsilateral or contralateral to the stimulated side, the latency was significantly ( $p < 0.05$ ) longer with TMS than without TMS for individual subjects and for the group (the group mean difference was 35 ms). For pure vergence, the latency increased significantly with TMS (the mean difference was 25 ms for convergence and 45 ms for divergence). For saccades combined with convergence, the group mean latency was longer with TMS (25 ms) showing a tendency for significance. In contrast, for saccades combined with divergence, there was no difference for the group between the TMS and no TMS conditions.

The results on pure saccades confirm prior studies. The new finding is that TMS also increases the latency of vergence movements and of saccades combined with convergence. This indicates the involvement of parietal cortex in all these types of eye movements. The finding of no group effect of the TMS for saccades combined with divergence, could be due to the longer latency of these movements. Perhaps, TMS is less effective when occurring outside of a certain time window during the process of computation of target location. Alternatively, the parietal cortex could differently be involved for different types of gaze shifts in

space. E. Isotalo was supported by the Fondation pour la Recherche Médicale and Foundation of Maud Kuistila.

## **Event-related fMRI of cortical activity related to pro- and anti-saccades**

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**Purpose:** To locate cortical activity correlated with pro- and anti-saccade task performance using event-related fMRI.

**Method:** subjects viewed, through a mirror, stimuli projected onto a screen attached to the back end of a MR-scanner (Siemens Vision 1.5 T). Each 17 s trial started with a central fixation point, which disappeared after 15.3 s. After a temporal gap (200 ms), a saccade target (1500 ms) appeared either 10 deg to the left or right of central fixation. The subject's task was to either make pro-saccades to the target or anti-saccades to the target's mirror location. During task performance, the subject's eye-movements were recorded using an infra-red limbus tracking technique (Kimmig et al., 1999, *Exp. Brain. Res.*, (in press). During performance of a single trial 12 scans (6x128x128 voxels, 4 mm slices, TE = 66 ms, TR = 1.5 s) were made. During each run, 10 trials were presented. Five subjects participated. Eye-movement recordings were used to verify correct performance of the pro- and anti-saccade tasks. Incorrect trials were evaluated separately in the final analysis.

**Results:** We could establish task-related activity in primary visual cortex, the frontal eye fields and the supplementary motor area.

**Conclusion:** Using event-related fMRI it is possible to establish saccade-related patterns of cortical activity, while retaining better control over subjects' actual task performance than in conventional block designs. We will discuss the present results in relation to saccade-related activity as found in block designs.

## Effects of visual training on saccade control in dyslexic subjects

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**Introduction:** We have previously shown that saccade control measured in an antisaccade task develops continuously in both normally reading and dyslexic subjects until about age 20. Yet, the saccadic performance of dyslexics stays significantly behind that of normally reading subjects at all ages. These results were interpreted as a dysfunction in attention mechanisms involved in saccade generation as well as in the reading process and probably controlled by the prefrontal cortex. The present study shows how a daily training of specified visual tasks can improve saccade control in dyslexics.

**Methods:** Seventy-eight dyslexic children and adolescents (age between 8 and 17 y) showing a strong impairment in fixation stability and/or in voluntary saccade control performed one or more of three tasks including a fixation, a saccade, and a distracter (requiring antisaccades) condition. In all tasks the subject had to detect (at fixation or after a saccade) the last orientation of a small pattern which changed its orientation quickly (speed adjustable between 90, 130, 170, 210 ms) between up, down, left and right direction. After some time the pattern disappeared and the subject had to press a key indicating the last direction of the pattern. Subjects practised 10 min a day for a minimum of one week (for one task) and a maximum of 8 weeks (for all three tasks together).

**Results:** 80% of the subjects showed an improvement of the error rate in a classical anti gap task after training. The average improvement was 19% in the error rate, 13% in the correction rate, and 48 ms in the saccadic reaction times (SRT), which were faster. The data also confirm that the ability of suppressing involuntary glances to the stimulus develops with age. The two curves describing the error rate before and after training at different ages were almost parallel. When compared with the data of 107 control children the mean values of the error rate in dyslexics after training still stayed behind at older ages in spite of the improvement in the performance. Children who trained only the saccade pro task did not show improvements in the anti saccade task.

**Conclusions:** Reading and writing are complex functions that involve auditory/language as well as visual/attention related brain regions. The finding of a deficit in voluntary saccade control in dyslexic subjects supports the hypothesis of a multifactorial etiology of reading problems including prefrontal functions. This deficit is not definitive, it can be changed by a daily training improving sensorimotor integration.

## **Voluntary saccade control of ADHD children and the effect of Ritalin**

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Voluntary saccade control is poorly developed at the age of 8 years (Fischer et al., *Brain Res.*, **754**: 285-297). Up to 50% of dyslexic children exhibit a developmental deficit in producing voluntary saccades as tested by an antisaccade gap task (Biscaldi et al., *Neuropsychologia*, **36**: 1189-1202). ADHD children, mostly boys, often also have difficulties in acquiring reading and spelling skills. Many of them are treated with Ritalin. We measured the eye movements of 24 boys (age 10 - 15; mean = 12 y) before and after the use of Ritalin using a prosaccade overlap task and an antisaccade gap task. For control we used the data of 24 normally developed age-matched boys. For analysis the variables extracted from the data were classified as F-variables that describe the quality of fixation or as A-variables describing the voluntary component (Fischer et al., *Brain Res. Protocols*, **2**: 47-52). Both the test and the control data were then individually compared with those of a large reference group (N = 94) of normal children subdivided into 3 age groups. For each child we counted the number of F- and A-variables that were off-limits by more than 2 standard deviations.

Before taking Ritalin the number of off-limits A-variables was significantly higher in the test as compared with the control group. Ritalin reduced this number to almost the value of the controls. The number of off-limits F-variables, by contrast, was not significantly different and did not allow to differentiate the ADHD group from the control.

This study shows that in ADHD the voluntary saccade control component is not fully developed while reflexive saccades are normal. Ritalin reduces this deficit for the duration of its effectiveness. This observation is in line with the hypothesis that in ADHD frontal lobe functions are affected. From preliminary observations we know that daily practice can reduce the problems in voluntary saccade control not only in dyslexia but also for children with ADHD. Unfortunately, not all of the present subjects were tested for dyslexia.

## **Impaired antisaccade performance in patients with focal cortical lesions**

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**Introduction:** In the antisaccade task a subject has to perform a voluntary saccade in darkness towards an eccentric spatial location that is located in the hemifield opposite to a peripheral visual target. Its cortical control has generally been attributed to the frontal lobe. Antisaccade performance requires at least 3 steps, each of them with a specific cognitive impact:

- 1) the suppression of unwanted reflexive saccades in response to target onset,
- 2) a shift of visuo-spatial attention from target location across the midline towards the internally-represented saccade goal, and
- 3) the initiation of a non-visually-guided intentional saccade towards the latter.

These subfunctions might rather be controlled by different parts of the fronto-parietal cortical network of areas involved in saccadic eye movements.

**Methods:** To address this problem we investigated horizontal antisaccades in 34 patients with focal unilateral lesions of the posterior parietal cortex (PPC), the frontal eye fields (FEF), the supplementary motor area (SMA), or the dorsolateral prefrontal cortex (PFC), and in a control group of 32 age-related healthy adults. Horizontal saccadic eye movements were recorded in darkness using infrared reflection oculography, with the head fixed on a head holder. Subjects fixated a central laser point. As soon as it moved unpredictably to 14 deg of horizontal eccentricity in the left or right hemifield, they had to perform a saccade into the opposite direction.

**Results:** The patients' deficits consisted of increased error rates of unwanted reflexive saccades toward the visual target, and of prolonged latencies of antisaccades, whereas antisaccade amplitudes showed a high variability in normal subjects and patients and did not differ significantly between the groups. Increased error rates were most pronounced in patients with FEF lesions ( $p < 0.001$ ), without directional specificity, but were significant also in patients with PPC lesions ( $p < 0.01$ ) and with PFC or SMA lesions ( $p < 0.05$  or  $p < 0.1$ ), though to a lesser extent. In contrast, prolonged latencies of antisaccades were most pronounced in patients with PPC lesions, more into the contralateral ( $p < 0.005$ ) than into the ipsilateral hemifield ( $p < 0.05$ ). In patients with frontal lobe lesions, only right FEF lesions were associated with prolonged latencies of contraversive antisaccades ( $p < 0.05$ ), but neither PFC nor SMA lesions. All these deficits were not related to the severity of visual hemi-neglect, indicating that they do not primarily reflect these patients' impairment in shifting attention across the midline, from stimulus location towards the saccade goal.

**Conclusion:** The cortical control of antisaccades is not restricted to areas of the frontal lobes. Instead, our results demonstrate a specific role of the PPC and - to

a lesser extent - of the FEF for the initiation of antisaccades, with directional preponderance for contraversive saccades. In contrast, the whole fronto-parietal network of cortical areas is involved in voluntary suppression of inappropriate reflexive saccades, with predominance of the FEF.

## **Deficits of voluntary saccade initiation in schizophrenic patients**

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Schizophrenics' reflexive saccades are found unimpaired in most studies, but abnormal saccadic distractibility can be shown in the antisaccade task, when a saccade should be directed away from a peripheral stimulus to its mirror image location. This could indicate problems with suppressing reflexive saccades to peripheral stimuli and/or deficiencies in the initiation of voluntary saccades without a physical target.

In this study, saccadic eye movement parameters and their interrelationship were investigated under different experimental conditions. 23 healthy controls and 34 schizophrenic patients were studied with various eye movement tasks (reflexive refixation task with and without temporal gap, voluntary saccades after central arrow cue, antisaccade task).

Schizophrenics showed normal latencies in the gap- and overlap-paradigm, indicating that no generalised deficit was present in schizophrenics. Number of express saccades in the gap paradigm was equal in both groups. Saccades after the central arrow and antisaccades were generally slower than reflexive saccades in the prosaccade task. In schizophrenics, these voluntary saccades were delayed to a similar degree during both the antisaccade and the arrow cue condition in schizophrenics relative to controls. Furthermore, patients made significantly more errors in the antisaccade task. Correlation between antisaccade latency and latency of arrow-cued saccades was -0.61 showing close relationship between these tasks.

Results support the hypothesis that initiation of voluntary saccades rather than inhibition of unwanted reflexive saccades is the process sensitive to schizophrenic pathology.

## **Development of oculomotor and neuropsychological functions in children and adolescents**

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Only few studies on the development of oculomotor functions after the age of 6 - 7 y have been published so far. Recently, Fischer et al. (1997) reported augmented error rates and response latencies of children aged 6 to 15 y in the anti-saccade task. The present study aimed at replicating and extending these results.

Three sex- and IQ-matched age groups (6 - 7, 10 - 11, and 18 - 26 y) of 17, 18, and 20 participants, respectively, were tested on two successive days. On day/session 1, horizontal pro- and antisaccades under the 200 ms gap and overlap conditions were measured. On day/session 2, a horizontal and a vertical antitask as well as a nogo condition were presented. Eye movements were measured binocularly with the IRIS infrared device (SKALAR, Delft, NL). Each of the task blocks comprised 100 trials (50 targets at either side in random order).

Adult and 10 - 11 year old participants exhibited faster saccadic reaction times (most pronounced during the antitask), less antitask direction errors, less anticipatory eye movements, and less go responses during the nogo fixation condition than 6 - 7 year old children. Adults differed from 10 - 11 year old children in showing reduced saccadic reaction times and proportions of errors during the antitask. Both children groups made more express saccades during the protasks than the older participants.

Our results suggest different degrees of improvement with increasing age for the oculomotor functions assessed in this experiment, these effects being greatest for the proficiency to inhibit reflexive prosaccades during the antitask. These results are consistent with the assumption of protracted development of pre-frontal cortical functions.

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## Saccade inhibition during pointing

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Several studies on eye-hand co-ordination have shown that, typically, saccadic eye movements precede goal-directed hand movements to a visual target stimulus. Moreover, it has been found that pointing accuracy suffers when subjects do not move the eyes to the target. Recently, it has been observed that neurons in the intermediate and deep layers of the Superior Colliculus in monkey, already known to be involved in the generation of saccades, are active shortly before and during arm movements as well. This brings up the possibility that interactions between the different motor systems can happen already at this level. The present study wants to investigate such eye-hand interactions in human subjects at a behavioural level. More precisely, the experiments were designed to investigate the question whether saccades are inhibited to saccade away from a target when subjects make a goal-directed hand movement to the (same) target.

Eye, head and hand movements were measured with infrared tracking devices. In the so-called dynamic trials, subjects were instructed to make an eye and arm movement to a visual target (LED). During the arm movement, a second visual target was presented, approximately at the time the pointing movement reached peak velocity; the eyes, then already fixated the first target. In the static trials, the second target was offered when pointing was completed. Subjects ( $N = 10$ ) were instructed to make a saccade as quickly as possible to the second target. The second target could appear at 6 different positions, above or at the left of the fixation/pointing target, with 3 different amplitudes. In a control experiment ( $N = 10$ ) only saccades had to be made, and this time the second target appeared with a short or a long delay after the first target, comparable to the inter-stimulus-intervals (ISI) found in the static and dynamic conditions of the first experiment. In a third experiment, ocular fixation position and pointing target were dissociated, subjects pointed at non-fixated targets.

- I. The results showed that latencies of saccades towards the second target were  $\pm 170$  ms longer in the dynamic condition, compared to the static condition.
- II. Saccades appeared to be delayed with approximately the deceleration time of the pointing movement, resulting in a 'normal' residual saccadic RT's of slightly more than 200 ms, when measured from pointing movement offset to saccade movement onset.
- III. In the control experiment, the latency of the second saccade out of a sequence of two, was on average only 30 ms larger when the 2 targets appeared with a short ISI, compared with trials with long ISI's. Therefore, the

saccadic refractory period cannot be responsible for the substantially bigger delays that were found in the first experiment.

- IV. The observed saccadic delay during pointing was modulated by the distance between ocular fixation position and pointing target. The largest delays were found when the targets coincided, the smallest delays when they were dissociated.
- V. In sum, our results provide evidence for an active saccadic inhibition process, possibly to keep steady ocular fixation at a pointing target and its surroundings.

### **The jumping point - a new oculomotor paradigm for inducing anticipatory saccades**

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Saccadic tracking is induced by a horizontally jumping point with continuously shortened intervals corresponding to 0.2 to 1.4 Hz. The increasing rate of jumps to the same locations in space (12,7 degrees apart) induce regularly anticipatory saccades, very few at the slow rate range (early anticipations), when reactive saccades dominate, and very often at the high rate range (late anticipations) when reactions are virtually impossible. To study the influence of stimulus frequency and the possibility of learning 23 subjects perform the time course in a decelerating and in an accelerating form over 14 repetitions. The results show that the stimulus frequency is the main cause for the anticipatory behaviour and the task cannot be learnt. Additional measurements on a large scale population (n = 521 from 4 to 90 years old) show that early and late anticipations are separate categories over the life span, negatively correlated with each other. Early anticipations are often in childhood and in the elderly and in the less intelligent adults. They were inhibited the more efficient and competent the person is. Late anticipations correlate well with psychometric intelligence scores (Galley & Galley 1999). Brain imaging studies are in progress to find out the separate neuronal networks responsible for these different anticipatory categories.

Galley, N., & Galley, L. (1999 in press). Saccadic latency and fixation durations as indicators of mental speed. In: I. Mervielde, I. Deary, F. De Fruyt, & F. Ostendorf (Eds.), *Personality Psychology in Europe* (Vol. 7). Tilburg University Press.

## **Eye movement "Pop-Out": An eye movement-based memory effect**

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In previous work, we showed that eye movement patterns can be used to provide an indirect measure of memory, revealing the effects of prior exposure on ongoing visual processing. The current results document another "eye movement-based memory effect": prior exposure to faces produces "eye movement pop-out" in the subsequent viewing of multiple-face displays.

Subjects studied a series of previously unfamiliar faces, presented individually on a computer monitor, then viewed 2- and 3-face displays, half of which contained a previously studied face. The presence of a previously studied face embedded in multi-face displays produced significant changes in eye movement patterns to those displays, distinguishing them from all-novel-face displays, regardless of whether the subjects were instructed to just study the displays or to perform a recognition task. Within a given multi-face display, eye movement pop-out was observed. Either novel-item or familiar-item pop-out occurred, depending on the task: when subjects were to just study the display, their eye movement search was focused on the novel item(s); when subjects were to perform a recognition task, their eye movement search was focused on the studied item. Thus eye movement pop-out occurred regardless of the task being performed. In addition, eye movement pop-out was shown to occur independently of explicit remembering. Amnesiac patients, with severe deficits of explicit remembering, tested on the same paradigm (but with study instructions only) exhibited the same eye movement-based memory effects. They showed differential search patterns to multiple-item displays containing a previously viewed item compared to all-novel-face displays, and within displays they showed novel-item pop-out.

The current research extends our findings on the eye movement-based memory effect, showing that the influence of previous experience can be observed in ongoing visual processing regardless of whether the stimuli are being viewed individually or embedded in multi-item displays, regardless of the nature of the task instructions, and independent of explicit remembering. The eye movement-based memory effect offers a way of testing memory indirectly in real-world situations, without depending on explicit verbal reporting, and provides a powerful way of assessing how processing is shaped by prior experience. The eye movement pop-out seen in the current multi-face displays is sufficiently reliable and robust to be observable in single subjects, thereby offering the promise of supplanting standard line-up methods of eyewitness identification.

## **Saccadic inhibition in voluntary and stimulus elicited saccades**

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In a series of experiments we investigated saccadic inhibition caused by an irrelevant flash occurring subsequent to the signal to saccade. We developed a paradigm that allowed comparisons of saccadic inhibition even across conditions which in the absence of a flash produce dissimilar saccadic RT distributions. Among the conditions contrasted were prosaccade versus antisaccade conditions; step versus gap versus overlap conditions as well as saccadic inhibition as a function of saccadic amplitude. Both the magnitude and timing of saccadic inhibition were compared across these conditions. The latency of saccadic inhibition was extremely fast beginning as early as 60 to 70 ms following the onset of the flash. These short latencies suggest a low level, reflexive oculomotor effect. We examine the plausibility that the superior colliculus is the neurophysiological locus of saccadic inhibition.

## **Prediction of saccadic amplitude during smooth pursuit eye movements**

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If humans try to pursue a moving target, the nervous system uses predictions to overcome some of its delays. The question is: on what are these predictions based? That is, during those delays, not only the target moves smoothly, but also the eye. An example of such delay is the latency of a saccade made in response to a target jump. The aim of the present study was to investigate whether such saccades take into account the error that builds up during this latency. To induce variations in this error, the gain of the pursuit eye movement was manipulated by adding a patterned background in one condition and a concomitant hand tracking in another. Although the gain of the pursuit eye movements was successfully lowered in the background condition and increased in the hand tracking condition, no significant differences in saccadic amplitude were found between conditions. We conclude that these error-driven saccades are generated independent of the gain of the pursuit eye movement.

## Oculomotor performance during contrast discrimination

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There have been no high resolution studies of eye fixations in a comparison task, in particular of the simple case of comparing two predictably located targets. This study aims to determine how perceptual task difficulty influences oculomotor performance when looking repeatedly to and fro between two target features. We chose contrast discrimination as a demanding perceptual task. For comparison we also characterised oculomotor performance when the centres of the same target patterns were fixated alternately, as precisely as possible, in a pure oculomotor task.

Subjects were asked to repeatedly fixate two bright vertical bars with sine-wave luminance profiles and decide which of these two bars appeared brighter. Pedestal luminance was set at 24 cd/m<sup>2</sup> and Michelson bar contrast was varied between 0.30 and 0.55. Two bar profiles were used, with the bars set 4 deg apart, and periods of either 7.5 or 60 minarc. The bars differed in contrast over a range that encompassed perfect to chance discrimination, using the method of constant stimuli. Target bars were exposed for a maximum of 6 s and subjects responded within this time. Data from 2 subjects were analysed. When eye movements are plotted as a histogram of the time the eye spends on any particular part of the target, the distribution is bimodal, with one peak for each bar. Accuracy and precision of eye movements between the two target bars were respectively computed as the mean amplitude between, and the average standard deviation (SD) of, the histogram distributions.

In the perceptual task the subject's decision delay is highly correlated with task difficulty. Reduced contrast difference also leads to a greater number of fixations. Fixation duration, however, remains relatively constant (~370 ms) at about half the value in the oculomotor task. While precision and accuracy did not change with level of task difficulty, fixation in the perceptual task differs from that in the oculomotor task in undershooting the targets and being less precise (e.g. for 7.5 minarc bars: SD of 11 and undershoot of 15 minarc in the perceptual task versus SD of 6.5 minarc and near-zero undershoot in the pure oculomotor task). In addition, precision is best for the narrowest targets in both perceptual and pure oculomotor tasks. We have already determined the relative contributions of large fixation-shifting saccades, smaller corrective saccades, and drift to the accuracy and precision of target fixation in the oculomotor task. We will report and compare a similar analysis of the eye movements in the contrast discrimination task. In conclusion, varying the demands of a contrast discrimination task has little effect on oculomotor performance except for the

## Saccade: fixation, memory and anticipation

increasing number of fixations with the difficulty, yet foveation is less exact in the perceptual task.

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## Selective effects of haloperidol and lorazepam on the modulation of volitional saccadic eye movements

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There have been few studies in man on the neuropharmacology of volitional saccadic eye movements (VSEM's). VSEM's have been found to be reliably impaired in various neurological and psychiatric diseases, however the modulating role of biochemical factors has been overlooked. The aim of the current study was to compare the effect of a 'typical' neuroleptic drug (i.e. haloperidol) with a high affinity for the D2 receptor and a benzodiazepine (i.e. lorazepam) on volitional and reflexive saccades, since little is known on the extent to which saccadic eye movements in humans can be distinguished neuropharmacologically.

Sixteen normal healthy volunteers participated in the study: 7 males and 9 females, mean age 28 y, sd = 6.4 y. Saccades were examined in four saccadic paradigms: reflexive, anti, memory-guided and predictive using an infrared CCD camera with a linearity range of +20 deg (Eye Tracker 3, Amtech GmbH). All subjects received single doses of haloperidol (2 mg), haloperidol (4 mg), lorazepam (2 mg) and matched placebo, at weekly intervals in a latin square, crossover, double-blind design.

Saccadic analyses were conducted with an interactive software which extracted saccadic latency, peak velocity, amplitude of primary saccade and final eye position. In the ANTI paradigm a saccadic distractibility error was registered when the primary saccade was made towards the direction of the target, instead of its mirror-image projection in the opposite hemifield. An error was registered in the MEM paradigm when a saccade occurred during the 500 ms delay between target offset and the imperative cue.

Lorazepam produced a high incidence of distractibility errors in the ANTI ( $F = 9.97$ ,  $p < 0.005$ ) and the MEM saccade paradigm ( $p = 0.06$ ). Lorazepam also produced a slowing of saccadic peak saccade and latency in all saccadic paradigms. There was no reliable effect of lorazepam on primary saccade amplitude or the final eye position of ANTI, MEM or PRED saccades. Haloperidol had a highly specific effect on VSEM's. Saccadic distractibility was increased during the MEM paradigm with haloperidol (4 mg) ( $F(1) = 7.51$ ,  $p < 0.01$ ) in contrast to the anti-saccade paradigm. Haloperidol (4 mg) significantly increased the anticipation latency of predictive saccades, most evidently in the no-vision (i.e. working memory) phase of the task ( $F = 11.95$ ,  $p < 0.001$ ).

No spatial parameter (i.e. primary saccade amplitude or final eye position) showed any sensitivity to haloperidol challenge. Similarly, no spatial parameter of volitional saccade proved sensitive to lorazepam. The findings clearly demonstrate the selective effects of haloperidol and lorazepam on the central programming of saccadic eye movements and suggest that the D2 receptor and GABA receptor complex are important for the modulation of VSEM's.

### **Listing's law in amblyopia**

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Eyes are able to rotate about three orthogonal axes in space: a horizontal, vertical and torsional axis. However, in normal subjects eye movements are restricted to two degrees of freedom. Helmholtz formulated this specifically with the so called "Listing's Law: There exists a certain eye position from which the eye may reach any other position of fixation by a rotation around an axis perpendicular to the visual axis. This particular position is called 'primary position'".

Recent research showed that people suffering from microstrabismus and amblyopia seemed to have an increased instability of ocular torsion compared with normal subjects. The present study investigated whether Listing's law applies in these patients.

Experiments were carried out in 5 normal subjects, 2 subjects with micro-strabismus with amblyopia in one eye and 1 subject with amblyopia ex anisometropia. Preliminary results show a distorted shape of Listing's plane in patients with amblyopia.

### **Suppression of displacement in severely slowed saccades**

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During saccades, displacements of objects in the visual world are less likely to be reported than are equivalent movements occurring during fixation (saccadic suppression of displacement, SSD). Zee et al. (1976, *Archives of Neurology*, **33**: 243-251) showed that people with severely slowed saccades are able to modify their saccades in-flight in response to intrasaccadic target displacements. They

used large (20 deg) displacements, awareness of which would still occur despite SSD. We investigated (1) whether a subject with severely slowed saccades could exhibit SSD under appropriate stimulus conditions, and (2) whether she could modify her saccades in-flight in response to movements of which she was not consciously aware.

The subject was a 38 year old female with a 20 year history of autosomal dominant spinocerebellar ataxia. Her saccades were markedly slowed with velocities < 20% of normal. Consequently saccade durations were increased, lasting hundreds rather than tens of milliseconds. Eight neurologically healthy controls (mean age 24 y, range 17 - 43, 6 female) provided comparison data.

Eye movements were recorded using an IRIS (Skalar Medical) infrared limbus tracker. A computer-generated stimulus (a red square target subtending 0.75 deg) was video front-projected on to a large screen. Subjects were instructed to follow the target as it jumped horizontally by 8, 12, 16, 20 or 24 deg. After a saccade toward the new target position was initiated, the target was displaced centripetally by 1, 2, 3, or 4 deg. Subjects were instructed to report awareness of an intrasaccadic target displacement after each trial by pressing a key. The task was performed in both well lit conditions and in the dark.

The subject exhibited SSD of the same magnitude and characteristics as did controls, despite her saccades lasting an order of magnitude longer. In well lit conditions, the subject was able to modify her saccades in-flight in response to target movements regardless of whether she consciously detected them or not. However, in the dark her eye movements were more like those of controls, showing subsequent corrective saccades rather than corrections during the course of the primary saccade. Her conscious awareness of intrasaccadic movements did not alter between lighting conditions.

We conclude that SSD can still be exhibited by a subject with severely slowed saccades. However, SSD was not complete, in that the oculomotor system could utilise displacement information effectively even when this information was not available to conscious awareness. Thus SSD makes displacement information selectively available to different levels of the nervous system. This dissociation between conscious awareness and motor control is similar to findings in blindsight and other related phenomena.

The subject's ability to modify her saccades in-flight was impaired in the dark. In such a situation, extraretinal information takes over from visual context in determining target location. Thus extraretinal information does not appear to be optimal in guiding the oculomotor system.

## **Directional motion contrast sensitivity and linear pursuit eye movement in positive- and negative-symptom schizophrenia**

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The aim of the present experiments was to investigate a relationship between directional motion contrast sensitivity and linear pursuit eye movement in groups with positive- and negative-symptom schizophrenia and a control group. Subjects with schizophrenia were selected using DSM-IV criteria and classified into positive- and negative-symptom groups using the Andreasen scales for positive (SAPS) and negative (SANS) symptoms and the Kay, Opler and Fiszbein Positive and Negative Syndrome Scale (PANNS) and measures of premorbid and current intellectual ability, age of onset, years of illness, medication as well as a number of other background factors. The positive- and negative-symptom groups were significantly distinct on the positive- and negative-symptom scales.

Experiment 1 measured directional motion contrast sensitivity at three spatial frequencies (1, 4, and 8 c/deg) and five temporal frequencies (0.75, 3, 6, 12 and 18 Hz). The results of a repeated measures analysis of variance showed that there were no significant differences between the control and positive-symptom group in threshold sensitivity for directional motion at any spatial and temporal frequency. In comparison with the control and positive-symptom groups there were significant reductions in sensitivity to directional motion at all spatial and temporal frequencies in the negative-symptom group. The findings show that visual processing at threshold is only disordered in groups with negative-symptoms and not in groups with positive-symptoms.

Experiment 2 measured linear pursuit eye movement as a function of target velocity (5, 10, 15, 20, 25, and 30 deg/s) in the same groups of subjects. Eye movements were recorded using an infrared limbus reflection device (Skalar, IRIS, Skalar Medical B.V.) with a linear range of 20 deg and an optimal resolution of 2 minarc and bandwidth DC to 100 Hz. The target stimulus was small circle of light (0.19 deg of visual angle and a contrast of 0.4) which was produced by a back-propagated laser beam controlled by a General Scanning Model XY0507V X-Y Optical Scanning Head (General Scanning Inc.) used to deflect a Uniphase Helium Gas laser beam onto the back of a large Rearlite (Opra) opaque projection screen viewed from a distance of 1.5 m. The scanning head was controlled by a Model DSC2005 Series Digital Scan Controller (General Scanning Inc.). The target stimulus was controlled by a modified REX (Real-Time Experimentation Platform) data acquisition and analysis system developed by Dr. T. Hain. The results showed that there were no significant differences in linear smooth pursuit gain (eye velocity / target velocity) between the control and positive-symptom groups. In comparison with the control and positive-symptom groups there were significant reductions in linear pursuit

gain at all target velocities between 10 and 30 deg/s but not at 5 deg/s in the negative-symptom group. The present findings show that directional motion sensitivity and pursuit eye movement are disordered in a group with negative-symptoms and not in a group with positive-symptoms and mirror an emerging consistency in studies which have shown that disorders in eye movement and visual processing are associated with the negative-symptom or 'deficit syndrome' schizophrenia.

### **Naso-temporal asymmetries in saccade latency: a study of normal and hemianopic subjects**

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Saccade paradigms have been used as tests of residual visual functioning (or 'blindsight') in patients with cortical blindness (see: Weiskrantz, 1990, *Proc. Royal Soc.*, **239**: 247-278). We examined saccade latency in hemianopic and normal subjects under distracter conditions. Saccades were made to a target presented in one hemifield, under monocular viewing conditions, and on some trials a distracter appeared simultaneously in the opposite hemifield. For the hemianopic subjects distracters always appeared in the functionally blind hemifield. The hemianopic subjects were not aware of the distracters. Visual distracters in the hemianopes blindfield did not influence saccade latency. By contrast, the latency of saccades made by normal subjects was increased under similar distracter conditions. Furthermore, a small naso-temporal asymmetry was observed with a greater interference effect for temporal field distracters. The distracters did not influence the amplitude of saccades made by the normal or hemianopic subjects. We argue that these results are inconsistent with the view that the small crossed projection from the nasal hemiretina to the mid-brain may mediate an inhibitory effect when the geniculostriate pathway is inoperative (Rafal et al., 1990, *Science*, **250**: 118-121). The presence of an inhibitory distracter effect in the normal subjects is interpreted in terms of inhibitory mechanisms operating in neural structures involved in saccade programming (Walker et al., 1997, *JNP*, **78**: 1108-1119).

## **Saccadic downpulsion and cerebellar disease**

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Ocular dysmetria is a feature of disease of the cerebellum and its connections. Saccadic lateropulsion frequently accompanies the lateral medullary (Wallenberg's) syndrome and less commonly, cerebellar disease. Torsional pul- sion or blips during saccades may be associated with brainstem or cerebellar disease. We have observed another type of conjugate ocular deviation occurring during saccades, 'saccadic downpulsion', in three patients with severe cerebel- lar affection. We have previously reported the phenomenon in two of these patients (Anderson, 1996, *Neuro-Ophthalmology*, **16**(Suppl): 269) and now pre- sent an additional case. The two earlier cases had multiple sclerosis and para- neoplastic cerebellar degeneration respectively.

The third patient is a wheel chair bound 31 year old male with multiple sclero- sis. He presented with ten years progressive ataxia, clumsiness, dysarthria, uri- nary incontinence and blurred vision. Clinical examination revealed a severe pan cerebellar syndrome with marked limb ataxia and tremor, moderate dysarthria and titubation of the head. Additional features were moderate py- ramidal weakness of the legs, increased reflexes, and loss of dorsal column sen- sation in the feet and hands. There was intermittent horizontal pendular nys- tagmus and gaze evoked nystagmus in all directions and square wave jerks. Smooth pursuit was markedly impaired. Horizontal saccades were of normal velocity but showed marked hypermetricity in each direction with saccadic os- cillations after leftward saccades. During horizontal saccades there was usually a prominent downwards deviation i.e. downpulsion. This downpulsion re- sulted in an oblique saccade (i.e. downwards and centrifugal) which was fol- lowed by corrective centripetal saccades and upwards drift. The saccadic downpulsion was confirmed with infrared eye movement recordings and documented by video camera. CSF examination revealed the presence of oligo- clonal IgG bands and MRI brain scan showed white matter changes typical for multiple sclerosis.

The fastigial nucleus has either direct or indirect influence upon the brainstem saccade generating circuits. It seems to be involved in calibrating motor error, thereby maintaining normal saccadic metricity, and in appropriate coupling of horizontal and vertical components, maintaining normal saccadic trajectory. The oculomotor vermis (lobules VII, VI and possibly V) is primarily involved in this process and has direct inhibitory Purkinje cell projections to the saccade- related fastigial nucleus neurones. Thus, damage to either of these two areas

can produce saccadic dysmetria and interfere with the coupling of horizontal and vertical saccadic components, resulting in inappropriate saccadic trajectory. Indeed, cooling the medial cerebellar nuclei of monkeys alters saccadic metrics and direction, and may result in a prominent downward vertical component during horizontal targeted saccades (Vilis, 1981, *J. Neurophysiol.*, **46**: 828-838). These inappropriate saccadic phenomena after reversible cerebellar nuclei lesions in the monkey are very similar to those documented in our patients. We therefore suggest that saccadic downpulsion in human cerebellar disease results from dysfunction of the fastigial nucleus and/or oculomotor vermis.

## **Yaw, pitch, and roll eye movements and motion sickness responses in humans**

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Eye movement data of animals are available over a wide variety of stimulus conditions. But, motion sickness due to angular stimulation about an earth horizontal axis may frustrate the measurements, why human studies are limited.

As part of a longitudinal investigation considering vestibular adaptation in aviators, we recorded eye movements evoked by angular velocity steps in yaw, pitch, and roll, about both the earth vertical and earth horizontal axis. This gives a data set of human eye movement parameters over all six basic conditions, though also in this study, not all subjects could withstand all conditions.

The results show that these parameters vary systematically between conditions. The most striking difference reconfirms the presence of only a one dimensional velocity storage mechanism, despite the three-dimensional nature of eye movements. With respect to the primary objective of this study, the data show that vestibular adaptation primarily takes place at the level of this velocity storage. Moreover, desensitisation of motion sickness by repetitive exposure to a provoking stimulus seems to coincide with a reduction of this velocity storage only.

These findings indicate that the susceptibility to motion sickness is determined at a central level, rather than at the peripheral level of the end organs.

## **Gain of the rotational Vestibulo-Ocular Reflex (VOR) in a large sample of humans**

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We measured the gain of the human rotational vestibulo-ocular reflex (VOR) in a total of 75 human subjects, about 10 times as many as most other studies, under both active and passive motion at 0.45 Hz in open-loop conditions. Examining a large number of subjects allowed an assessment of VOR gain resistant to individual differences; many prior studies used small numbers of subjects, and this is a likely cause of the variation of gains reported in the literature. While undergoing sinusoidal oscillation, active VOR gain averaged 0.99 and passive gain averaged 1.0, very close to complete VOR compensation. These gain measurements, while differing from older estimates, agree closely with some more recent estimates, and support a reinterpretation of the role of VOR in eye stabilisation during head movement. The human rotational VOR appears sufficient

for complete rotary compensation; visual (i.e. optokinetic) feedback compensation functions only to correct vestibular error, and in many subjects it operates in the same direction as head acceleration.

We made a number of decisions regarding parameters:

- 1) We employed sinusoidal oscillation at 0.45 Hz, 30 deg amplitude since this imitates a natural rate of head motion.
- 2) Subjects were asked to imagine an earth-fixed target, as this seemed the best way to examine the normal compensatory properties of the VOR.
- 3) We employed both active and passive rotation to assess VOR in both these situations.
- 4) Since subjects were in the apparatus for less than 2 min, it is unlikely they experienced decreased arousal, and so they were asked merely to fixate targets when present, and perform saccade-free fixations when absent. Recording intervals were limited to 5 s, so that fatigue was not an issue and the eyes did not drift significantly from their original laser-oriented position.
- 5) Computation was performed by taking the ratio of root-mean-square eye velocity to root-mean-square head velocity, since this is the most common approach in the literature.

Subjects were trained to not make saccades during dark phases.

A spot of red laser light was beamed via a mirror onto a hemicylindrical screen (viewing distance = 90 cm). Head position was measured with a Polhemus Fastrak magnetic field emitter unit in conjunction with a receiver mounted on a helmet that was tightly strapped to the subject's head. Eye position was monitored by paired infrared sensitive photocells attached to the helmet and positioned below the right eye. A head-mounted infrared LED provided constant illumination of the eye. Bandwidth of the photocell system exceeded 0 - 400 Hz, and spatial resolution is 15 minarc. The eye monitor was calibrated by having subjects fixate 3 fixation marks 15 deg apart in succession, with background lights illuminating the marks. When fixation was stable at a mark, the experimenter pressed a key to enter the corresponding a/d value into the computer. Recorded eye positions were interpolated from these values.

## **Cervical and vestibular control of ocular torsion in man**

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Ocular torsion (OT) in response to static or dynamic head tilt is generally considered to reflect functioning of the otolith organs or semicircular canals, respectively. Cervical contributions are either ignored or avoided by examining the response during tilt of the whole body. However, for horizontal eye movements it has been shown that the neck proprioceptors are responsible for anti-compensatory gaze shifts. The aim of the present study was to investigate whether similar effects exist for the OT response.

To differentiate between inputs from the otoliths, the semicircular canals and the neck proprioceptors, we used three sinusoidal roll tilt stimuli (the head alone, the trunk alone and the whole body) both in an upright and supine body orientation. The stimulus frequency in these dynamic conditions was 0.2 Hz, and the amplitude was 25°. The OT response was recorded in five healthy subjects by means of video-oculography with a sample frequency of 50 Hz.

The results showed a clear cervical contribution which was best noticeable by comparing the raw recordings obtained in conditions with only head tilt and conditions with whole body tilt. Although there was no difference in the slow component velocity (SCV), the amplitude of the OT nystagmus was significantly smaller during head tilt. Rotation of the neck generated anti-compensatory saccades, reducing the torsional excursions of the eyes. This is analogous to the cervically induced gaze shift observed with horizontal eye movements. On average, the cumulative amplitude of this cervical component amounted to 2.5°. Interestingly, the OT response to rotation of the trunk alone was much smaller (mean amplitude 0.4°). In fact, trunk rotation only produced an OT response in the upright body orientation, but not in the supine body orientation. These findings suggest that at least some vestibular stimulation is required for the cervical effects to become visible.

In addition to the sinusoidal roll stimuli, we also studied the OT response to static tilt of only the head, only the trunk or the whole body. This yielded similar data, although of smaller amplitude, confirming that the influence of the neck proprioceptors depends on the amplitude of the vestibular response. We therefore conclude that the cervical contribution to OT is to modulate eye position - not velocity - during an existing vestibular response, so that the eyes remain oriented in a head-fixed frame of reference. The usefulness of this cervical control may be explained as follows. During normal locomotion, the vestibular response produces ocular counterrolling which sufficiently stabilises the visual surround. However, during head movements to intentionally look at an object, it would be more appropriate to display the object straight (i.e. not tilted) on the retina. In that case, the vestibular response should be neutralised, which is achieved by the anti-compensatory cervical response.

## **Orientation strategies influence vestibular nystagmus**

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The fast phases of vestibular nystagmus do not simply return the eye to the centre of the orbit, but also direct the eye beyond this primary position, in the anticompensatory direction. This induces a shift of the ocular beating field (Schlagfeld). This shift of the beating field has been mainly documented in studies of eye-head co-ordination in monkeys and cats. From studies in the cat, the functional role of this shift was interpreted as an anticipatory orienting response towards a "centre of interest". We investigated in humans whether this shift could be related to some strategy of orientation.

Eye movements were measured with an infrared system during two experiments on self-motion perception in the dark. Subjects were asked to rotate, by means of a joystick, a mobile robot on which they were seated in order to reproduce a previously imposed passive rotation (80 - 340°). In the first experiment, no specific instruction concerning orientation strategies was given. From this experiment, we made the hypothesis that the shift of the ocular beating field could be the manifestation of two different orientation strategies based on allocentric and egocentric reference frames, respectively. It was also proposed that subjects who preferably used the first strategy exhibited large shifts of the beating field, while the others who probably used egocentric memory did not exhibit any shift.

To further test this hypothesis in a second experiment, we gave to the subjects consecutively two different instructions: in the first set of runs, naive subjects, who had no mental image of the experimental room since they had never seen it before, were asked to pay attention exclusively to their sensations of body rotation in place, during both stimulus and reproduction rotations. Then, subjects were shown the room, and during the second set, subjects were asked to try to 'see' themselves turning in the room (to visualise mentally the room). Both during the stimulus and the reproduction rotations, mean gaze shifts were indeed larger in the second condition (5.73 ±17.03 deg; 6.32 ±17.05 deg) than in the first one (1.05 ±15.63 deg; 1.80 ±17.44 deg).

Therefore, we believe that the shift of the beating field could be influenced or could even participate in an orientation strategy when this strategy is based on an internal representation of the experimental room.

## **Event-related potential studies of the gap effect**

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The 'gap effect' (faster saccades to a peripheral target when its onset is preceded by the offset of the central stimulus) has often been referred as an example how attentional processes and oculomotor control interact. The neural processes underlying the gap effect were studied in a series of experiments by measuring high-density event-related potentials (ERP's) time-locked both to the target presentation and the saccade execution. We observed three neural correlates of the gap effect: (i) a frontal positivity / temporal negativity complex in response to the fixation offset or to other warning cues which may reflect specific preparatory processes, (ii) an enhancement of the early cortical visual responses to the peripheral target following either an offset or a change of the fixation stimulus similarly to the effect of attentional manipulations, and (iii) a prolongation of parietal activity before saccade execution when the fixation stimulus remained on which might be a correlate of a disengagement process. These results suggest that several factors contribute to the gap effect, each having its own neural basis, and that the cortical processes uncovered by these studies cannot explain the gap effect entirely. The results of similar studies in infants suggest that the behaviourally similar gap effect might be based on the functioning of different neuronal structures and that the cortical control of saccades undergoes a rapid development during the first year of life.

## **Cortical potentials associated with remembered saccades**

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Prior to saccade initiation several cortical areas are activated and this pattern of activation depends on the type of eye movement. Accordingly, the organisation of a visually guided saccade requires the activation of parietal areas and this phenomenon is expressed on the cortical potential obtained at about 200 ms prior to saccade onset over the parietal areas. In the case of remembered saccades the pattern of cortical activation should be more complex than that of visually guided saccades.

We recorded the cortical potential in an experimental paradigm with three variants. First, the pure remembered saccade task (MEM task) in which the target was flashed followed by a variable delay of 1 - 6 s. At the end of delay period the go signal permits the execution of a saccade towards the position of the flash. In the second task (DEL task) the target remained on for a period of 1 - 6 s and the saccade was made towards the still visible target.

The third task (DEL<sub>1</sub>) was a variant of the DEL task but the target disappears with the appearance of the go signal.

The EEG was recorded with 25 electrodes (10/20 IO system) and the movements of the right eye with the IRIS device. The off-line analysis consisted of averaging procedures with the trigger on the sensory (peripheral target) as well as the motor (saccade onset) events.

The pattern of cortical activation linked with the peripheral target was qualitatively similar between tasks. At about 500 - 600 ms after the peripheral target the EEG activity reaches a maximum over the central -frontal areas and then starts to decline in a such a way that at the end of long delay trials the EEG activity is found to oscillate near the base line. On the other hand the EEG activity with the MEM task is significantly larger over middle-left anterior areas than with the two delay tasks and this difference shows a weak but significantly correlation ( $R = 0.21$ ) with the accuracy of the remembered saccade. As for the potentials obtained with triggering the saccade onset, the two delay tasks are followed by larger activation than the MEM task over the posterior areas. It seems that the presence of the peripheral target enhances the cortical activation for, additionally, the DEL task produces larger activity than the DEL<sub>1</sub> task.

In summary I conclude that the anterior activation obtained with the MEM task could be considered as a memory related effect. However, it remains to be seen whether this phenomenon can be assigned to working memory mechanisms supposed to participate in the programming of remembered saccades.

### **Event-related brain potentials during the execution of visually-guided and antisaccades: experimental task modifications and reliability analyses concerning the PreSaccadic Negativity (PSN)**

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The preparation of saccadic eye movements is associated with a surface-negative potential shift, the presaccadic negativity (PSN). A series of experiments aimed at investigating the impact of (a) the saccade type (task blocks of visually-guided versus antisaccades), (b) the task instruction (speed versus no speed), and (c) the degree of information about the forthcoming saccade (direction versus no direction information, delivered by a peripheral cue) on the PSN amplitude and topography, as well as (d) the reliability of PSN measurement (4 weeks retest interval).

Visually-guided and antisaccades were elicited within the two-stimulus paradigm, with a 3.5 s SOA between the central fixation point and the saccade eliciting stimulus presented randomly at the left or right side. The EEG was recorded with a DC amplifier (MES, Munich), and AgAgCl electrodes were at-

tached at 25 to 64 recordings sites over both hemispheres, using a sampling rate of 100 Hz (bandpass DC - 30 Hz). Healthy subjects (N1 = 23, N2 = 28, N3 = 16) participated in the experiments. In one of the experiments, the EyeLink system (SMI, Teltow) was additionally used in order to measure eye movements.

The following results were obtained. First, in all experiments the PSN had a topographical maximum at central sites, its amplitude being significantly larger preceding anti- than visually-guided saccades. Second, the instruction to respond "as quickly as possible" reduced this task effect and augmented saccadic reaction times (SRT) for visually-guided and antisaccades, when compared to an instruction that did not stress response speed. Third, direction information delivered by a peripheral cue 3.5 s before the forthcoming saccade, augmented the PSN amplitude both before the anti- and visually-guided saccades when compared to a condition with unreliable directional cueing. Fourth, for a retest interval of 4 weeks, the PSN amplitude at Cz turned out sufficiently reliable (anti:  $rtt = .80$ , visually-guided:  $.57 < rtt < .70$ ), but less reliable than SRT (anti:  $rtt = .88$ , visually-guided:  $rtt = .77$ ).

Altogether, our results indicate that the PSN is a retest-reliable measure of saccade preparation, which is sensitive to the experimental variation of the saccade type, the task instruction, and the amount of information enabling saccade preparation.

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### **Lateralised cortical activity in saccade preparation with and without warning interval**

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The relation between lateral shifts of visual attention and saccade preparation was investigated, by measuring EEG differences contra-ipsilateral to the relevant stimulus or to the required saccade.

In experiment 1, participants had to make saccades either to a saliently coloured or to a grey circle, simultaneously presented in opposite visual hemifields, under different task instructions. Three components of lateralisation were found:

- (1) an inferior-parietal component, 250 ms after stimulus onset, reflecting the shifting of attention to the relevant stimulus.
- (2) another inferior-parietal but more wide-spread component, at 400 ms, reflecting the enhancement of the attentional shift if the relevant stimulus was also the saccade-target.
- (3) activity contra-lateral to saccade direction, beginning about 100 ms before the saccade, largest above mesial parietal sites, with some task-dependent fronto-central contribution, reflecting saccade-associated activity.

In experiment 2, preparatory activity was measured in the S1-S2 interval in a choice-response task with four alternatives (look or press right or left), following different amounts of S1 information. When providing information about movement side, S1 evoked contra-lateral parietal activity at 300 ms and fronto-central activity at 400 ms, with the fronto-central component being larger and the parietal component being smaller when saccades were announced than when key-presses were announced. These two components might be related to component (1) and (2) of experiment 1, again reflecting saccade-related shifts of attention in the parietal and frontal systems.

## Oculography in the diagnosis of bilateral Duane's syndrome

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Duane's Retraction Syndrome (DRS) is a neurogenic brainstem ocular motor dysfunction so named because of the retraction of the globe (caused by synchronous contraction of the horizontal recti) and narrowing of the lid fissure that occur on attempted adduction. DRS may be bilateral (15 - 20% of cases).

By using EMG examination, this syndrome can be classified into three types (Huber, 1974, *Brit. J. Ophthalmol.*, **58**: 293-300): I) Palsy of abduction with retraction on adduction. EMG shows absence of electrical activity in the lateral rectus muscle on abduction but paradoxical electrical activity on adduction. II) Palsy of adduction with retraction, and intact abduction. EMG reveals electrical activity with contraction of the lateral rectus muscle on both abduction and adduction. III) Palsy of adduction and abduction, with retraction on attempted adduction. The EMG demonstrates co-contraction of the horizontal recti on both adduction and abduction.

Because the EMG is not easily applicable to paediatric patients, other instrumental examinations like eye movements recording have been proposed. As shown by Metz (1975, *Am. J. Ophthalmol.*, **80**: 901-906), in type I DRS the average abduction saccadic velocity is usually quite slow, while the average adduction velocity is only moderately reduced. In type II DRS average abduction saccades are generally normal in speed, but adduction saccadic velocity is markedly subnormal. The type III DRS has both slowed saccades medially and laterally. Gourdeau (1981, *Arch. Ophthalmol.*, **99**: 1809-1810) recorded slowed adduction saccades in the sound eyes in all the considered 5 cases of monolateral DRS, as well as asymmetric vestibulo-ocular reflex, optokinetic nystagmus, and after-nystagmus. Previously, Nemet and Ron (1978, *Brit. J. Ophthalmol.*, **62**: 528-532) found that the motility of the sound eye was affected in all their 10 patients. On the contrary, Metz (1982, *Arch. Ophthalmol.*, **100**: 843-844) found normal saccadic velocities in the sound eye of 28 DRS patients.

In our study we measured the electromyographic firing patterns of the horizontal recti of the normal (right) eye, in one case (16-year-old boy) of monolateral type II DRS with alterations of the saccadic velocities in both eyes.

Saccadic eye movement recordings of both eyes revealed an increased slope of the Duration-Amplitude relation in adducting saccades. The linear regression fit for the left eye was  $D = 10.9 * A + 35.6$  ms for rightward saccades and  $D = -6.8 * A + 38.6$  ms for leftward saccades while for the right eye it was  $D = 1.9 * A + 31.3$  ms for rightward saccades and  $D = -4.4 * A + 28.8$  ms for leftward saccades. Also the Peak Velocity-Amplitude relation showed significant differences between abducting and adducting saccades with remarkable slow

down of the adducting movements. We used the best-fit with the non-linear relation  $V_p = 1/(a + b/A)$  to quantify these differences. For abducting saccades  $1/a$  was 523 and 1045 and  $1/b$  was 40 and 64 respectively in the left and in the right eye; for adducting saccades  $1/a$  was 388 and 426 and  $1/b$  was 77 and 84 respectively in the left and in the right eye. The EMG of the horizontal recti of the right eye showed, as present in the affected left eye, a paradoxical activity of the lateral rectus muscle during adduction.

Our results about the saccadic characteristics of the normal eye in one DRS patient show a bilateral saccadic velocity alteration. It is in accordance with Nemet and Ron (1978) and partially with Gourdeau (1981), who found slower saccades although still within the normal range. In our case, detecting the saccadic alterations in a boy where an extraocular muscles EMG seemed to be possible to execute, the EMG of both eyes showed a bilateral co-contraction of lateral rectus during adduction, being this one a case of II type DRS. We agree with Gourdeau (1981) that DRS may possibly relate to a disturbance not only of the sixth nerve and its nucleus but also to a disturbance of the horizontal-gaze system controlled through the internuclear projections of the abducens nucleus via the medial longitudinal fasciculus to the contralateral oculomotor complex and that the other alterations of eye movements he detected suggest again that premotor structures in the brainstem may be involved in DRS. Our case demonstrates that clinical evidence of monolateral DRS can be inadequate for a correct diagnosis, being indispensable the EMG of the normal eye at least in the cases with bilateral saccadic alterations, before speculations about the possible origin of the syndrome.

In conclusion, EMG revealed a bilateral type II DRS in a patient with an apparently normal right eye, but where dynamic alterations were present during the adducting saccades.

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## **Measuring saccade velocity using a Vacuum Fluorescent Display (VFD) flicker**

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A novel method for measuring saccade velocity has been developed in our laboratory. When a moving flicker radiant is displayed in front of the eye, a row of radiants is "painted" onto the eye. Thus, the eye simultaneously perceives several radiants. This phenomenon is known as visual persistence, and occurs because of the limited time resolution of the eye. In the same way, when a tiny flicker radiant is displayed at a fixed location during a saccade (in a dark room), a row of radiants is perceived. As the spatial interval between the perceived neighbouring radiants is relative to the speed of the eye, the saccade velocity

can be calculated from this interval (Ando, 1994, *Neuro-Ophthalmology Japan*, **11**: 318-325).

The vacuum fluorescent display (VFD) is widely used in Japan in digital clocks and graphic equalisers as a display device that is able to emit a bright green light that flickers at high frequency. In this study, a radiant was used that incorporated a VFD (32 x 32 dots matrix with 0.3 mm dot pitch) capable of emitting flickering signals, on or off simultaneously. The flicker frequency could be adjusted from 100 Hz to 990 Hz and the light duration was fixed at 0.1 ms. The configuration pattern of the radiant was either an open circle or a solid rectangle (9.6 mm width x 9.6 mm height), which was produced on a Windows PC then loaded onto the VFD through the serial port. The VFD and fixation targets (which consisted of red LED's) were located on a arch-shaped arm (300 mm radius) attached to a rotator (400 mm radius), to measure every possible saccade direction.

Guided by visual and audible cues (LED's and beep sounds), subjects looked alternately at two fixation targets (0.5 Hz) using only one eye. The flicker pattern was then displayed on the saccade trajectory. To the subject, the image appeared as either a row of circles or rectangles. When the frequency of the radiant is low, a gap between the circles or rectangles should be perceived. At high frequency, no gap should be perceived. Measurements were taken using gradual increments from low to high frequency and the subject was asked to report the presence or absence of gaps. The saccade velocity was calculated using the radiant frequency that closed the gap between the perceived radiants (where the subject responded "no gap" for the first time).

This method for measuring saccade velocity has the following advantages:

- 1) the apparatus is simple and inexpensive;
- 2) any direction of saccade can be measured with the same accuracy;
- 3) results can be obtained without instrument calibration;
- 4) the methodology is non-invasive and safe.

The advantages for using the matrix VFD, over a row of optical fibres as previously reported, is that the radiants are more distinguishable since it emits a certain 2D pattern, and that it is easier to be equipped.

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## **Parafoveal-on-foveal priming during eye movements: Interaction between visual and semantic effects**

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The interaction between visual and semantic properties of a target word, presented in the parafovea, were investigated in an eye tracking experiment. Participants were required to fixate a 'prompt' word before to make a saccade to a 'target' word and to judge about their semantic association. Three conditions of associations (semantic factor) and two polarities were manipulated (visual factor). The parafoveal 'target' word might be semantically related or unrelated with the 'prompt' word, or might be associated with a 'non-word'. Each pair of 'prompt-target' words were counterbalanced across polarity, either in positive polarity (Dark letters on bright background) or in negative polarity (Bright letters on dark background). Gaze duration on the prompt showed a sensitivity to a semantic pre-processing of the 'target' word only in positive polarity. In this visual condition, 'prompt' word gaze duration was reliably shorter when the parafoveal word was semantically associated. No effect arose in negative polarity. More detailed analyses on the mean fixation duration and single fixations cases confirmed this tendency. Further analyses on saccade extent and landing position on the target will be given later. The results reported here manifestly showed that properties of the parafoveal target word can influence foveal gaze duration and that influence is tightly related to the visual quality of the 'target' word. That effect can be related to well-known facilitation effects showed by priming experiments onto visual degraded target (Stanovitch & West, 1981). Such parafoveal-on-foveal effects are incompatible with models of reading allocating the attention sequentially to successive words. The data suggests rather that foveal and parafoveal information occurs in parallel. The specific interaction between visual/semantic parafoveal effects shed also into light some reading problems occurring on display.

## **Investigation of a phase-locked mechanism: saccades to non-flickering targets on a bright pulsating background**

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Pulsating illumination of VDU is usually regarded as an important source of visual discomfort or fatigue especially during reading. To understand the causes of these effects, previous studies investigated saccades to stimuli that are presented intermittently on cathode ray tubes at refresh rates of 50 - 125 Hz. Results showed that flicker seems to affect saccadic control both on latencies, saccade extent and velocities. Several explanations have been also mentioned stipulating either a direct effect on saccadic computation during latencies (Kennedy et al., 1998) or during the saccade itself (Baccino, 1999). Moreover, the lack of any DC control condition in these studies does not allow to disentangle between these interpretations. To extend these researches we measured saccades executed from central fixation to eccentric (5 deg) targets (red points of laser light, unmodulated in time). These were presented on a bright background produced by a purpose-made fluorescent lamp that was able to produce either steady DC light, or short pulses of light, since the special fast phosphor had a 2 ms rise-time and a 1 ms fall-time. The moment in time when the saccades began and ended was detected on-line and triggered the lamp to switch between steady light and trains of Gaussian-like light pulses of 4 ms duration. We gave trains of pulses with 2 frequencies (50, 100 Hz) in 4 conditions: during fixation of the central launching position only (1), during the latency only (2), during the latency and during the saccade (3) or during the flight of the saccade only (4). Before and after these trains of pulses, steady light of the same luminance of 67 cd/m<sup>2</sup> was presented. Moreover, one condition was completely flicker-free. Compared to a reference condition of continuous DC light, the saccadic latency was significantly longer ( $F(1,21) = 22.92$ ,  $p < 0.001$ ,  $n = 24$ ) when a train of light pulses (at 50 Hz) was presented only during the latency, while steady light appeared before and after. In this case, the saccade onset seemed to be delayed. These findings allow to claim that the main effect of pulses on saccadic control occurs mainly during the computation of the saccade (e.g., during the latency). All other conditions had similar latencies as continuous DC light condition. Trying to see whether these effects might be due to a kind of phase-locked mechanism operating at 50 Hz, the results failed to show this hypothesis.

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### **Three-dimensional representation of sensorimotor cerebral activation during optokinetic stimulation**

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After a study of optokinetic stimulation (OKN) with FLASH functional magnetic resonance imaging, which showed activation of a cerebral network of sensorimotor and subcortical areas (Bucher et al., 1997), we examined the three-dimensional representation of these activation patterns using fMRI multislice echo planar imaging. Five normal subjects, were examined on an 1.5 T scanner (Siemens Vision, Erlangen, Germany). Alternating periods of 5 images at rest followed 5 images during small-field OKN in a series of 50-100 T2\*-weighted scans using an EPI sequence. Image analysis was performed on a UltraSPARC workstation (Sun Microsystems Inc.) using the SPM96 software package (The Wellcome Department of Cognitive Neurology, Institute of Neurology, London, UK). The data were realigned, anatomically standardised in the stereotactic Talairach space, smoothed and analysed using a delayed box-car reference waveform. OKN was associated in all subjects with bilateral activity in the visual cortex, precentral and posterior median frontal gyrus (frontal eye field), prefrontal cortex, medial part of the superior frontal gyrus (supplementary eye field), posterior parietal cortex (parietal eye field), lateral occipitotemporal cortex, anterior and posterior insula, basal ganglia and thalamus. SPM data analysis enables us to demonstrate a three-dimensional representation of this sensorimotor network during OKN. Thanks to the use of Talairach co-ordinates a more precise localisation of activated areas, and a comparison with anatomical and neurophysiological data of primate studies was possible.

## **Disjunctive oculomotor learning caused by feeble image size inequality: differences between primary and tertiary positions**

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When normal emmetropic subjects view dichoptically an image sized differently for the two eyes saccades become rapidly disjunctive. This allows a bi-foveal fixation immediately after the saccade. The disjunctivity can be retained for a few minutes under subsequent monocular viewing. This indicates oculomotor learning (e.g. van der Steen and Bruno, 1995; Kapoula et al., 1995). Prior studies used relatively important image size inequality (8% - 10%). The disparity created by such inequality corresponds to that created by a difference of power spherical lenses of about 4 - 5 dioptries. The purpose of the present study was to test whether feeble image size inequality (2%, approx. 1 diopetre) causes also disjunctivity of the amplitude of the saccades.

Six normal subjects participated in the study. All subjects wore an afocal magnifier of 2% in front of their preferred eye; consequently this eye viewed the image 2% larger. Subjects were seated at 1 m in front of a screen where a random-dot pattern was projected. They made saccades at 8° and 16° along the horizontal and vertical principal meridians and along tertiary positions at ±16° in the upper and lower field. Subjects performed this task for a training period of 16 min; the point aimed by each saccade was disparate, i.e. 2% more eccentric because of the magnifier. To test for learning before and after training saccades were recorded under monocular viewing (no disparity). Binocular eye movements were recorded with search coils (Robinson, 1963; Collewijn et al., 1975). A bidimensional calibration (Helmholtz co-ordinates) was used for data analysis.

During the training compensatory disjunctivity of the amplitude of the saccades occurred for the principal horizontal and vertical meridians; the group mean difference in the disjunctivity of saccades between the before and the during training condition was  $0.14 \pm 0.04^\circ$ ,  $n = 6$  subjects for horizontal saccades, and  $0.15 \pm 0.07^\circ$ ,  $n = 6$  for vertical saccades. Such increased disjunctivity persisted even after training suggesting learning: the group mean difference in the disjunctivity of saccades between the before and the after training condition was  $0.12 \pm 0.02^\circ$ ,  $n = 6$  for horizontal saccades, and  $0.15 \pm 0.01^\circ$ ,  $n = 6$  for vertical saccades. In contrast, for horizontal saccades to tertiary positions made in the upper and lower field no consistent changes in the disjunctivity occurred, neither during training nor after the training condition.

In conclusion this study shows that even a 2% image size inequality, frequently present in subjects wearing spectacles, stimulates oculomotor learning leading to persistent disjunctivity of saccades. The limitation of such mechanism for tertiary positions is an intriguing new finding. This limitation could be sensory, e.g. difficulty to evaluate horizontal and vertical disparity at the same time,

and/or motor, e.g. difficulty to produce convergent or divergent movements when the eyes are at elevation or depression. Further research is needed.

### **The effect of accessory stimulus intensity on visual-auditory interaction in saccade programming**

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Recently it has been shown that the presentation of accessory auditory stimuli reduces reaction times of saccadic eye movements towards visual target stimuli. The magnitude of reduction depends on the spatio-temporal relationship between visual target and auditory non-target (Frens et al., 1995). Psychological and physiological experiments give evidence for convergence and common processing of visual and auditory sensory information in central processing stages (Hughes et al., 1994, Stein and Meredith, 1993).

In this complex system changes of stimulus intensities may influence processing time on different levels:

- (a) Changes in stimulus intensity could evoke changes in the arousal state of the organism: Non-target stimuli would act as a general warning signal independent of spatial stimulus arrangement.
- (b) It is known that peripheral processing time decreases with increasing stimulus intensity. Thus the effect of stimulus intensity may be mediated completely by changes in peripheral processing time. Colonius & Arndt (1998) developed a model of visual-auditory interaction proposing such a mechanism. In this model stimulus intensity influences reaction time by changing the probability of visual-auditory interaction. Thus, processing of the combined bimodal information does not depend directly on stimulus intensity.
- (c) Stimulus intensity could modify the shared processes directly.

In the experiments reported here the intensity of the auditory stimulus is systematically changed in steps of 3 dB SPL while visual stimulus intensity is kept constant (10 cd/m<sup>2</sup>). Five levels of auditory stimulus intensity were applied in separate blocks. Six different spatial combinations of visual and auditory stimuli were tested in a step paradigm. The subjects' task was to redirect the eyes from the fixation point to the visual stimulus as fast and as accurate as possible and to ignore the auditory stimulus.

The data suggest that the auditory stimulus does not act as a mere warning signal. The amount of reduction of reaction time depends critically on the spatial stimulus arrangement. As expected, mean reaction times decreased with increasing stimulus intensity. The effect was significant for intensity differences of 9 - 12 dB SPL. The model of Colonius & Arndt allowed to fit the mean reaction times and resulted in physiologically plausible estimated processing times

for peripheral and central processing stages. A direct influence of stimulus intensity on central processing times is not necessary to account for the data.

### **Anti-saccade performance indices in a large sample of normal male subjects**

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These results are part of a large perspective study on vulnerability factors related to schizophrenia and other psychiatric disorders. In the experimental design of this large study that included testing of cognitive, oculomotor and psychometric batteries on a large population of healthy subjects recruited from the Greek airforce we included the study of an anti-saccade paradigm. In this preliminary report we present data on the analysis of anti-saccade performance in a sample of 200 individuals. We used the well known antisaccade eye movement paradigm. The eye movements were measured with an IRIS SKALAR device (sampling rate 600 Hz, monocular sampling). We analysed the error rate and the Response Latencies for each individual separately.

**Latencies:** The mean response latency for correct anti-saccades was 274.96 ms (SD = 46.49) and 204.52 ms (SD = 42.62) for error saccades ( $p < 0.0001$ ). The mean response latency for the corrective saccades in error trials was 157.52 ms (SD = 61.84).

**Errors (DF):** The mean DF for the population was 0.76 (SD = 0.17). The lowest 5% of subjects had a DF below 0.42 forming a subset of bad performers.

**Correlation:** The correlation of DF with the age, the level of education (measured in years of education) and the laterality indices were not significant on the contrary the DF was positively correlated with the IQ as measured with the Raven's Progressive Matrices test ( $R = 0.18$ ,  $t = 2.83$ ,  $p < 0.01$ ).

### **Attentional orienting and real-world semantics**

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Recent studies of attentional orienting to objects in real-world scenes have suggested that object semantics partly determine which objects are most likely to draw attention. However, experimental findings have been quite contradictory. When the semantic consistency of objects in their contextual scene is manipulated, some studies find attentional priority for inconsistent objects and others find attentional priority for consistent objects.

In the present paper, we report performance and eye-movement data from three different paradigms: overt object selection during free scene exploration, covert object selection in an attentional-cueing paradigm and overt object selection under forced-choice conditions.

Based on our findings, we present a working model of the interaction between semantic object-scene consistency and voluntary versus involuntary attention shifts.

### **Simulated adaptive control of horizontal eye position using retinal slip as an error signal**

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Horizontal eye-position with one degree of freedom is controlled by the lateral and medial rectus muscles, which have two. The rule used by the oculomotor control system to solve this redundancy problem is not known. The effectiveness of a plausible candidate rule, namely minimisation of post-movement retinal slip, was tested by modelling an adaptive controller for horizontal eye position that used retinal slip as an error signal.

The adaptive controller was represented by two linear nets, one for each horizontal rectus muscle. Premotor neurones formed the first layer of each net, and oculomotor neurones (OMN's) the second. The OMN pool for an individual muscle contained 100 neurones, each connected to a motor unit: motor unit strengths were derived from the measurements of Meredith and Goldberg (1986). The pools received (i) uniform excitatory input from a single premotor neurone with the same ON-direction, corresponding to position-vestibular-pause cells; and (ii) individual inhibitory input from a single premotor neurone with the opposite ON-direction, corresponding to cells in the nucleus prepositus hypoglossi (the putative integrator for horizontal eye position). On each trial, a random horizontal eye-position was used to generate the firing rates of the premotor neurones. Retinal slip was estimated from the discrepancy between this position and the one adopted by the model, then used as an error signal for a gradient-descent learning rule that adjusted the inhibitory weights. After learning was complete, the resultant simulated firing rates and muscle forces were compared with those observed experimentally.

The main findings were:

- I. The firing-rate slopes for the simulated OMN's increased with their thresholds in accordance with electrophysiological findings. This was a consequence of the push-pull arrangement of premotor inputs: higher threshold units received more powerful inhibitory input.
- II. With noise-free OMN firing-rates the model learnt accurate position control, but the muscle forces used were dependent on the initial conditions, and in general were unrealistically high.

- III. When a noise term, consistent with experimental data (Goldstein and Robinson 1986), was added to OMN firing-rates the model learnt position control and exhibited the following features:
- A. the values for muscle forces were realistic;
  - B. firing-rate threshold increased with motor-unit strength (the size principle);
  - C. the system displayed minimum-norm (i.e. pseudo-inverse) control over the central  $\pm 30$  deg of the oculomotor range as is found experimentally (Dean et al. 1999).

It appeared that the learning rule suppressed those units making the largest contribution to the noise-related error, causing the strongest units to have the highest thresholds. Because firing-rate threshold was linked to slope, this in turn meant stronger units had higher firing rate slopes, as required by minimum-norm control. These findings suggest that a learning rule based on image slip applied to a simple architecture is able to generate important properties of OMN's and their motor units.

### **The accuracy of vergence responses to volitional stimuli**

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Volitional stimuli are felt to generate coarse spatiotopic responses of vergence which are subsequently refined using retinotopic stimuli. The aim of this study was to examine the accuracy of vergence responses to volitional stimuli.

Ten subjects with mean age of 24.5 y and a standard deviation of 4.2 y, participated in the experiment with informed consent. All subjects were emmetropic with vision of 6/6 or better in both eyes. The subjects were naive as to the purpose of the experiment. Subjects were shown a series of targets (Snellen E {6/9 equivalent size} printed on 35 mm slides) at vergences of 0.25, 0.50, 1.00, 2.00, 3.00 and 5.00 D. Subjects were then placed in darkness and instructed to imagine that they were looking at the same "target" distances again in a random order. They were then instructed to imagine that they were looking at a very distant target and a very near target. Vergence responses were measured using an infrared eye tracker with a resolution of  $\sim 0.25$  MA.

All subjects produced appropriate vergence responses for imagining very near or very far distances. The responses to the remembered target distances showed considerable inter-subject variability, but tended to be very inaccurate. Subjects generally produced two flat response regions to volitional stimuli which corresponded to far (0.25 - 2.00 D) and near imagined distances (3.00 - 5.00 D). The subjects would switch between these responses depending upon the stimulus

distance they were asked to imagine. The experimental results can be accurately modelled with a new model of vergence.

Volitional stimulation produces coarse, inaccurate responses of vergence in agreement with the spatiotopic/retinotopic classification. These responses can be grouped into a far response region for perceived distances of  $> 50$  cm, and a near response region for perceived distances of  $< 50$  cm.

### **Saccade-contingent visual mislocalisation under background and dark conditions and under predictable and unpredictable conditions**

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The previous studies showed that mislocalisation of a brief flash stimulus presented temporally proximate to the saccadic eye movement may occur because of the mismatch of the extraretinal eye position signal and the object image displacement on the retina (Honda, 1989, *Perception & Psychophysics*, **45**: 162-174). However, the saccadic localisation was more accurate in the presence of the exocentric cue, suggesting that localisation is based on a combination of exocentric and egocentric cues (Dassonville et al., 1995, *Vision Research*, **35**: 2191-2199). Furthermore, the final phantom flash of the repeatedly flashing stimulus (500 Hz), which was extinguished at various points of time after saccade onset, was observed near the attended positions during the saccade (Ebisawa & Fujiwara, submitted). This suggested that mislocalisation of the flashing stimulus is a function of the attended position rather than the efference and afference copies related to the saccade. The purposes of this study are to investigate the influence of the existence of the fixation point and saccade target as exocentric cues and to investigate whether or not the attended position influences localisation of a single-flash stimulus.

Two experiments were conducted with subjects' heads immobilised: "Dark" and "Background" experiments. Each experiment consisted of "Predictable" and "Unpredictable" conditions. In the Background experiment, the fixation point (FP) and saccade target (ST), were presented consistently near the time of the saccade. The subject made a saccade from FP (0 deg) to ST (8 deg). In the Dark condition, the two stimuli were extinguished before the saccade, which was made from the extinguished FP position to the remembered ST position. In both experiments, each of the four stimuli located -4, 0, 4, and 12 deg, respectively, flashed for 1 ms at various points of time near the saccade (approximately from 200 ms before until 200 ms after saccade onset). In the Unpredictable condition, the subject did not know either the time or position of the flash stimulus, whereas in the Predictable condition, the positional information of the flash stimulus was given to the subject visually at the beginning of each trial.

The results of three subjects commonly showed that in both Background and Dark experiments, the degree and duration of mislocalisation decreased in the Predictable condition compared to the Unpredictable condition. In addition, for both Predictable and Unpredictable conditions the degree and duration of mislocalisation in the Background experiment decreased in comparison to those of the Dark experiment. The difference in the mislocalisation between the Background and Dark conditions suggested that the visible stimuli (FP and ST) work as the positional references, supporting the suggestion of Dassonville et al. (1995). The difference between the Predictable and Unpredictable conditions suggested that the attention shifts influence the mislocalisation concerning a single-flash stimulus as well as the repeatedly flashing stimulus (Ebisawa and Fujiwara, submitted). This is because the subjects probably directed their attention to each known flash position in order to accurately determine the apparent position of the flash in the Predictable condition.

### **The effect of semantic relatedness on intrasaccadic source and target changes**

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Experiments by Verfaillie et al. (*JEP; LMC, 1994*) on transsaccadic integration of biological motion showed that intrasaccadic changes in in-depth-orientation were easily detected, whereas intrasaccadic changes in position were hard to detect when compared to extrasaccadic changes. Experiments by Boucart and Humphreys (*Perception, 1997*) on the temporal dynamics of the processing of physical and semantic information of objects, led to the conclusion that semantic relations between to be judged objects can have facilitative/inhibitory effects in terms of response times and errors, but only if one has to make decisions on the global shape of an object. It can be argued that when one has to make decisions on the in-depth orientation of an object, global shape has to be judged but not so when judgements about position have to be made. In the present experiment subjects made a saccade from one object (the source) to another object (the target) and had to detect saccade-contingent display changes, either in the position, either in the orientation of one of the objects. The semantic relation between source and target is manipulated. We predict an effect of semantic relatedness on the detection.

## Localisation of memorised targets during fixation

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When a target is flashed before, during, or after a saccade its perceived location depends on the timing of the flash (Jordan & Hershberger, 1994, Schlag & Schlag-Rey, 1995), but also on the retinal eccentricity of the flash (O'Regan, 1984) and on the visual frame of reference (Honda, 1999). These studies showed how saccades affect the metrics of the visual space, but they also revealed that these metrics depend on the content of the actual visual scene as well. We investigated whether the localisation of brief flashes depends 1) on symmetry of the visual stimulation around the point of fixation or 2) on the centre of spatial attention which can be shifted even without a subsequent saccade.

Six healthy subjects, whose eye movements were recorded with an infrared system (IRIS, Skalar, Delft, Netherlands), participated in the experiments. Subjects were seated in darkness and fixated always a central target spot. An additional single reference target was presented for 800 ms on the right or on the left side on the horizontal meridian at eccentricities that varied from trial to trial ( $9 \pm 1$  deg). The central fixation spot was blanked 400 ms after the disappearance of the reference target and 100 ms later a test flash (duration 30 ms) appeared on the horizontal meridian in close neighbourhood to the previous reference target. In a forced choice alternative task (200 trials per session) the subjects had to decide whether the test flash appeared right or left from the reference.

1) In this first experiment 5 of the 6 subjects overestimated of the eccentricity of the test flash with respect to the reference position. The average mislocalisation was  $0.5 \pm 0.7$  deg ( $N = 6$ ).

2) In a second series of experiments (non-cued) two reference targets were presented symmetrically around the fixation spot. The subjects did not know on which side the test flash would be presented next and consequently they had to distribute their spatial attention symmetrically to the left and to the right. In this experiment subjects showed only an insignificant tendency ( $p < 0.26$ ) to overestimate the eccentricity of the test flash with respect to the reference position by  $0.45 \pm 0.9$  deg ( $N = 6$ ).

3) In the third experiment (cued) the subjects were instructed to memorise only one of the two reference targets which was cued by the colour of the fixation spot. Shifting the visual attention in such a way towards the reference target, did not affect the localisation error ( $0.61 \pm 0.66$  deg;  $N = 6$ ). The small increase of 0.16 deg with respect to the non-cued experiment did not reach significance ( $p < 0.8$ ). In all experiments the accuracy of the localisation ranged between 0.6 and 3 deg.

These results suggest that large mislocalisations of more than 3 deg as they are observed before saccades are not induced by asymmetries of the visual stimulation (1, 2) or a shift of the visual attention towards the saccade target alone (2, 3).

### What do eye movements reveal about reading strategies in acquired dyslexia's?

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**Introduction:** In normal reading, lexical and sublexical reading processes are activated in parallel, and either the fastest process wins ("horse race models"), or both processes contribute to the recognition of a word ("interactive models"). On the other hand, in acquired alexia's often one reading routine is pathologically preferred, while the other can not be activated at all, so that the reading strategies can be separated. While there is much research done on eye-movements in normal reading, there are only few studies on eye-movements in acquired alexia's (Montant et al., 1998).

**Hypothesis:** Since eye-movements are conducted by cognitive processes in reading (Just & Carpenter, 1980), we expect that differences in reading strategies cause differences in eye-movements. If this is true, the registration of eye movements would enable us, to detect a switch in reading strategy between item groups according to frequency or word length and different tasks like reading aloud and lexical decision, which would be of theoretical and diagnostic value. If differences in reading strategies cause differences in eye-movements, we expect the following:

		Number of Fixations / Refixations	
		Little (1-2)	High (proportional to number of letters)
Reading Aloud	Lexical /Normal	+ Depending on frequency Not depending on length	-
	Sublexical	-	+ Depending on length Not depending on frequency

**Method:** The study consists of a reading aloud task and a lexical decision task. Stimuli, balanced for concreteness and number of syllables, are the following:

- 120 words,
  - 30 high frequent words, short (4-5 letters),
  - 30 high frequent words, long (8-9 letters),
  - 30 low frequency words, short (4-5 letters),

- 30 low frequency words, long (8-9 letters),
- 30 pseudowords, which do not violate the orthographic regularities of German words,
  - 15 pseudowords, short (4-5 letters),
  - 15 pseudowords, long (8-9 letters),
- 15 nonwords, which violate the orthographic regularities of German words.

Eye movements were registered with the pupil-corneal-reflection method (Debic 84). We examined the following subjects:

- 10 healthy students without any reading disorders,
- 3 aphasic patients with pathological lexical reading strategy,
- 3 aphasic patients with pathological sublexical reading strategy.

The data analysis comprises reaction time, number of fixations and number of refixations kept separate for each stimulus group and for right and wrong reactions.

Results: The data analysis is not completed yet but first results show that eye-movements reveal pathological reading strategies.

Literature:

Just, M.A., Carpenter, P.A., 1980. A theory of reading: From eye fixations to comprehension. *Psychological Review*, **87**: 329-354.

Montant, M., Nazir, T.A., Poncet, M., 1998. Pure Alexia and the Viewing Position Effect in Printed Words. *Cognitive Neuropsychology*, **15** (1/2): 93-140.

## **An updated SIMULINK model of the saccade generator**

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An updated SIMULINK model of the horizontal saccade generator is described in this report. The neural network model incorporates the superior colliculus as the saccade initiator and the cerebellum as the saccade terminator. The neural burst generator model uses a first-order time optimal (burst discharge-saccade amplitude independent) controller, and is based on microelectrode recordings, eye movement measurements and systems control theory.

The neural circuit consists of the neurones in the paramedian pontine reticular formation (burst, tonic and pause cells), the vestibular nucleus, abducens nucleus, oculomotor nucleus, cerebellum, substantia nigra, nucleus reticularis tegmenti pontis, the thalamus, the deep layers of the superior colliculus, and the oculomotor plant for each eye. Agonist burst cell activity begins with the maximal firing due to an error between the target and the eye position, and continues until the internal eye position in the cerebellar vermis reaches the desired position, then decays to zero. The cerebellar vermis is responsible for adapting the duration of the burst firing based on the initial eye position of the eye. There are two sets of neural integrators in the neural network. One oper-

ates within the cerebellar vermis to predict the width of the pulse, and the other within the paramedian pontine reticular formation to maintain the eyes at their destination. Antagonist neural activity inhibited during the agonist burst activity. After the agonist burst, antagonist neural activity rises with a stochastic rebound burst due to input from the fastigial nucleus, and then falls to a tonic firing level necessary to keep the eye at its destination. The onset of antagonist tonic firing is stochastic, weakly co-ordinated with the end of the agonist burst, and under cerebellar control. A linear homeomorphic oculomotor plant is used that is fourth-order linear homeomorphic with state variables of angular position, angular velocity, angular acceleration and angular jerk, and with inputs of agonist and antagonist active state tension. This model depicts the agonist and antagonist (lateral and medial rectus) muscles, and the eyeball.

Each of the neural sites in the model fire as predicted by the experimental data and simulate fast eye movements with main sequence characteristics. The neural network successfully simulates (predicts) horizontal saccades of all sizes, including microsaccades, under the time optimal controller and using parameters based on physiological evidence. A common mechanism based on cerebellar gating explains a number of different saccade types, including dynamic overshoot, glissadic overshoot and undershoots, and undershoot.

### **Objective evaluation of difficulty in going up and down the stairs using eye movements**

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In this study we aimed to evaluate the difficulty in going up and down the stairs and examined the eye movements while going up and down stairs or slopes.

In everyday life, we often use stairs. They have an important role to connect the different floors. But stairs with inappropriate size cause fatigue and even accidents in some cases. When people go up or down such stairs, they must be careful, namely, they need to look at each step or to go slowly. Consequently it is expected that the behaviour or reaction of human beings and difficulty in going up and down stairs have a certain relationship. We focused on visual information processing and analysed the eye movements while ascending and descending stairs.

In the experiment we used two types of stairs and one slope as the stimuli. One type of stairs almost satisfied the requirement of comfortable stairs and another type of stairs had an unusually large tread depth. In comparison with these two stairs, it was highly easy to go up or down the gentle slope used in this experiment.

Seven subjects participated in this experiment. They were instructed to go up and down the stairs or slope as usual.

The pattern of eye movements while going up and down stairs was common among the subjects. At the beginning, all the subjects paid attention to their own feet. Then the subjects moved their sight line in front of them. After that, they often looked at their own feet again. It means that they processed the visual information of the steps before they went up or down the stairs based on the result of the information processing.

The quantitative analysis showed that these movements differ in detail depending on the type of the stairs. For the stairs with large tread depth, the sight line moved mainly in the narrow area of the visual field. In the case of the stairs in normal size, the distribution of sight line was comparatively wide. However, it was common for these two cases, that all the subjects watched very often the steps. Especially when they went down the stairs, they watched the steps for longer time. In some cases, the subjects watched the steps for over 90% of the total time. On the other hand, when the subjects went up or down the slope, they looked often in front of them. In addition, the average viewing duration was longer, when the stairs were hard to go up or down. In such cases, the subjects needed more visual information of the stairs.

In this experiment it was confirmed that there was a clear relationship between eye movements and difficulty of the stairs to go up or down. It suggests that by using the data of eye movements it is possible to objectively evaluate the difficulty in going up or down the stairs.

### **Very fast and express fixations in different tasks**

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Since the discovery of saccadic express reactions there is an increasing interest in very fast oculomotor reactions and fixations. Using the electrooculogram and computer defined saccades we had collected a large corpus of looking behaviour in several tasks on N = 521 subjects from 4 to 90 years old, including picture inspection, unstructured interview with open and closed eyes, tracking a sinusoidal and rectangular moving point, and solving the RAVEN matrices. We reanalysed these data for the regularities of very fast fixations and express fixations, defined as time windows between 40 to 90 ms for very fast fixations (no visual correction) and 90 to 150 ms for express fixations (fast visual correction possible), and the relationship to two categories of longer fixation durations, between 150 and 900 ms (cognitive modulation), and very long fixation duration, 900 - 3000 ms. We found in the adult from 20 to 90 years an increasing percentage of very fast fixations during LOOKING AT PICTURES (5.4 to 6.9% of

all fixations) as well as during the RAVEN task (4.1 to 6.6%), but a decrease in express fixations (10.2 to 7.2% during PICTURE and 13.1 to 9.9% during RAVEN over the years), while the very long fixations increase ( from 10.5 to 16.6% during PICTURE and 9.2 to 11.7% during RAVEN; all changes are highly significant). During childhood (i.e. from 4 to 13 years) the trends in express fixations are increasing while in very long fixations decreasing.

Conclusions: separating distinctive categories of fixation durations outside the mostly used cognitive range is justified, while the borderlines need to be proofed. Cognitive theory of fixation duration needs a completion by inhibitory processes for example of a spontaneous high frequency saccade generator.

### **The abnormal looking behaviour toward upright and upside-down faces in autistic children**

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Autism is a rare but severe psychiatric disorder, including deficiencies in social and communicative behaviour. One of the more striking abnormalities observed in autistic children is their abnormal looking behaviour toward other persons in their environment. It has been suggested that these autistic children are unable to process facial information correctly. This notion has been supported by psychological experiments designed to test the ability of autistic subjects to recognise, match and identify faces.

These experiments showed that autistic children were less able to recognise, match and identify faces on basis of emotional expression and identity than normal children. Langdell (1978, *Journal of Child Psychology and Psychiatry and Allied Disciplines*, **19**: 255-268) and Tantam et al. (1989, *Journal of Child Psychology and Psychiatry*, **30**: 623-630) reported that autistic children performed worse in these tasks for upright faces, but that for faces which were turned upside down their performance was equal to or even better than in normal children. These results suggested that autistic children are less influenced by the turning of the human face, whereas the face-processing of normal children is hampered by this inversion effect. This disruption can also be seen in the 'Thatcher- illusion' where the upright orientation of the eyes and mouth in an upside-down face is hardly noticed.

These results led Langdell to suggest that the scanning of faces in autistic children differs from normal children. Autistic children would rely less on the natural configuration of the facial element and, hence, would be less influenced by the distortion of this configuration. We tested this hypothesis in an experiment where autistic and normal children looked at 12 upright oriented faces

and twelve upside-down orientated faces. We recorded their eye movements and analysed their fixation behaviour for these faces.

Our results showed that normal children spent more time looking at upright oriented faces and spent less time looking at upside-down oriented faces than the autistic children. The looking times of autistic children were similar in the two conditions.

From this we can conclude that there is indeed a difference in looking time and possibly scanning strategies between autistic and normal children for human faces. The difference in scanning time could account for the differences in performances in psychological tasks with upright and upside-down faces. The equal performance for upright and upside-down faces as observed in autistic children is in concordance with the same amount of time these children spent looking at these two types of faces. The decrease in performance as observed in normal children is also in concordance with their decrease in looking time for upside-down faces. Further analysis and experiments are necessary to elaborate these results.

### **Representational systems in transsaccadic object perception**

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To account for the integration of extrafoveal and foveal views across eye movements, two representational systems have been proposed. The first is a permanent lexicon of object detectors, which fire whenever evidence for particular objects is apprehended, regardless of their location. The second is a set of temporary, episodic object files, which each are constructed for a specific object occupying a particular location in space. In the experiments from which these two representational systems were inferred, observers typically were required to make a saccade to a location in between two extrafoveal target objects. The target objects were or were not shifted during the saccade and subsequent ease of target identification was measured. In the present study, participants were required to make a saccade to a specific target object as opposed to a location in between two objects. This situation, in which a single object to which the eyes are to be sent is selected, is not only less artificial but also creates different attentional demands. As such, the goal of this study is to test the theoretical propositions of the dual representational system under more natural circumstances for saccadic and attentional processes.

## **Evidence for strategic scanning in serial visual search**

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The study of saccadic eye-movements during visual search has revealed much about the underlying processes that allow targets to be selected amongst distracters. This project has been greatly influenced by seminal work on reaction times (RT's) and visual search, with much of the recent research being concentrated on comparing oculomotor behaviour between parallel and serial search conditions. The current study aimed to characterise scan path patterns in serial search in more detail and look for qualitative difference across display conditions.

In Experiment 1 we compared three search tasks all of which involved detecting the presence or absence of an E. Condition 1 was a pop-out search task (search for an E amongst O's). Condition 2 was a serial search task in which the distracters were homogenous and similar to the target (search for an E amongst F and L's). Condition 3 was also a serial search task but with highly heterogeneous distracters (search for an E amongst 24 different letters).

For measures of RT, number of saccades and errors, condition 3 was most difficult and condition 1 was least difficult. This supports the idea that both distracter heterogeneity and target-distracter similarity determine task difficulty in search (Duncan & Humphreys, 1989, *Psychological Review*, **96**: 433-458). For conditions 2 and 3 we found strong evidence for stereotypical, strategic scanning patterns; this effect was strongest in condition 3. There is also a clear relationship between strategic scanning and RT: this can be used to account for large differences in RT between trials.

In Experiment 2 we investigated whether the increased use of the strategy in condition 3 compared with condition 2 was a result of distracter heterogeneity or task difficulty. It appears that task difficulty is the overriding factor.

Overall these experiments support the idea that as search becomes more difficult there is a systematic shift from one scanning behaviour to another.

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## **Endogenous saccades are preceded by shifts of visual attention: Evidence from a novel priming task**

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Over the past 20 years, a considerable amount of research has been conducted to determine the relationship between the visual attention and oculomotor systems. Specifically, researchers have attempted to determine if a movement of attention precedes endogenous (voluntary) saccadic eye movements. Previous studies that have examined this question have typically used a dual-task paradigm in which the primary task is an eye movement task and the secondary task is a manual response task, sensitive to attentional allocation. However, the results of these dual-task studies have provided conflicting evidence.

The present study used a novel priming paradigm, in which a saccade is a necessary part of a single task, to examine the relationships between attention and eye movements. Participants were required to identify an object, located in the periphery, to left or right of fixation. The location of the target was indicated by a central arrow (the location cue) and the target was so small that the only way to make the discrimination was to make a saccade to the target. In Experiment 1 a prime that was compatible or incompatible with regard to target identity was presented at the target location simultaneously with the location cue. The prime was either predictive (80% valid) or unpredictable (50% valid) of the target identity. The results showed that there were priming effects (lower RT's when prime and target were compatible than when they were incompatible) in both validity conditions and that the priming effect was larger when the prime was predictive. This suggests an attentional shift to the target location prior to the execution of the saccade. In Experiment 2 the prime (now always unpredictable) was presented at the target or non-target location and it was presented simultaneously with (0 ms SOA), or prior to (-250 ms SOA), the onset of the location cue. The results showed that there was a priming effect when the prime appeared at the target location, but not when it appeared at the non-target location. Furthermore, the priming effect at the target location was larger when the prime appeared simultaneously with the location cue, than when it appeared prior to the location cue. Experiment 3 used the same design but with an additional control condition in which participants were to remain centrally fixated. Priming effects were found in the eye movement conditions, with greater priming effects with the 0 ms SOA than with the -250 ms SOA. Only the 0 ms SOA yielded priming effects in the fixation conditions.

Overall, these results suggest that a shift of attention precedes saccades and that a shift of attention accompanied by oculomotor programming is faster than an endogenous shift of attention without oculomotor programming. These results further support the view that the visual attention system and the oculomotor system are intimately related.

## **Intrasaccadic orientation changes in stationary and moving objects**

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An experiment is conducted to examine the detection rate of intrasaccadic orientation changes for stationary and moving objects. The influence of organisational factors present in the scene is investigated. Previous research indicates a quite high detection rate of intrasaccadic changes in the orientation of a stationary object. The detection of those changes for a moving object (rotating) were rather poor (Verfaillie, K., De Troy, A. and Van Rensbergen, J., 1994, *Journal of Experimental Psychology: Learning, Memory, and Cognition*, **20**: 649-670). Whether this means that orientation information extraction is less exact for moving objects than for stationary objects remains unclear. Its importance can depend upon the kind of movement in which the object is involved or even the kind of orientation change. In other words, the organisational factor in a scene can (as in position change detection) be important for orientation change detection. The stimulus situation used in the experiment shows one object moving horizontally towards another (stationary) object. By manipulating the combinations of the two possible orientations for the stationary and moving object, different situations (organisations of the scene) are created. In some of these situations, no orientation change takes place. In others, the orientation changes concern the moving object and result in a 'turning' of the moving object towards or away from the stationary object. In the last type of situations orientation changes of the stationary object result in a 'turning' away from or a 'turning' towards the moving object. The influence of the status of the object (stationary or moving) and the kind of orientation change on detection of orientation changes made during eye movements, is examined. The results are discussed in the scope of theories on transsaccadic memory.

## **Topography of event related negativity during the execution of visually guided and antisaccades**

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The involvement of cortical areas in the generation of eye movements enables the investigation of these processes with the event related potential technique. Applying the two stimulus paradigm several studies found a negative potential shift with a maximum at central leads preceding the peripheral cue. This negative component is called presaccadic negativity (PSN). The PSN is normally larger during anti- as compared to prosaccade tasks. The participation of different cortical structures should produce topographical differences between tasks,

whereas metabolic changes would only produce amplitude differences over similar cortical structures. The aims of this study was a) to increase the spatial resolution of the PSN records in order to compare the PSN topographies during the pro- and antitasks, and b) to improve the artefact correction with the MSEC method in combination with single trial examination in order to analyse the ERP during the interval after onset of the peripheral cue.

28 participants were tested in this study. Pro- and antisaccades were elicited within the two-stimulus paradigm: a central fixation point was followed 3.5 s later by a peripheral cue, appearing randomly  $\pm 4^\circ$  to the left or right. Fixation point offset preceded cue onset by 0.2 s (gap condition). Four blocks of 40 trials were provided for each task. The EEG was recorded with a DC amplifier using a 32-channel electrode montage. The data sets from 22 participants were used for further analysis.

Analyses of the scalp potential and Laplacian topography of the presaccadic negativity (PSN), the presaccadic negative spike (PNS), and the postsaccadic negativity (PostSN) during the prosaccade and antisaccade tasks were accomplished in the present study. Saccadic reaction times were significantly slower (about 80 ms) during the antitask than during the protask. Statistical analyses on a subset of 12 electrodes revealed central maxima of the PSN, PNS, and the PostSN, that were larger during anti- as compared to the protask. The anterior amplitude augmentations were consistent with the assumption of topography change for the PSN and PNS. Our results suggest that the cortical generators of the PSN and PNS are located more anteriorly during antitask than during the protask. The PNS may reflect a brisk increase of the PSN after presentation of the cue.

### **An eye movement adaptation of a standardised test of auditory comprehension for adults**

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The distinction of competence from performance issues is often problematic in the differential diagnosis of communication deficits in neurologically impaired patients. Motoric and perceptual deficits are frequent confounding factors when traditional linguistic comprehension test items, requiring overt responses (verbal, gestural, or graphic), are administered. A failure to respond, or to respond correctly, on traditional tests of linguistic comprehension does not necessarily indicate a failure to comprehend, especially in patients with severe mo-

toric difficulties. Problems of linguistic competence in many individuals thus may be frequently overestimated by clinicians' judgements.

The development of methodology for assessing linguistic comprehension via eye movement responses has important implications for research and clinical practice. Major advantages of applying this methodology to research and clinical practice are that it:

- offers an alternative, non-linguistic response mode, providing information about intact comprehension ability that is currently unavailable for many severely inexpressive patients;
- allows for stimulus adaptations to control for perceptual, attentional, and oculomotor deficits;
- does not depend upon patients' understanding of instructions prior to the presentation of actual testing stimuli;
- does not interrupt the comprehension process with intervening verbal instructions, prompts for responses, or demands for subjects' conscious planning of responses;
- allows for a continuous record of processing, simultaneous with processing tasks;
- allows for testing of a broad range of sentence types, lengths, and grammatical structures; and
- may yield important information about prognosis for recovery of linguistic skills and about treatment outcomes.

An additional advantage in studying eye movements in this context is that they are often preserved even in cases of severe motoric and cognitive deficits. Hallowell has previously demonstrated the feasibility of assessing auditory and reading comprehension through eye movements.

The primary objective of the current study was to validate an adaptation of a standard test of auditory comprehension for neurologically impaired adults, using eye movement responses. A widely used, standardised test of reading for patients with aphasia, the Revised Token Test (RTT) (McNeil & Prescott, 1978, Pro-Ed) was used as the basis for systematic stimulus and subject response mode modifications. This test was selected to allow for maximal clinical and research applicability of experimental findings. Language-normal adults were used as subjects to ensure the validity of subject responses and to allow for assessment of reliability of findings from modified and standard versions of the test.

The RTT stimuli were presented to subjects in each of two conditions. In the standard testing condition, the test was presented according to the published instructions. In the experimental condition, subjects viewed RTT stimuli on a computer monitor, and were not instructed to "look at" anything.

Results support the feasibility of employing eye movements to index subject responses to auditory linguistic stimuli in the modified testing protocol. Implications for further methodological developments, including visual and verbal

stimulus design, and analysis procedures, are discussed, as are possible applications of this methodology to other patient populations.

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## **Dependent measures for quantifying visual responses in studies of cognitive processing using eye movements**

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An essential step in the development of methodology for the use of eye movements to yield on-line information about cognitive processing is the establishment of reliable means of differentiating scans elicited under different cognitive processing conditions. Numerous research reports include findings that the observer's task influences the way that he or she scans a visual display. However, the means of quantifying differences between scans evoked under different experimental conditions vary widely across a vast range of studies within and between disciplines.

Authors (e.g., Yarbus) of some of the seminal studies employing eye movement measures to study cognitive processes support their conclusions that there are differences between scans by relying on their (and their readers') subjective impressions of overall differences when comparing scan patterns superimposed upon pictures viewed. In some cases, one needs only to look at the mapping of fixation points onto a visual display to see clear differences in where fixations are concentrated for one versus another condition. Very often, though, such differences are not so obvious. Further, even when one may subjectively judge that two scan patterns look different, it is often difficult to characterise quantitatively how the scans differ. The same dependent measures that may differentiate one scan from another (e.g., the proportion of total looking time spent focusing on various features of a picture) may not apply to all other pairs of contrastive scans.

A framework for the selection of appropriate dependent measures and analysis procedures is offered here in an effort to foster improved validity of eye movement analysis and interpretation and to achieve greater consistency in the reporting of data in the research literature concerning eye movements and cognitive processes.

An outline of the paper follows.

- I. Issues in selecting and reporting eye movement measures
- II. Consideration of potential dependent measures for scan differentiation (advantages and disadvantages of specific measures highlighted)
  - A. Measures pertaining to fixation on "target(s)"

1. Most fixations on target(s)? (binomial)
  2. Greatest duration on target(s)? (binomial)
  3. Total number of fixations on target(s)
  4. Total duration on target(s)
  5. Proportion of total number of fixations in the scan attributed to target(s)
  6. Proportion of total duration in the scan attributed to the target(s)
- B. Measures pertaining to time to arrive at target(s)
1. Number of fixations to arrive at target(s)
  2. Duration to arrive at target(s)
  3. Proportion of total fixations in scan to arrive at target(s)
  4. Proportion of total scan duration to arrive at target(s)
- C. Measures of constraint or sequence
1. Number of items fixated in the scan
  2. Number of fixations per scan
  3. Total duration per scan
  4. First-order asymmetric lambda
  5. Other measures of sequential predictability
- III. Statistical relationships among dependent measures: Correlations among durational measures, numbers of fixations, and proportional measures
- IV. Conclusions
- A. Improving rationale for and validity of eye movement analysis and interpretation
  - B. Improving consistency in reporting of data concerning eye movements and cognitive processes

### **Using a combined pro- and anti-saccade task to investigate preparatory set**

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The time to execute a saccadic eye movement typically depends upon several factors including the complexity of the task. To investigate how on-line changes in instruction influence saccade initiation, we devised a paradigm that combined pro- and anti-saccades and the instruction of which saccade to generate was sometimes changed in the middle of the trial. Such a change of instruction requires subjects to alter their preparatory "set".

Nine adult subjects (ages 22 - 46) were recruited to participate. Each trial started with the appearance of a central fixation point (FP) and subjects were instructed to fixate upon it. After a variable delay, an eccentric stimulus appeared and subjects generated a saccade either toward the stimulus (pro-saccade) or away from the stimulus (anti-saccade). The FP remained illuminated for the duration

of the trial and its colour instructed the subject which type of saccade to make. A red FP indicated a pro-saccade trial and a green FP indicated an anti-saccade trial. On a small percentage of trials (25%) the instruction changed in the middle of the trial when the colour of the FP changed colour (from red-to-green or green-to-red) prior to appearance of the eccentric stimulus. The time of the shift in FP colour (i.e., shift time) occurred randomly 0 - 400 ms (in 100 ms increments) before target appearance. On the remaining 75% of trials the FP colour and therefore the instruction did not change.

On control trials (i.e., FP colour did not change), saccadic reaction times were typically longer for anti-saccade trials than pro-saccade trials and subject generated more direction errors on anti-saccade trials (i.e., saccades toward the stimulus instead of away from it). However, on trials in which the instruction changed immediately prior to the appearance of the eccentric stimulus, both SRT and the frequency of direction errors increased dramatically. These increases in SRT and frequency of direction errors occurred for both red-to-green and green-to-red changes in the FP and were greatest for trials with the shortest shift time (0 ms), least for largest shift time (400 ms), and changed gradually for intermediate shift times (100 - 300 ms).

These results demonstrate that this paradigm may be very useful to investigate the neurophysiological mechanisms underlying preparatory set. In addition, such a paradigm may be a useful tool in clinical investigations of frontal lobe function and saccade initiation.

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### **Kinematic modelling of binocular fixation point trajectories in the horizontal plane of regard**

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The saccadic and vergence systems were considered independent in the past. Combined saccade-vergence movement can be viewed through the resultant trajectories of the binocular fixation point, which were originally described by Yarbus for motion in the horizontal plane of regard. According to Yarbus, pure conjugate saccades are performed along iso-vergence arcs; saccade-vergence co-action results in triphasic trajectories --- the first and last being along iso-vergence lines and the intermediate one comprising the superposition of conjugate and disjunctive motion. This classical picture has been revised and updated, subsequent research revealing that the two systems are intertwined. In particular, we know now that even supposedly conjugate saccades are accompanied by intrinsic disjunctive motion. This phenomenon can be explained by peripheral mechanisms although its real cause is yet unknown and it could be central. Another aspect of the interaction is the speeding or facilitation of disjunctive

movement by saccades. Furthermore, an asymmetry has been observed between converging and diverging motion.

The studies of the last decade have led, in effect, to the abandonment of the triphasic Yarbus scheme. Recently, Collewijn and his colleagues (1997, *Vision Research*, **37**(8): 1049-1069) examined saccade-vergence interaction as reflected in binocular fixation point trajectories in the horizontal plane of regard. They observed vergence motion along iso-version lines at the initial and final portions of non-conjugate saccadic movement, thereby partially recovering the triphasic model. Moreover, the amount of vergence achieved before the start of a saccade increases together with the ratio of required vergence relative to the size of conjugate motion. This is indicative of a common timing mechanism for the two systems.

The most elaborate and successful model to date of saccade-vergence interaction is the dynamic model proposed by Zee et al. (1992, *J. Neurophys.*, **68**(5): 1624-1641). However, the model does not address the existence of initial pure vergence motion and the pattern of temporal co-ordination. Also, the reported results are presented in ocular angle co-ordinates which are difficult to compare with data of fixation point trajectories.

In order to overcome these shortcomings, we construct a simple kinematic model that is intended to reproduce the main features seen in fixation point trajectories. The basic building blocks of the model are smooth binocular velocity functions that can be interpreted as the actual velocity of the eyes or as the activity in motoneuron pools. Each such velocity function is a bell-shaped Gaussian, in conjugate or disjunctive co-ordinates. The model provides a parsimonious representation of a variety of trajectories. In addition, it touches upon the current controversy as to whether saccade control is essentially binocular or monocular.

### **Consequences of eye orientation for the visuomotor transformation in arm control**

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The common assumption that the brain maps visual space using a spatially additive operation, which combines retinal representations of visual stimulus with 2-D eye position, does not account for the rotatory nature of 3-D eye orientation and its effect on stimulation sites on the retina. Projections of lines onto the retina curve as a function of 3-D eye orientation, such that geometrically correct measures of retinal error (RE) for horizontal lines at different elevations in space do not stimulate purely horizontal points on the retina. Instead these RE's tilt out in a fan-like pattern as the eye is rotated away from primary position

(Crawford & Guitton, 1997). Previous research has shown that the brain does perform the 3-D reference frame transformation to compute correct eye displacements when reading 2-D retinal information (Klier & Crawford, 1998). We wanted to determine if the arm movement system makes the same corrections when pointing between horizontally displaced targets while looking up or down. If pointing responses are accurate or any minor mistakes resemble those of the eye, this would suggest that eye and arm share a common or similar neural mechanism.

**Methods:** Seven right-handed subjects participated in this experiment in complete darkness with their heads fixed. They were asked to point toward a LED target briefly flashed  $40^\circ$  to  $80^\circ$  to the right of fixation, across 5 elevations over a vertical range of  $\pm 30^\circ$  from eye level. 3-D eye and arm orientations and oculocentric target directions (RE) were computed from the search coil signals from the right eye and arm. These results were compared with controls where subject pointed toward peripherally-viewed LED's in dim light (with feedback).

**Results:** Subjects showed a consistent vertical offset when pointing toward the remembered target, but showed little or no systematic error as a function of eye position. Moreover, pointing responses did not follow the fanning out predictions of an additive spatial model. When actual vertical pointing errors were compared to those predicted, the averaged slope across subjects was  $-0.035$  ( $\pm 0.101$  SD). The findings show that the visuomotor transformation for pointing does account for 3-D eye orientation in correcting for retinal curvature of space. This requires that the mechanism for comparison between RE and eye position be rotatory (i.e. multiplicative) rather than additive.

### **The effect of single pulse transcranial magnetic stimulation applied over prefrontal cortex on the accuracy of memory-guided saccades**

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Single pulse and repetitive transcranial magnetic stimulation (TMS) over the prefrontal cortex (PFC) have been shown to interfere with memory-guided saccades when applied midway through the delay period. In this study we demonstrate disruption of memory-guided saccades when single pulse TMS is applied over the PFC coincident with target onset and describe the effect of altered TMS parameters.

With local ethical approval, 13 healthy volunteers (ages 21 - 49, 9 male) took part in a series of studies (6 subjects per study). While fixating a central light emitting diode (LED) embedded in a vertical screen, a target LED flashed on for 50 ms at one of 8 positions ( $\pm 3.75$ , 7.5, 11.25 and 15 deg along the horizontal).

The subject was required to make a saccadic eye movement to the remembered target location after a delay of 2 s, cued by central LED offset. Eye movements were recorded using an infrared eye movement detector (Skalar). TMS was delivered at 80% of the maximal stimulator intensity using a MagStim 200 stimulator connected to a 7 cm figure-of-eight coil (maximum output 2.2 Tesla). TMS parameters were varied to investigate the most effective:

- 1) Time of TMS, relative to target onset;
- 2) Position of TMS coil, on a grid of 9 points over the right prefrontal cortex;
- 3) Direction of induced current, out of eight directions, 45° apart.

Disturbance in memory-guided saccade performance was seen as an increase in the variable error of the final eye position of the saccade (variance of final eye position around mean final eye position). Variable error increased when TMS was applied coincident with target onset, 6 cm anterior and 2 to 4 cm lateral to the vertex. TMS mid-delay did not consistently result in a decrease in accuracy at any of the prefrontal positions. An antero-lateral induced current direction was optimal for this increase in variance. The presence of a TMS induced blink did not affect saccade accuracy. Using the same parameters, TMS did not affect reflexive saccades, suggesting that the increase in variable error was not due to a disruption of target perception. This leads us to consider that TMS applied over the PFC resulted in a disturbance in the registration phase for spatial memorisation.

In summary, single pulse TMS of the prefrontal cortex coincident with target onset was found to disturb the accuracy of memory-guided saccades. These results suggest that the PFC is involved very early in a memory-guided saccade task, which has not been previously shown with TMS. This agrees with single cell electrophysiological studies in the monkey which show phasic visual responses in the PFC to target onset of a memory-guided saccade (Funahasi et al, 1990, *Journal of Neurophysiology*, **63**: 814-831).

### **Age differences in skill acquisition with conjunction search displays**

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Studies examining ageing and skill acquisition in visual search have found conflicting results. Some researchers have found that when a semantic category search task is consistently mapped (CM), younger adults show significant disruption at reversal whereas older adults do not. This suggests that only younger adults are able to reach automatic levels of processing and thus, it has been hypothesised that older adults have difficulty manipulating the attention-attraction strength of targets and distracters. However, Scialfa, Jenkins, Hamaluk, & Skaloud, (*Journal of Gerontology*, under review) used a more tra-

ditional visual search procedure and found no age differences in disruption at reversal.

The present study examines this issue by incorporating eye movement data to investigate age differences in the acquisition of visual search skills in conjunction search. The stimuli in the display consisted of white and black line segments that were either oriented 45 deg to the right or to the left. The initial target was a white line oriented to the right and at reversal, the target was changed to a black line oriented to the right. Older ( $n = 10$ ) and younger ( $n = 10$ ) adults performed 3840 trials of CM conjunction search over 16 sessions. Reversals occurred every 4th session to determine the degree of disruption over time and to determine if transfer was evident over several reversals. Reaction time (RT) and eye movement data were recorded to measure search efficiency and to determine if participants could attain automatic levels of performance. Eye movements also determined whether participants could selectively attend to objects that possessed target-like features, suggesting some degree of rule-based transfer.

Consistent with Scialfa et al. (under review), results suggested that although age differences were apparent initially, these age differences were eliminated as training progressed. Reduction in both RT data and fixation frequency data demonstrated improvement in search efficiency as training progressed. Age differences in display-size effects continued throughout the training sessions. However, at reversal, RT and fixation frequency increased comparably for both age groups, suggesting no age difference in the degree of automatic processing. Furthermore, subsequent training sessions found no age differences in transfer. Results are discussed in terms of the priority-deficit learning hypothesis and generalised slowing.

### **The strategic control of gaze direction during problem solving**

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Eye movements were recorded while subjects solved the "Tower of London" task, a test used in the neuropsychological assessment of problem solving and planning ability. Subjects viewed a series of pictures showing two arrangements of coloured balls in billiard pockets. They were asked to plan the shortest sequence of ball movements to rearrange the balls in one half of the display (Workspace) to match the arrangement of balls in the opposite half of the display (Goalspace). Subjects had to plan, rather than execute the ball movements required to solve the problem, and then pressed a response button as soon as they had worked out the correct solution. Two groups of subjects were pre-

sented with an identical set of Tower of London pictures. However, one group was instructed to solve the problems with the Workspace arrangement in the upper half of the display, whilst the other group were instructed to solve the problems by rearranging the balls in the lower half of the display.

For difficult problems, gaze was more likely to be directed towards the Goalspace in the initial period after presentation of each problem picture. Later on in the trial, subjects directed gaze towards locations in the Workspace. Finally, prior to pressing the response key, fixations were once again more likely to land on the Goalspace. This pattern was found regardless of whether the subjects solved the problems by rearranging the balls in the lower or upper visual fields, demonstrating that the biases in fixation correlated with discrete phases in problem solving. A second experiment demonstrated that the pattern of fixations was dependent upon the problem moves being internally rehearsed by the subject, independent of the influence of salient stimulus features. Marked differences were also found in the distribution of fixations made by subjects who solved problems accurately and those who made errors.

It is concluded that efficient visual problem solving involves the co-ordination of appropriate gaze strategies. The detailed analysis of eye movement patterns can provide insights into problem solving and higher cognitive processes.

### **Visual scanning in air traffic control**

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This paper presents a study of visual scanning patterns of novice and expert air traffic controllers, executed in a simulator at the Air Traffic Control Centre in Malmö.

Knowledge about how visual information is used in the work of Air Traffic Control (ATC) is important in order to design the user interface (which is now going through a major update in many European countries), to design the air traffic controller education and in order to develop efficient training tools for rated controllers. Eye movements studies could also contribute to the understanding of what characterises ATC work in terms of cognitive aspects.

The purpose of air traffic control is to keep aircraft at a safe distance from one another and to make them fly the shortest possible path, in other words to make the air traffic safe and efficient. To obtain these goals, air traffic controllers use cognitive skills such as planning, problem solving, memory and perception. Combining these skills in a successful manner results in a good so-called situation awareness (SA). Controllers have to distribute their attention to a number of perceptual sources, most of which are visual (radar screen, flight strip board,

weather information screen) although some concern other modalities (neighbouring controllers, pilots).

**Method:** Four novice controllers and four experienced controllers each worked in a simulated 30 min scenario with a medium workload. The interface with radar screen, strip board and communication devices is a typical example of the interfaces now slowly being replaced. A head mounted eye tracker was used to measure the subjects eye movements and pupil diameter.

The results show that the expert controllers spent a significantly larger portion of time looking at the radar screen than the novice controllers did. There is, however, no significant difference between the groups regarding how much the subjects looked at different 'areas of interest' on the radar screen. Instead there are considerable individual differences between controllers *within* the groups.

To pay more attention to the radar screen is likely to increase subjects' SA. That the expert controllers spent more time looking at the radar screen can probably be explained by the fact that the novice controllers were not experienced in using the flight strips, and therefore had to look more at them. We can further explain this difference in terms of the experts being capable to chunk more flight strip information in each glance than the novices were.

Both experienced and novice controller exhibited very individual search strategies, in terms of how many times controllers look at different areas of interest, i.e. areas on the radar screen that contain important information or areas where the probability of conflicts between aircraft is high. The reason for these differences, and whether they implicate different SA levels, remains to be investigated.

## **Detection of saccadic eye movements using the Eye Link System**

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The authors have been working on eye movement in reading text, and in this study it is vital to achieve accuracy in the determination of fixation as the measurement of fixation duration seems to have strong relationship with evaluating cognitive processes involved in reading. A great variety of the techniques for determining fixation has been proposed and yet none of them are free from the limitation imposed by the sampling rate and the accuracy of the eye movement recording device that is employed for the eye movement studies. Traditionally, fixations have been determined by the co-ordinates of loci and the time threshold when a cluster of the co-ordinates stayed within a certain radius. Some researchers may use topological techniques to cluster out groups of co-ordinates into fixations. The authors have long awaited for a day when we

can employ the velocity and the acceleration of saccadic eye movements for the detection of fixation since the onset of a fixation is marked with the end of a saccade and the end of a fixation is marked with the onset of a next saccade.

For making this come true, NAC's EMR 7 that runs at 30 Hz is far from being adequate in terms of sampling resolution. EMR 6 (600 Hz) seemed to be what we needed but it turned out to fall short of our expectation because the data obtained was more distorted than being negligible, which could not be compensated by data processing. At long last, we obtained Eye Link System (250 Hz) and we developed the programs for data acquisition and analysis. With this utility software the system proved to be accurate enough to detect not only the onset of a saccade when the eyeball already has a certain amount of inertia before triggering a saccadic movement but also it can cope with those saccades when the eye overshoots. The system can differentiate the real saccades from 'phantom' saccades that sporadically appear probably on account of sampling noise and/or tremors during smooth pursuit.

Our research result using Eye Link System is that the onset of a saccade can best be detected to be the point  $m$  when the acceleration is over  $1,300 \text{ deg/s}^2$  at  $m + 1$  point,  $3,000 \text{ deg/s}^2$  at  $m + 2$  point, and  $5,000 \text{ deg/s}^2$  at  $m + 3$  point, and that the saccades terminates at the point  $n$  when the acceleration falls below  $2,000 \text{ deg/s}^2$  and at  $n + 1$  point the velocity is below  $100 \text{ deg/s}$  as well as the acceleration is below that of  $n$  point.

### **Using interactive perception to optimise the visual quality of approximated objects in computer graphics**

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In real-time computer graphics applications, such as Virtual Reality (VR), three-dimensional objects are often represented as meshes of triangles. Real-time frame rates limit the number of triangles the graphics engine is able to display per frame. Therefore, meshes with a high number of triangles often have to be replaced by meshes with a lower number in order to achieve acceptable display rates; i.e. the Level Of Detail (LOD) needs to be reduced. Several techniques have been developed to derive meshes of lower LOD from one with a high resolution. These approaches are based on the mathematical or logical properties of the original mesh. The results differ in visual quality depending on the strategy used. Visual quality can be described in terms of the probability of the degradation being recognised by the viewer. None of the methods presented so far take the viewer's perception into account.

We present a new, interest-dependent strategy for decreasing the LOD of a given object. The most interesting regions (i.e. triangle clusters) of the object are retained at high resolution for as long as possible, while less interesting regions are coarsened earlier. Thus, the reduction in accuracy should be less recognis-

able by the viewer. A viewer's interest in a triangle cannot be determined a priori. Hence the object in question is shown to a test viewer, while simultaneously their eye-movements are tracked. We associate a counter with each triangle to measure the frequency with which they fixate it. The number of fixations is then interpreted as a measure for the test viewer's interest in a triangle, and the order with which regions are coarsened is updated accordingly. In other words, the lower LOD meshes get moulded interactively by the test viewer's interest. Meshes created in this way showed significant improvements over meshes created by more traditional methods, even when the LOD was significantly reduced. As yet, this technique has been tested only on the authors, but results were very promising and it is intended to carry out more extensive tests with multiple subjects.

### **The effect of viewing distance on fixation disparity: the role of dark vergence and vergence gain**

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The mean resting position of vergence (referred to as dark vergence when measured in a dark visual field to exclude any fixation stimulus) is about 1 m, with an inter-individual range of 50 cm to infinity. For fixation targets closer than dark vergence the static vergence response shows a negative error (defined as response minus stimulus), i.e. an under-convergence, also referred to as exo-fixation disparity. Conversely, for targets more distant than dark vergence, an over-convergence or eso-fixation disparity occurs. These observations were made with peripheral fusion stimuli that lead to large fixation disparities of up to 10 deg (Francis and Owens, 1983, *Vision Res.*, **23**: 13-19).

The aim of the present experiment was to investigate the role of dark vergence in the presence of strong fusion stimuli (a string of text characters) in foveal vision similar to those that are usually present in normal vision and clinical optometric tests. The resulting fixation disparities amount to only a few minutes of arc. Fixation disparity was measured psychophysically (with dichoptically presented vernier lines) at viewing distances of 460, 100, 60, 40, and 30 cm in 40 young adult subjects with normal binocular vision. The resulting distance-dependent fixation disparity curves were compared with dark vergence, which was measured with flashed vernier targets in a dark surround without any fixation target.

We found a significant linear effect of viewing distance (expressed in vergence angle): mean fixation disparity was 1.9 minarc (eso) at 460 cm and - 3.2 minarc (exo) at 30 cm. When the vergence response was expressed as gain, i.e. as percentage of the stimulus distance (relative to dark vergence) no significant effect of distance was observed (for stimuli closer than dark vergence). Thus, the linear slope of the distance-dependent fixation disparity curve reflects a conver-

gence gain of less than 100%, which does not vary with viewing distance. The individual neutral points between eso- and exo-fixation disparity were significantly correlated with the individual dark vergence ( $r = 0.7$ ). Thus, the fixation disparity of a subject tends to be zero close to the individual dark vergence.

These results suggest that two factors may contribute to an exo-fixation disparity at short viewing distances: the first factor is the gain of the convergence mechanism: the lower the gain, the steeper the fixation disparity curve. The second factor is dark vergence: the more distant the dark vergence, the larger the exo-fixation disparity. Slope and dark vergence were not correlated with each other. A multiple regression analysis showed that the individual fixation disparity at 40 cm can be predicted ( $r = 0.6$ ) from the individual measures of slope, dark vergence and vernier bias; the latter is the offset required to align the vernier lines without dichoptical separation (Jaschinski et al., 1998, *Vision Res.*, **39**: 669-677).

### **SPEM-dysfunction in families of schizophrenics and affective disorder patients**

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Smooth pursuit eye movements (SPEM) have been found to be disturbed in schizophrenic patients and their unaffected relatives raising the hypothesis that SPEM abnormalities may be a genetic marker of vulnerability for schizophrenia. Of particular relevance for this hypothesis is the question of specificity. Psychiatric controls as well as their unaffected family members should show better SPEM performance than schizophrenics and their relatives. Previous results were inconsistent. We conducted a family study to further evaluate the familial specificity of SPEM dysfunction. A sample of 263 subjects (54 schizophrenia spectrum patients, 46 affective psychotics, 43 healthy first-degree relatives of schizophrenics, 36 healthy first-degree relatives of affective psychotics, 84 healthy controls) were examined. Horizontal eye movements were recorded by electro-oculography. Five trials were presented. Pursuit gain was calculated as the ratio of average eye velocity to target velocity.

Both schizophrenia spectrum patients and affective psychotics had lower overall pursuit gain than healthy controls ( $p < 0.001$ ) whereas the patient groups did not differ from each other ( $p > 0.5$ ). Comparison of the bipolar and the major depression patients did not reveal differences in eye tracking performance. Both relatives of the schizophrenia spectrum patients and of the affective psychotics showed worse smooth pursuit than healthy controls ( $p < 0.05$ ). No difference was found between groups of relatives ( $p > 0.5$ ). It is concluded that SPEM dysfunction is not limited to schizophrenia spectrum families. Pursuit impairment

may reflect a genetically based vulnerability for the development of various forms of major psychotic illness. (Supported by DFG grant Bo 710/2).

### **Effects of dual task demands on the accuracy of smooth pursuit eye movements**

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Everyday experience suggests a close relationship between pursuit eye movements and direction of attention. As yet, the role of attention in SPEM performance has been discussed mainly in the literature on disturbed SPEM's in schizophrenia. The assumption that SPEM's benefit from the allocation of attentional resources was tested by comparing SPEM performance in single and dual task conditions.

Eye movements were electro-oculographically recorded in 27 healthy subjects who tracked a visual target which moved horizontally with constant or unpredictably changing velocity. In some trials, subjects performed additional auditory discrimination tasks varying in difficulty.

The auditory distracter tasks suited to focus attentional capacity to processing modalities other than those used for the concurrent eye tracking task not only left SPEM performance unaffected but even led to an improvement of tracking accuracy. When difficulty of the secondary task was increased, SPEM performance was insensitive to this manipulation if the target movement was highly predictable.

The independence of tracking error from secondary task difficulty in the constant velocity tracking condition suggests that eye tracking can be done in the automatic mode, at least under the conditions used here. Even more, it seems that controlled processing of the eye movement is dysfunctional as it interferes with the skilled automatic mode that permits optimal tracking. In the laboratory situation, single task tracking induces the allocation of resources to the oculomotor process rather than to target analysis due to the fact that the target usually has no task significance other than being the eye tracking target. If visual or auditory analysis tasks are added to the pure eye tracking task, the natural situation is restored as attention is redirected to the object analysis process.

## **Visual-auditory interaction in saccades: Interstimulus contingency effects**

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In this study on interstimulus contingencies the probability of presenting a target stimulus at a certain location was varied in dependency of the occurrence of an accessory stimulus at the same or at the opposite location. A focused attention paradigm was used: Subjects were asked to make an eye movement as quickly and accurately as possible to a visual target and to use an accessory auditory stimulus only as a possible cue for the location of the visual target. The auditory stimulus was presented in the same or in the opposite hemisphere at the same horizontal eccentricity (15 deg) as the visual target via a virtual auditory display. The probability that the auditory stimulus occurred in the same hemisphere as the visual target was 20, 50 or 80%, resp., in different blocks of trials. In addition, the visual and the auditory stimulus were presented with varying SOA's. Trials with visual targets only were interleaved in the bimodal trials, whereas trials with auditory targets only were measured in separate blocks in the first and last session of the experiment. Saccadic reaction times in the bimodal trials showed a facilitative effect in the 80% condition in comparison to the 20 or 50% condition. This effect was especially apparent when the auditory stimulus was presented before the visual target. The results will be discussed in the context of a probability distribution inequality (race inequality) by Miller (1982) which builds a boundary condition between race models and models of coactivation.

## **Impaired modulation of event-related brain potentials preceding antisaccades in schizophrenic patients**

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Among the anomalies associated with schizophrenic disorders are impaired antisaccadic test performance and amplitude reductions of the contingent negative variation (CNV). Before forewarned saccadic responses, a slow surface-negative potential similar to the CNV, the presaccadic negativity (PSN), arises. In the present study, we examined the topography of the PSN in schizophrenic and healthy participants during the execution of pro- and antisaccades.

Seventeen medicated patients with an ICD-10 schizophrenia diagnosis (F20; mean age 29.8 y, range 20 - 47; 12 male) and nineteen healthy controls (mean age 31.3 y, range 20 - 51; 13 male) matched with patients for age, sex, and education participated in our study. Horizontal pro- and anti-saccades were elicited in 4 blocks of 80 trials each (ABBA design; 40 stimuli to either side in each block; SOA = 3.5 s). The EEG was recorded from 32 channels with a Nihon Kohden AC amplifier (sample rate 256 Hz, time constant 10 s).

The results reveal the following statistically significant effects for the scalp potential data ( $ps < 0.05$ ). Under all conditions and in all groups a PSN with a topographical maximum over the vertex arises. Schizophrenic patients exhibit generally reduced PSN amplitudes. The PSN is larger before anti- as compared to prosaccades in healthy controls but not in schizophrenic patients. Our results suggest impaired modulation of preparatory cortical activity in schizophrenic patients.

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### **Saccadic eye movement and neuropsychological test performance in young, elderly, and old subjects**

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Impairments in the antisaccade task and unstable ocular fixation can be observed in neurological patients with lesions of the prefrontal cortex. Prefrontal cortical functions are widely assumed to be among the first functions deteriorating with ageing. The present study aimed at examining saccadic eye movement and neuropsychological test performance in elderly participants carefully screened for the absence of ophthalmologic, neurologic, geriatric, and psychiatric disorders.

Forty elderly (mean age 72.3 y, range 59 - 87; 20 males) and 20 young (mean age 26.0 y, range 20 - 29; 10 males) subjects participated in this study. Horizontal pro- and antisaccades, elicited under the 200 ms gap and overlap conditions, were measured in 4 blocks of 200 trials each (100 stimuli to either side in random order; ordering of blocks permuted across participants). Furthermore, neuropsychological performance was assessed with the Wisconsin Card Sorting Test and computerised tests of working memory, stimulus-response incompatibility, alertness, and response inhibition. Eye movements were elicited and measured monocularly with the ExpressEye infrared system (OPTOM, Freiburg).

Old as compared to young participants exhibited a widespread decline in ocular motor functioning, including delayed pro- and antisaccadic reaction times, and great amounts of anticipatory responses and reflexive prosaccades during the antitask. The senior participants also exhibited worse performance in most of the neuropsychological tests when compared to young adults. The results of our study argue in favour of the assumption of a general decline in oculomotor and neuropsychological functioning during healthy ageing.

### **Smooth pursuit latency in schizophrenia and its modification by temporal gaps**

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Deficits in smooth pursuit (SP) are one of the most extensively studied behavioural features of schizophrenia. It has been suggested that they might serve as a biological marker for the underlying genetic and neurobiological abnormalities which lead to the disease. And yet basic questions remain about the nature of deficits. Many studies have concentrated on the maintenance phase of SP. We have now examined SP initiation in a group of schizophrenic patients and have investigated the effect of introducing a temporal gap between the extinction of the fixation target and the illumination of the pursuit target.

With local ethical approval a group of 12 schizophrenic subjects (11 male, 1 female; age range 23 to 40 years, mean 32.1) were recruited and given full optometric and orthoptic assessments. Oculomotor testing was carried out in a quiet room, with lighting dimmed. We used a chin rest and cheek pads to stabilise subjects' heads. They viewed a stimulus monitor with their left eye from 57 cm; the right eye was occluded. A fixation target (contrast 25%), presented for a variable period (0.5 - 1.5 s) in the middle of the display, was replaced by the SP target (contrast 25%; speed: 14 deg/s) which moved from 5 deg to the left/right of fixation, through the centre of the display. In sets of four interleaved tasks (two leftward, two rightward) presented in random order, one task had no gap, the other three had gaps of 100, 200 or 400 ms. Eye position was recorded using infrared oculography. Pre-saccadic SP latency was measured off-line from velocity traces using a regression technique.

All but one of the schizophrenic subjects responded to stimuli in a manner qualitatively similar to control subjects. However, quantitative analysis revealed that in non-gap trials, for both leftward and rightward SP, the latencies in the schizophrenic group were significantly longer than the latencies of a control group (leftward: 234 ±51 ms vs. 198 ±41;  $t = 7.438$ ,  $df\ 273$ ,  $p < 0.0001$ ; rightward: 266 ±58 vs. 210 ±39;  $t = 10.03$ ,  $df\ 187$ ,  $p < 0.0001$ ). Whereas 100 ms gaps caused significant reductions in all control subjects, latency was only reduced significantly in three schizophrenic subjects for rightward and one for

leftward SP. Longer gaps produced significant reduction in seven subjects for leftward and two subjects for rightward SP. Across all four gap durations for both directions of SP, the mean latencies for the schizophrenic group were significantly longer than the control group latencies.

Contrary to some previous reports, we find that SP latency is significantly longer in schizophrenic compared to control subjects. This complements recent reports that there may be a deficit in motion processing associated with schizophrenia. We also find that the gap effect on SP latency is altered, although a definitive conclusion requires larger data sets from schizophrenic subjects.

### **The role of visual resolution and cognitive skill in determining eye movement patterns**

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Psychophysical and eye movement measurements showed that processing speed and eye movement patterns are determined both by the visual resolution needed for the safe recognition of the critical details and by the cognitive skill to quickly process the recognised images (Zangemeister et al. 1995, Krischer et al. 1998). Based on such findings a model of reading eye movement control was suggested (Krischer et al. 1998) in which saccadic amplitudes are automatically chosen to allow both safe sensory decoding and cognitive processing during fixations of approximately constant duration. We now present reading eye movement data showing how saccadic frequency can decrease either because sensory performance is degraded by slowing the retinal function or by presenting letters too small to be quickly processed during the (normal) fixations.

In measuring the duration of reading fixations as a function of the quality of visual input we show that fixation duration remained constant at about 300 ms for all display conditions provided retinal function was intact (i.e. for blurred display) but increased to 400 ms if retinal function was slowed by dimming.

In a re-evaluation of classical developmental reading eye movement data by Taylor (1965) a new diagram shows that fixation duration increased from 270 to 333 ms below grade level 3 (reading speed < 50% of the normal value). In Taylor's experiments the letters of normal size were obviously too small for comfortable processing.

Conclusions: The data showed that a prerequisite of smooth visual processing with constant saccadic frequency is appropriate imaging in the centre of the retina (the fovea for visual acuity = 1) having the best cortical representation. Reductions of the saccadic pace are to be expected either for intrinsically slowed retinal performance or when the central information density is higher than can be cognitively processed during fixations of normal duration.

## Poster Presentations

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### **Rapid effects of spatial correspondence cues on eye movements and covert orienting**

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Two experiments are reported investigating effects of bilateral letter cues (T and X) on covert and overt visual orienting. In the spatial correspondence conditions targets usually ( $p = 0.8$ ) occurred on the same side as one of the letters (e.g. T). In the spatial translation conditions the bilateral letter cues were identical, and targets tended to occur on the right following one of kind of letter cue (e.g. T+T), and on the left following the other (e.g. X+X). Experiment 1 showed that the time course of covert orienting in the spatial correspondence condition was extremely rapid, and comparable to that observed in studies of reflexive orienting: response latencies were faster on valid than on invalid trials even at the shortest stimulus asynchronies (SOA's) between cue and target (0, 33, 66 ms). The time course of orienting in the spatial translation conditions was somewhat slower: a difference between valid and invalid trials was only observed at longer SOA's (150 ms or greater). Experiment 2 examined effects of peripherally presented spatial correspondence cues on the latency to initiate saccades to targets presented 5.5 deg to left or right of a central cross. Saccade latencies were shorter on valid than on invalid trials, and the magnitude of this effect did not vary as a function of SOA. At brief SOA's (0 - 100 ms) the advantage in saccade latency for valid over invalid trials was achieved without loss of directional accuracy. Implications of these results for views of visual orienting are discussed.

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## Attentional biases during eye fixation and smooth pursuit

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Attentional biases have been observed in the perception of geometric forms (Avrahami, 1998, *Perception*, 27: 431-438; Latimer et al., 1999, *Quarterly Journal of Experimental Psychology*, B in press). For example, subjects distinguish forms more quickly when their discriminating features are located at top and right rather than at other positions within the forms. This paper further explores detection of stimuli as a function of retinal locus while the eyes hold a centre-field fixation or are in smooth pursuit of a small moving target. In the static condition, subjects gazed at a central fixation point, and while holding this fixation, were required to detect a stimulus which could be a small cross or a small circle appearing randomly at one of 128 positions within the visual quadrants: top-left, top-right, bottom-left and bottom-right. The subject pressed one of two response buttons to signal the cross and the other button to signal a circle. Eye movements during trials were monitored, and trials during which a subject failed to maintain centre fixation were rejected. As hypothesised, targets appearing in the top-right quadrant were detected faster than those in other quadrants. In the smooth-pursuit condition, subjects tracked a small white dot moving within a square window. Again, small target circles or crosses appeared at random in the four visual quadrants and eye movements were monitored to ensure that subjects were pursuing the moving dot during detection of the peripheral targets. Early results suggest again that detection of targets appearing top-right of gaze point are detected faster than those appearing in other quadrants. Explanations of the attentional bias in terms of experience at reading from left to right and optic flow from top to bottom of the visual field during forward locomotion are discussed. An artificial neural network that acquires top-right bias when it is trained to recognise patterns that scroll onto its visual field from top to bottom (as in forward locomotion) and right to left (as in reading text) is described.

## **Evaluation of the EOG for communication through eye movements**

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For severely handicapped persons measurement of eye movements can play a significant role, especially when those movements remain as the last possibility for communication.

To get an electrical representation of eye movements, the dipole characteristic of eyes is used. By placing electrodes around the eyes, we can measure a voltage between the active electrodes corresponding to the visual angle of the eyeball. So the eyeball position can be computed and related to a mark on a computer screen. By changing the visual angle it is possible to move this mark to a certain position and to select icons.

As communication system the EyeWriter was developed consisting of an EOG amplifier a microcontroller and a PC. The microcontroller implements the signal adjustment as well as noise detection and elimination. To achieve a high degree of compatibility the visual angle is converted into a screen position which is sent as standard mouse-compatible code by wireless transmission to the PC's serial Com-port. As a visual feedback a cursor is moving on the PC screen between displayed icons which can be selected in order to execute the desired functions. Therefore this measurement of eye positioning behaves similar to conventional mouse and can drive any standard or non-standard software.

The EOG signal is quite inaccurate and noisy. These artefacts must be eliminated by appropriate hard- and software filters to make the eye controlled communication useful and as comfortable as possible. Other ways to measure the position of the eyes are more complicated and expensive. In comparison with these, our way of measuring the eye movements is less cost sensitive, easier and much more attractive for the end users.

The EyeWriter is in use since November 1998. Patients are able to write short messages by selecting letters on a screen by eye movements only. In the same way they can control any kind of switched equipment e.g. lights, doors, windows etc. by choosing the appropriate functions on the PC.

## **Saccadic suppression of displacement: effect of ambient lighting conditions**

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Vision is degraded during saccades, as shown by decreased sensitivity to visual events (saccadic suppression of vision) and by elimination of the perception of the visual blur which should be seen during saccades (saccadic omission). These phenomena have been shown to be due largely to visual masking effects from the clear fixations before and after a saccade. A small contribution to the effect is due to extraretinal influences, however. This is probably a 'corollary discharge' of the efferent oculomotor commands. In contrast to other forms of suppression, saccadic suppression of displacement (SSD, a decrease in sensitivity to visual displacements during saccades) has often been considered to be due to this efferent component rather than to visual masking.

The aim of this experiment was to explicitly assess the importance of visual conditions in SSD. In two allied experiments a small computer-generated stimulus made random horizontal jumps. An infrared limbus tracker (IRIS, Skalar Medical) was used to detect the saccade toward the new position, triggering a smaller centripetal displacement. Subjects reported awareness of these intrasaccadic displacements by pressing a key. Each subject performed the task in both a well lit environment and in complete darkness.

In Experiment 1, 8 normal control subjects performed 180 trials in both lighting conditions, with initial target jumps of 8 - 24 deg and intrasaccadic displacements of 0 - 4 deg. In Experiment 2, 14 normal control subjects performed 44 trials in both lighting conditions, with initial target jumps of 15 - 24 deg. Rather than a range of absolute sizes, intrasaccadic displacements were 0 - 30% of the initial target jump.

Sensitivity to target displacements was measured by the area under the curve (AUC) of the receiver operating characteristic curve. AUC ranges from 0.5 (chance performance) to 1.0 (perfect sensitivity and specificity). In Experiment 1, sensitivity was slightly lower in the dark (AUC = 0.73 vs. 0.80, Wilcoxon matched pairs test,  $p < 0.05$ ). In Experiment 2, sensitivity was also lower in the dark, but not significantly so (AUC = 0.70 vs. 0.75, ns).

The absence of clear fixations before and after a saccade eliminates other forms of suppression (Campbell & Wurtz, 1978, *Vision Research*, **18**: 1297-1303). If visual masking was responsible for causing SSD as it is for other forms of suppression, then a large increase in sensitivity would be expected in the dark. Al-

though visual conditions had some effect on sensitivity to intrasaccadic displacements, this effect was small and in the opposite direction.

Thus visual masking is not responsible for SSD in the way that it is for other forms of suppression. Other authors have provided evidence that SSD is not due to a simple efferent signal either. Our results are consistent with the view that SSD results from a high level pre/post saccade cognitive comparison process (e.g. Blackmore et al., 1995, *Perception*, **24**: 1075-1081).

### **Toward a non-linear approach to new-born infants tracking eye movements**

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Huberman (*Annals of the New York Academy of Sciences*, **Vol. 504**, 1981) proposed a mathematical model of eye tracking which explains some of the eye movement dysfunctions observed in pathological subjects. He supposed that the eye behaves as a non-linear forced oscillator. The dynamic of such a system is complex and its behaviour may dramatically vary according to various parameters. First, the driving frequency, i.e. the target's frequency, may impose stable states or chaotic modes depending on its distance from the eye natural oscillation frequency. On the other hand, the model includes two restoring coefficients, a linear one (K) and a non-linear one (L). If the L/K ratio is small, the eye tracking motion is a periodic signal with the same frequency as that of the target. If the ratio is larger, the system may encounter a chaotic regime characterised by broadband noise in the power spectral density. We propose to use that model in order to analyse the tracking eye movements of new-born infants. The examination of power spectra from data obtained from eye movement experiment in new-born infants reveals an intrinsic dynamics which could be attributed to a large L/K ratio. Such analysis allows the study of the intrinsic dynamics of the system and the explanation of the observed dysfunctions in the absence of cognitive underlying processes.

### **Monitoring eye movements in tactical decision making**

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This research is part of a multi-year research project funded by the U.S. Department of Defense under the Office of Naval Research. The subjects are U.S. Navy Officers who were undergoing additional training prior to their third tour of duty. Broadly, the research objectives are:

- to execute a schema based-cognitive analysis of the decision support system used by the officers; and

- to investigate ways that eye-movement data can contribute to cognitive models of the tactical decision making process.

At ECEM, we propose to describe the simulated Command & Control Centre in which we collect data, the cognitive features of the task confronting the officers, and the patterns of officers' eye movements during the task.

**Theoretical Perspective** -- The underlying theory of tactical decision making is based on schema's, which are structures for storing knowledge in memory. In previous research, we identified four essential types of knowledge that individuals need for good schema's: identification knowledge, elaboration knowledge, planning knowledge, and execution knowledge (Marshall, S. P., 1995, *Schemas in Problem Solving*, NY: Cambridge University Press). These four types have been studied in tactical situations and found sufficient to describe performance of highly competent teams and performance of relatively naive ones. These findings are the basis for a new assessment tool to evaluate shipboard teams in the future.

**Research Setting** -- The research was carried out at the Surface Warfare Officers School in Newport, RI, USA, as part of a large collaborative experiment under the TADMUS Program. Sixteen teams of officers participated, with each team having six members. The point-of-gaze of one member from each team was tracked using the SMI EyeLink System. Each team went through an initial training program to familiarise them with the displays and then worked through a series of 5 simulations of tactical situations at sea. Each simulation lasted 25 min.

**Research Results** -- Two main findings will be presented. The first result is the cognitive task analysis of the decision support system used by the officers. The display consists of two innovative screens designed to help officers collect and use vital information. The analysis identifies the schema knowledge embedded in or supported by specific areas of the screens.

The second results are analyses of eye movements and point-of-gaze information recorded as the officers used the screens to make tactical decisions during the simulations. The analyses focus on several critical events that occurred during the simulations to determine which information was most important to the officers during these events and to locate the screen areas where they sought the information.

**Significance** -- The research demonstrates the feasibility and validity of using eye-tracking systems in real training situations. The findings show how eye-movement data can support the cognitive analysis of a complex task. An added benefit is the recording of screen use over an extended time period; this information provides valuable feedback to designers of the system because it informs them of areas on the screens that are not utilised as they intended.

## **Contextual constraints in accessing relevant distant information during reading**

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The anaphoric resolution process, and more precisely the retrieval of the relevant prior information has been extensively studied. Several studies showed an effect of physical distance between an anaphor and its antecedent even when close and early antecedents were backgrounded (O'Brien, Albrecht, Hakala & Rizella, 1995, *Journal of Experimental Psychology: Learning, Memory and Cognition*, **21**: 626-634; O'Brien, Plewes & Albrecht, 1990, *Journal of Experimental Psychology: Learning, Memory and Cognition*, **16**: 241-249). However, the advantage of proximity should be reduced when the intervening sentences explicitly or implicitly refer to the antecedent. This assumption is consistent with the memory based text processing conception. This conception (see Lorch, 1998, *Discourse Processes*, **26**: 213-221) assumes a bottom-up access in which concepts and propositions derived from the text representation resonate in response to related concepts in the current processed sentence. The interaction between the text processing and the retrieval of information from long term memory results in a highly connected representation providing an elaborated context for understanding the current sentence.

We conducted an eyetracking experiment to test the hypothesis that an elaborated context provides a rapid access of the pronoun referent despite the distance between the anaphor and its antecedent. This was achieved by writing texts in two versions. In one texts version, the topic was kept and concepts semantically connected to the referent were mentioned, while in the other version the topic shifted and no concepts were related to the referent. The referential coherence was maintained throughout text by the mention of the protagonist in each sentence so that there was no break of local coherence. Each version of texts contained potential candidates on the basis of number and gender agreement and they could be located either in the Middle or at the End of the sentence. The last sentence contained an unheralded pronoun which referred to a concept evoked in the common first sentence of texts (see McKoon, Gerrig & Greene, 1996, *Journal of Experimental Psychology: Learning, Memory and Cognition*, **22**: 919-932). The remaining of that sentence contained disambiguating information that was supposed to point to the relevant antecedent of the pronoun. The subjects' task was to read each sentence while their eye movements were monitored and then to answer to a comprehension question.

We investigated eye movement behaviour during the initial processing and re-processing of the anaphoric sentence. This was achieved by dividing the sentence into several zones. Thus, we tracked precisely the time course of the ana-

phoric resolution processes. Eye movement data showed three main results. First, the anaphoric resolution begins in the region (i.e., a word) immediately before the pronoun, suggesting a parafoveal pre-processing. During this early processing, the degree of Context Elaboration interacted with Position of potential candidates. As a consequence, the Pronoun zone was skipped more often supporting the parafoveal pre-processing hypothesis. Finally, when a non elaborated context was used, resolution processing persisted until the re-processing of the zone following the pronoun immediately (i.e., a verbal phrase).

### **Cerebral and cerebellar regions involved in the control of smooth pursuit - A functional magnetic resonance imaging study**

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**Introduction:** Electrophysiological and lesion studies in primates as well as studies in human patients have demonstrated complex cerebro-cerebellar networks that initiate and maintain smooth pursuit eye movements (SP) and correct for positional errors by means of small saccades. SP-related cortical regions in primates include the striate cortex, the middle temporal area (MT) and middle superior temporal area (MST) of the superior temporal sulcus, the posterior parietal cortex as well as the frontal eye fields (FEF) and supplementary eye fields (SEF). Prior fMRI studies on SP were focused on the relevant regions in the cerebral cortex. One goal of this study was to demonstrate corresponding activation in cerebellar areas that are known to be involved in SP control, e.g. the flocculus, paraflocculus, or the posterior vermis.

**Methods:** Seven right-handed healthy volunteers were asked to track a laser dot projected on a screen in a darkened room. During the activation period the following conditions were tested:

- (1) Continuous sinusoidal stimulation (0.5 Hz; amplitude 10 deg) which normally leads to steady-state SP without many catch-up saccades.
- (2) Sequential step-ramps with a ramp movement from the left into the right hemifield (velocity 16 deg/s). This triggers the initiation of SP (and frequent catch-up saccades).
- (3) Sequential step displacements to elicit pure visually-guided saccades. Constant fixation in centre position served as control.

Functional mapping of the whole brain was performed at 1.5 T (echoplanar sequences, TR/TE/flip angle = 3 s/66 ms/90 deg, voxel size 3x3x4 mm). The protocol consisted of 6 cycles alternating between task and control condition

(25 ms each). After realignment, spatial normalisation and smoothing, individual and group analysis was performed using SPM 96 ( $P < 0.05$ ).

**Results:** In both SP tasks, activation was found in the striate cortex bilaterally. Additional activation in the FEF and SEF, in the posterior vermis and the paramedian cerebellar hemispheres was more pronounced during step-ramps compared to sinusoidal stimulation, possibly due to an increased number of catch-up saccades in the step-ramp condition. In line with that, pure saccades also activated the FEF, SEF and the posterior vermis. Furthermore, a right hemispheric preponderance of activity during step-ramps was found in the area V5, the precuneus, and the intraparietal sulcus (IPS). This seems to reflect the rightward direction of SP.

**Conclusions:** By means of fMRI, we were able to demonstrate SP-related activation in distinct regions of the cerebral cortex, and, additionally, in certain cerebellar areas, especially in the posterior vermis. From animal studies these location are known to be part of the cortico-cerebellar networks that control SP. However, some of the activation (e.g., in FEF, SEF and the posterior vermis) might be due to co-stimulation of saccade-related neuronal activity.

### **A comparison of applied visual search parameters in different environments**

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The correct interpretation of visual information is an important factor in many applied settings. The analysis of visual search behaviour of human observers within these situations can give a unique insight into the perceptual and cognitive processes being used. Often the skills that observers develop are complex and only arise from many years of exposure to a particular task and consequently the nature of these skills is not easily investigated. A greater characterisation of the skills required for expert performance within a domain is essential if the number of errors that are made is to be minimised. This presentation compares the findings from two different applied settings that rely heavily on visual inspection, namely; medical imaging and airport baggage inspection.

For a number of years we have been investigating how expert radiologists interpret the information contained in radiographic (X-ray) images, which are two dimensional representations of three dimensional anatomy. Consequently the pathologies that can be visualised on a radiograph are often obscured by overlying structures, making their correct detection and interpretation difficult. Also within medical screening environments (such as breast cancer screening) the radiologist must examine many normal images in order to detect the very few abnormal variants that may indicate the presence of a malignant process.

The X-ray screening of passenger baggage is carried out by trained security personnel. Each item of luggage is individually examined to detect a variety of restricted items that may compromise the security of the aircraft. These items include gas canisters, knives, guns and explosive devices. As in a medical screening environment, the vast majority of images that are examined will contain no restricted items, but it is vital the few bags that do contain these target items are correctly identified.

The results of a number of studies that we have carried out examining both medical image and baggage X-ray interpretation are presented. The use of eye movement recording equipment throughout these studies has enabled different aspects of the skills involved to be identified. Also tachistoscopic image presentation has been used to examine the relative importance of focal and peripheral visual processing. Data from the studies allow a comparison between the two areas across a number of different visual search parameters. These include fixation and saccade characteristics, general search patterns, time to locate targets, and image coverage. The relationship between image characteristics and visual search guidance is investigated.

The results of the studies show that there are similar patterns of visual search behaviour between the two domains, but there are also very important differences. The nature of these differences and the implications for procedures and training within the two domains are examined. This research demonstrates that monitoring visual search within two different applied environments can give unique and valuable insights into the visual inspection process. The studies also demonstrate that care must be taken when attempting to extrapolate the results between different applied settings even when they appear to be very similar.

### **Co-ordinated binocular eye movement during binocular and monocular viewing**

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When human observers change fixation between targets which differ in direction and distance, they make co-ordinated binocular eye movements. The movements of both eyes can be in the same or opposite directions and have different amplitudes.

The purpose of this study is to investigate these co-ordinated binocular eye movements during binocular and monocular viewing. The subjects were ten healthy adults and were requested to change fixation between three LED's. The LED's were located at point A (60 cm away from the eye) and at two far points C and F (120 cm away, with a 5 deg difference between them) and lit alternately

for 3 s, in a F-A-C-A sequence. The difference in direction between C and A was less than 5 deg and that between F and A was more than 5 deg. The experiments were performed under two conditions. The first was using the normal visual field for a visual input to both eyes, that is binocular vision. The second was creating a separate visual field by placing a black board at the centre of the face producing visual input to just one eye, that is monocular vision. The movements of both eyes were recorded by a Vision Analyzer.

The results were that eye movements of equal (F-A) and opposite (C-A) directions were observed under binocular vision, but under monocular vision the directions of the movements of both eyes were the same even in the two conditions F-A and C-A.

F-A: In monocular vision the movements of one eye were about 70% of the movement of the other eye. The amplitudes of the eye movements during monocular viewing were larger than the amplitudes during binocular viewing.

C-A: The eyes moved in opposite directions during binocular viewing, but in the same directions during monocular viewing. In monocular vision the movements of one eye were about 65% of the movement of the other eye.

It means that monocular vision could not control exactly the non-input eye with regard to amplitude and direction. With regard to the amplitude, it drove the non-input eye 20% larger than the same eye movements during binocular vision.

### **Saccadic eye movement disturbances in whiplash patients**

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**Introduction:** The so-called whiplash injury of the cervical spine is a benign condition with a lack of identifiable physical or neurological damage and a fair rate of recovery. However, different previous studies reported impaired cognitive performance in a segment of patients who suffered whiplash injury. Patients after whiplash frequently complain of dizziness, continuous neck-pain, headache, and poor concentration, origin of which still remains unclear. Previous eye movement studies in whiplash patients testing visually-guided saccades, vestibulo-ocular reflex and smooth pursuit, were unconvincing. The aim of actual study was to examine whiplash patients with more behaviourally relevant saccade tasks.

**Subjects and Methods:** Three groups of individuals were examined:

1. a symptomatic group (11 subjects) complaining of continuous neck-pain, headache, dizziness and poor concentration at the moment of examination;

2. a recovered group (10 subjects) who had suffered whiplash injury, but did no longer complain of trauma-related symptoms;
3. a healthy control group (16 subjects).

The following paradigms were tested in all three groups: reflexive visually guided saccades with or without gap, antisaccades, and memory-guided saccades.

**Results:** In the antisaccade task, the percentage of errors (i.e. failure to suppress saccades to a peripheral target) was significantly increased in the symptomatic group (mean: 42%; range 10 - 80%) compared with the control group (17%; range 0 - 27%  $p < 0.002$ ). The percentage of errors in the recovered whiplash group was not increased (16%; range: 10 - 23%). In the memory saccade task, a significant difference of unwanted reflexive saccades toward the flashed target (18%, range 3 - 30%  $p < 0.0001$ ) compared to the control group (6%, range 0 - 17%) was found. Furthermore, the symptomatic group showed significantly longer latencies (mean:  $477 \pm 144$  ms vs.  $382 \pm 100$  ms;  $p < 0.02$ ) and significantly reduced accuracy of memory-guided saccades ( $0.31 \pm 0.16$  vs.  $0.21 \pm 0.07$ ;  $p < 0.019$ ) compared with the control group. The recovered whiplash group showed no significant differences for all these parameters. In the visually guided saccade paradigms (gap and overlap task) there were no significant differences in the performance between all three groups.

**Conclusions:** This study shows that:

- 1) in whiplash patients with complaints a typical constellation of eye movement disorders may be found. Whiplash patients seem to be impaired in prefrontal functions such as the suppressing unwanted reflexive saccades (in the antisaccade task and in the memory-guided saccade task) and the triggering of intentional saccades. On the other hand, they show no disturbances in reflexive visually-guided saccades suggesting intact parietal functions;
- 2) whiplash patients without actual complaints performed the saccade tasks without restrictions, compared to a control group. Therefore, the observed eye movements disorders seem to be an further objective indicator for a functional disturbance of prefrontal functions in whiplash patients, and are in agreement with recent functional imaging studies showing prefrontal dysfunction in whiplash patients.

## **Target selection is different for a saccade-and-pointing movement sequence compared to a single saccade**

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Visual search studies usually demand subjects to react with a key-press when a pre-specified target is found among a set of distracters. When the target-distracter similarity is high, RT's tend to increase with the amount of non-targets in the display (set size), as well as the error rate rises with the set-size. After parallel simple-feature analysis, or bottom-up processes, have taken place, a serial process is assumed to process the remaining information features until the target is found, under top-down, or attentional control (Wolfe, 1994, *Psychonomic Bulletin and Review*, **95**: 15-48). An advantage of measuring saccades as a reaction on visual search, as it is done in the presented work, is the guarantee that the visual search processing took place on a stationary visual scene. A saccade is probably the fastest possible answer in tachoscopic visual search.

Classical visual search studies do usually require central fixation, but do not control this. In this study it is investigated if the planned reaction upon localisation of the target does influence these top-down processes. The rationale behind this study is that different goal-directed actions require different target information, and can influence top-down demands in visual search, if these processes subservise information processing for motor-purposes. Since a key press per se, as it usually measured to address visual search performance, does not require any target information, subjects had to react with a fast saccade towards the target, when it is found, or with a saccade-grasping sequence towards the target. Grasping requires prior knowledge of, for example, object orientation, in order to plan the movement successfully. A saccade alone does not require this information. Visual displays contained real 3D Plexiglas objects, that were lit from within, in a completely darkened room. 3 display sets were used, one with no distracters (just the target object), one with 4 distracters and a target, and one with eight distracters and a target, in a combined search task. Distracters differed from the target with respect to form (cylinder vs. bar) and colour (green vs. orange). For example, subjects had to saccade or saccade/grasp to a green bar (target) among green cylinders, orange cylinders and orange bars. Target forms and colours were completely randomised.

- I. It is found that subjects were more likely to make an erroneous saccade to a distracter with the wrong shape, and correct colour (shape errors), when the saccade executed alone, and was not part of a saccade-grasp sequence. For saccadic colour errors, no such difference was found.
- II. This implies that visual processing in a search task is influenced by the intended action, because form is a relevant feature for grasping, but not for a

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saccade alone. Form might be evaluated with higher quality when the reaction is a saccade/grasping movement.

### **Differences between reflexive and voluntary eye movements in patients with neglect**

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Oculographic analyses in patients with neglect have provided evidence for a direction-specific deficit of saccadic orienting. When required to perform reflexive eye movements towards targets in the left and right periphery saccades in contralesional direction showed (a) increased reaction times, (b) were hypometric, and (c) were increased in number creating a 'staircase pattern' of saccadic eye movements. One might assume that these deficits are associated with a general impairment in disengaging attention before shifts in the contralesional direction which has been discussed as the mechanism underlying neglect. If so, affected contralesional saccades should be observed not only with sudden appearance of peripheral targets but also in spontaneous visual search. In the present study we analysed (i) reflexive saccades towards targets suddenly appearing in the periphery and (ii) voluntary saccades during free exploration of space. As in previous studies, neglect patients showed a direction-specific 'staircase pattern', i.e. contralesional saccades were hypometric and increased in number. However, during free exploration of space we found no evidence for a direction-specific deficit, neither for the number of saccades nor for the average duration of fixation. Saccade amplitude was reduced regardless of direction. In conclusion, we found no indication for a general direction-specific deficit of saccadic eye movements in neglect. The results argue against an interpretation of neglect as a basic deficit to disengage from an attentional focus to a target located in the contralesional direction.

### **The effect of colour and neutral density filters on saccade latency**

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Some dyslexics show increases in reading speed and reading accuracy when they view text through coloured lenses or filters. The use of colour appears to reduce a collection of distinctive visual symptoms known as Meares-Irlen syndrome (MIS). We have reported previously that in gap saccade tasks, saccade latency is modified differently in dyslexic subjects with MIS compared to non-dyslexic control subjects. Latency in non-gap tasks was also altered when MIS subjects viewed stimuli through their precision coloured tint. This effect was significantly different from changes observed in a luminance control experi-

ment (Northway et al., 1998, *Perception*, 27: 144). We have investigated further whether the type of colour filters used in the treatment of MIS or neutral density (ND) filters alter saccade latency or the gap effect on saccade latency in normal subjects.

Six non-dyslexic subjects with normal visual acuity aged between 19 and 30 were tested in a standard saccade task. Subjects' heads were stabilised and they viewed a visual display from 57 cm with their left eye. The right eye was occluded. Subjects were presented with a fixation target for a random period (0.5 - 1.5 s) after which a saccade target appeared at an eccentricity of 5 deg; targets consisted of dark 0.3 deg squares presented on a light background. In sets of four tasks presented in runs of 96 trials, normal (gap = 0 ms) and gap (gap = 200 ms) trials to the left and right were presented pseudorandomly. Left eye position was recorded using infrared oculography, digitised and stored on disc for analysis. Subjects viewed the display under 3 conditions: normal viewing, viewing through coloured lenses, and viewing through neutral density filters chosen to reduce the luminance of the background and target by the same amount as the coloured lenses. Saccade latencies were measured off-line from velocity traces. Saccades with latencies of less than 70 ms were considered to be anticipatory and not included in the analysis.

For both saccades to the left and right, there were small but statistically significant reductions in saccade latency in the colour (e.g. left mean latency 184  $\pm$ 32 ms) and neutral density (185  $\pm$ 38 ms) conditions compared to the normal viewing condition (196  $\pm$ 39 ms). There was no significant difference between the colour and neutral density trials. In all three conditions saccade latency was reduced in gap compared to non-gap conditions (e.g. reductions for saccades to the left in colour condition: 27 ms; ND: 32 ms; normal: 28 ms). Distributions in all three conditions were unimodal; latency ranges were: colour: 74 - 349 ms; ND: 72 - 350 ms; normal: 96 - 351 ms.

Thus in normal subjects colour and neutral density filters did not appear to modify the gap effect in any clear and consistent manner but both produced small reductions in latency compared to normal viewing. This might suggest that target luminance and not hue might be the key to understanding the benefit of coloured filters and lenses. Further careful analysis of saccade performance in MIS subjects is now required to define further the benefits they receive from the changes induced in hue and luminance by coloured filters and lenses.

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## **Influence of auditory stop-signals on visually guided saccadic eye movements**

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In a stop-signal task subjects are instructed to perform a reaction time (RT) task, but must withhold their response as soon as a stop-signal is presented. Stop-signals occur unpredictably at different time points after presentation of the go-signal. In this study, the effect of auditory stop-signals on saccades towards a visual target is investigated. The spatial distance between the visual target and the auditory stop-signal was varied, whereby the position of the stop-signal was controlled via a virtual acoustic environment. The data are tested against the horse-race model (Logan & Cowan, 1984) which holds that RT's and stopping performance are exclusively determined through the relative finishing times of the go- and stop-processes, assumed to be stochastically independent random variables. We found the RT data are in agreement with the model. However, changes in movement parameters such as hypometric saccadic amplitudes and reduced peak velocities in signal-respond trials indicate a violation of the independence assumption of the model. The spatial position of the auditory stop-signal did not show an effect on performance.

## **Effects of the flashing frequency and background stimuli upon saccade-contingent mislocalisation of a repeatedly flashing stimulus**

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In darkness, a brief flash stimulus presented near the time of a saccade is perceived in different positions from the actual stimulus position. This saccade-contingent mislocalisation was explained by the subtraction theory (Honda, 1989, *Perception & Psychophysics*, **45**: 162-174). That is, mislocalisation is produced by the mismatch of the extraretinal eye position signal and the object image displacement on the retinal. However, the experimental results concerning the mislocalisation of a repeatedly flashing stimulus suggested that the attended position temporally proximate to the saccade is responsible for the time course of mislocalisation (Ebisawa and Fujiwara, submitted). Especially, when the subjects were asked to shift their attention to follow the apparent motion produced by the phantom flashes, the final phantom flash position shifted gradually along with the estimated time course of the attended position. In the present study, the effects of the flashing frequency and background stimuli upon the time course of mislocalisation of a flashing stimulus are investigated.

Three male students participated in the present experiment. Two experiments were conducted in complete darkness. Their heads were immobilised. Three green LED's were located in the centre of the visual field, 10 deg to the right, and 10 deg to the left as a fixation point (FP), saccade target (ST), and background stimulus (BS), respectively. A flashing stimulus (FS, red LED) was located in the centre, above the FP.

In Experiment 1, after extinction of the background stimuli (ST, FP, and BS), the subject made a saccade from the position of the extinguished FP to the position of the remembered ST. The FS was flashed repeatedly at one of four flashing frequencies (40 - 500 Hz, flash period: 1 ms). The FS was extinguished at various times after saccade onset. The subject was asked to report the finally perceived phantom flash position after observation of each trial. Generally, the FS was mislocalised to the same direction of the saccade. The degree of mislocalisation of the final flash of the FS decreased with the decrease of the flashing frequency. This result was considered as follows. The higher flashing frequency produced more phantom flashes, yielding the apparent smooth motion, and this guiding the attention toward the saccade goal.

Experiment 2 consisted of the dark and background conditions. In the background conditions, the stimuli (ST, FP, and BS) were presented throughout the saccade. The results showed that the time course of mislocalisation was a constant from onset until 200 ms after onset of the saccade in the background condition, whereas the localisation error increased gradually after onset until 50 ms after onset of the saccade in the dark condition. This means that the mislocalisation suddenly increased at saccade onset because of no mislocalisation before saccade onset (Ebisawa, submitted). These findings suggested that the background stimuli disturbed the smooth attention shift, producing the sudden attention shift close to saccade onset.

### **Influence of lower and higher-level factors on saccadic eye movements during visual search**

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Two experiments were designed to examine the relationship between three measures in visual search. (1) Reaction time (RT), (2) number of first saccades to target and (3) number of trials in which no saccade was made before target identification. It is typically assumed that as search becomes more difficult then there will be a concurrent increase in RT, a decrease in the number of first saccades to target and a decrease in no-saccade trials.

In both experiments the display consisted of four capital letters arranged symmetrically in a square around the fixation point and the participants' task was to decide whether either the target letter T or H was present in the display.

Experiment 1 had three conditions. In condition 1, participants searched for the targets among three capital letter O distracters. In condition 2, heterogeneous distracters (A, X, Y) were used and in condition 3 the target letter was displayed on its own without any distracters. Manual RT for the target decision was fastest for condition 3 (542 ms), slower for condition 1 (626 ms) and slowest for condition 2 (800 ms). Consistent with the RT data, percentage of target directed first saccades was highest in condition 3 (100%), lower in condition 1 (81%) and lowest in condition 2 (46%). For RT and first saccade to target, a comparison between condition 1 and 3 would suggest that the O distracters impart a cost. However, there were more trials that contained a saccade before response in condition 3 (96%) than in condition 1 (73%) and 2 (84%). We explain this surprising results in terms of lower-level factors i.e. the global effect (Findlay, 1982, *Vision Research*, 22: 1033-1045) and the automatic generation of a saccade to an isolated target.

In Experiment 2 there were 3 conditions. Condition 1 and 2 replicate conditions 1 and 2 in Experiment 1. In Condition 3 the target letter was present with the distracters S, U and O. Comparison of condition 2 and condition 3 is of special interest here. RT decreased between condition 2 (714 ms) and condition 3 (675 ms) as did the number of saccade trials (condition 2: 83%, condition 3: 73%). Likewise, the number of first saccades to target in Condition 2 was lower (48%) than in Condition 3 (53%). A further analysis of the direction of the initial saccades revealed that in condition 2 misdirected saccades were distributed equally over distracters but in condition 3 this was not the case. This suggests that higher-level factors such as item identity also influence search performance.

Together these experiments demonstrate the influence of both lower-level and higher-level factors in determining saccade and RT performance in search.

## **Memory-guided saccades to vertical disparate targets**

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The co-ordination of horizontal memory-guided saccades is similar to that of visually-guided saccades, albeit more variable. When the remembered target is made disparate, horizontal memory guided-saccades become disjunctive; disjunctivity persists even when the remembered target is no longer disparate, suggesting learning (Kapoula et al., 1998). The purpose of this study is, first, to examine the natural binocular co-ordination of vertical memory-guided saccades. Second, to test if such binocular co-ordination is modifiable by a learning mechanism. Subjects wore an afocal magnifier (8%) in front of their dominant eye. The following paradigm was used to elicit memory-guided saccades. The subjects fixated a central spot. Another target point was flashed, for only 100 ms, up or down at a randomly chosen position  $\pm 5^\circ$ ,  $10^\circ$ ,  $15^\circ$ . Subjects were

instructed to continue fixate the central dot. After a memory delay of 1 s, the central dot was switched off and the subject was instructed to saccade in complete darkness, to the remembered target location. This paradigm was performed under the following three conditions:

- Before training (3 min) : Viewing was monocular with the eye wearing the magnifier; thus the target to be remembered was non-disparate. This control condition was used to determine the natural conjugacy of memory-guided saccades.
- Training (15 min) : Viewing was binocular. The size of the target and its eccentricity were 8% larger in the eye wearing the magnifier, thereby disparate.
- After training (3 min): to test the persistence disjunctivity, subjects performed memory-guided saccades under monocular viewing (non-disparate targets).

Nine experiments were run on 7 subjects. For six runs, eye movements were recorded with the IRIS SKALAR device; for the other 3 runs, the search coil-magnetic method was used (Robinson, 1963). The results show that the natural binocular co-ordination of vertical memory-guided saccades is good comparable to that of vertical visually-guided saccades : the group mean disjunctivity was  $0.37 \pm 0.19^\circ$   $n = 9$  subjects. During training with disparate targets, in 6 of the 18 individual cases (9 runs up or down saccades), saccades developed disjunctivity. The group mean difference from the before value was  $0.40 \pm 0.12^\circ$ ,  $n = 6$  cases. After training, for five from the 18 cases, the disjunctivity persisted even though the remembered target was no longer disparate: the mean difference between, the before and after training condition was  $0.53 \pm 0.21^\circ$ ,  $n = 5$  cases. These results indicate that vertical disparity can be memorised and can modify the conjugacy of vertical saccades. It should be emphasised, however, that the disjunctive oculomotor learning based on the memorisation of vertical disparity is more subject-dependent and smaller in amplitude than that found for horizontal memory-guided saccades (Kapoula et al., 1998). Perhaps, memory based disjunctive oculomotor learning can be reinforced, in conditions where vertical disparities occur naturally (e.g. proximal and tertiary gaze).

### **Accessing compound words: the role of meaning and decomposition**

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The meaning of spatially unified English compound words differs from the meaning of its constituent words when these constituents appear as free lexemes. For such morphologically complex words, one central question is whether these words have a lexical representation of their own or if they are only lexically represented by their morphological constituents. Two general models have emerged to address this question. According to a lexicalised model such

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compound words have an independent entry in the mental lexicon. In contrast, the predominant model of compound word recognition, morphological decomposition, proposes that each lexeme retains a distinct function during word recognition.

To determine whether compounds are morphologically decomposed, we selected English compound words in which we controlled the overall word frequency, but orthogonally varied the frequencies of the individual lexemes (low/low, low/high, high/low, high/high). If compounds are decomposed into their constituent lexemes, then corresponding frequency effects should emerge for one or both lexemes. To examine whether the locus of such effects, if any, is driven by the location of overall compound meaning, we selected for each condition compounds in which the overall meaning was essentially associated with the beginning lexeme ("headed") or the ending lexeme ("tailed"). If this is the case, a bigger frequency effect for the beginning lexeme should emerge for the "headed" compounds. The opposite should be true of the "tailed" compounds, with a bigger effect emerging for the ending lexeme. The data from a lexical decision and a naming task demonstrated a robust frequency effect for both first and second lexeme, supporting a morphological decomposition model. The data also showed that the frequency effects were mainly influenced by the location of the meaningful lexeme, with a larger frequency effect in the beginning lexeme for headed compounds and a larger effect in the ending lexeme for tailed compounds. This also indicated that the interaction between meaning and frequency occurred after the compound word form was accessed.

We are currently working on an eye-movement experiment where the same compounds are embedded in sentences in order to examine lexeme and meaning effects in a more natural reading environment. The eye-tracking task should give a more accurate time-locking of lexeme and meaning effects, since it allows analyses of immediate processing (e.g., first fixation duration) as well as delayed processing (e.g., gaze durations, second fixations and/or spillover). For example if the interaction between meaning and frequency accrues after the meaning of the whole compound word was accessed, we would expect an interaction in the gaze or second fixation durations on the compound word but not in the first fixation durations.

In addition, we will also present data from lexical decision, naming, and eye-tracking tasks in which we compare English transparent compound words, where the overall meaning is equally split between both lexemes, and opaque compound words, where the overall meaning is not related to the meaning of the individual constituents.

## **Guidance of search processes by parafoveal information**

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The Guided Search model proposed by Wolfe, Cave and Franzel (1989) and Wolfe (1994) argues that information extracted preattentively guides search behaviour. Several recent studies provided evidence for this model by examining the bias in the distribution of saccadic endpoints. In the current study, two experiments were conducted to further investigate whether participants could use the peripheral vision to guide the search process when the foveal information was masked. A moving-mask paradigm was used: a 4 deg diameter patterned mask was displayed and remained centred on the point of gaze with a delay of 50 ms or 100 ms after the onset of the fixation. In Experiment 1, unimodal distracters with high-, medium- and low-similarity to the search target were used. In Experiment 2, we used distracters sharing one feature dimension (colour, shape or orientation) or two dimensions (colour and shape, colour and orientation, or shape and orientation) with the target. Robust visual guidance is observed in both experiments even when the foveal information is masked, despite the finding that longer RT's and higher error rates are found in the masking conditions. Results from the current study suggest that parafoveal information can be used effectively to guide the search process.

## **How does the distracter ratio influence the patterns of eye movements?**

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The Guided Search theory by Wolfe (1994) argues that information extracted preattentively could guide the shift of attention during visual search. This was supported by several recent studies in which the bias of the distribution of the saccadic endpoints was examined. The current study examined the flexibility of guidance during the search process by manipulating the ratios of the distracters within an array of fixed display size. The participants were asked to decide whether a green X was present or absent among same-shape distracter (red X's) and same-colour (green O's). Results suggest strong influence of distracter ratio on RT and patterns of eye movements. The reaction time, number of fixations and latency to move are longer when the two types of distracters were equally represented on the display than when one type of distracters was relatively rare. Furthermore, the distribution of saccadic frequency was flexibly biased by the distracter ratio. When there were few same-colour items on the display, the saccadic selectivity was biased towards the same-colour distracters. In contrast, when most of the distracters shared colour with the search target, the saccadic selectivity was biased toward the same-shape distracters. Larger saccadic bias

was found in the first saccades than in the subsequent saccades. The results are discussed in terms of the top-down and bottom-up activation during visual search.

## Eye movements during reading of CT scans: How do radiologists make their diagnosis?

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**Introduction.** Since many years eye movements in cognitive psychology are recorded to analyse structure and use of knowledge. Analysing eye movements during reporting in radiology has been an issue since the end of the 1960's (Kundel & Wright, 1969, *Radiology*, **93**: 315-320). But almost all studies since then use conventional radiographs for their experiments. The analyses were focused on visual search strategies during the viewing of chest radiographs, satisfaction of search looking for lung nodules and detecting tumours in Mammograms (Beard, 1997, *Journal of Digital Imaging*, **10**: 14-20). There are only a few studies analysing eye movements reading computed tomography (CT) scans. (Beard, 1990, *Journal of Digital Imaging*, **3**: 230-237).

**Hypothesis.** Since eye movements are conducted by cognitive processes in reading (Just & Carpenter, 1980, *Psychological Review*, **87**: 329-354), we expect that also eye movements during reading CT scans reflect reading-strategies of the radiologist (as they do in reading conventional radiographs and text) and that radiologists with different expertise use different strategies. To know and understand these reading-strategies will help:

- to increase teaching efficiency for students and residents
- to avoid missing important pathological findings
- to develop computer aided scanning models
- to design workstations for CT interpretation under ergonomic issues

**Method.** The study consists of reading 3 different sets of CT's: cranium, chest and abdomen. Each set consists of 5 normal scans and 15 scans with pathological findings: 5 lesions that are easy, 5 that are moderate and 5 that are difficult to detect. Eye movements were registered with the pupil-corneal-reflection method (Debic 84). We will examine the following subjects:

- 10 radiology residents with little CT experience
- 10 board-certified radiologists with great CT experience

Reading time for each item is 1 min. After reading, the subject has to report the findings and differential diagnosis looking on the blank screen. Eye movements are recorded continuously. The data analysis comprises number and duration

of fixations and refixations, the fixation path and correctness of findings and diagnosis.

Results. Acquisition and data analysis is not completed yet but first results show differences of eye movements between the two subject groups.

### **Analysis of error in eye rotation estimation from search coil observations**

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Scleral search coil systems facilitate the estimation of eye orientation from either four or six observations, depending on whether there are two or three magnetic fields inducing current in the two scleral coils. The computation of rotation between observed orientations is of particular interest to those investigating the "Listing's law" hypothesis. An often-cited approach to the estimation of orientation from the coil observations arranges them in a 3x3 rotation matrix (Tweed et al., *Vision Research*, **30**: 97-110). Eye rotation is estimated by taking the product of a pair of such matrices, which is transformed into a rotation quaternion for subsequent analysis.

The author has investigated the cumulative error in the above approach and found that it is greater than that of an alternative solution to a similar problem known in the domains of computer vision and inertial navigation systems (Horn, *Journal of the Optical Society of America*, **8**(10): 629-642). This approach solves for the minimal four parameters of a quaternion directly. A sufficiently detailed explanation is given to facilitate reader implementation. An error analysis is provided for the cases of both four and six observations.

Apart from the algorithm used, a likely source of error is non-orthogonality of the magnetic fields. A variety of such error has been simulated and the resulting rotation distortion presented. Much of this distortion is similar to that which has been found by others and possibly erroneously-interpreted as naturally-occurring deviation from Listing's plane.

Finally, it is demonstrated how rotation deviations from a plane are more easily analysed when the quaternion elements are plotted in a spherical, rather than Cartesian, co-ordinate system.

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## Perception of sequentially flashed dots immediately before saccades

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It is well known that a stimulus flashed in the dark before, during or after saccade tends to be mislocalised. Size of the mislocalisation depends on the difference between stimulus onset and saccade onset. This phenomenon has been frequently used to examine the time course of internal representation of eye position (e.g. Honda, 1990, *Attention and Performance*, XIII: 567-582). In such studies, it is assumed that the size of mislocalisation is equal to the deviation of internal representation of eye position from real eye position at the moment of stimulus onset. This assumption is generally accepted as far as stimulus is flashed in the dark, however, is that really true? To examine the validity of this assumption, we executed two experiments.

In experiment 1, we measured the time course of mislocalisation of a dot flashed for 1 ms before leftward saccade, and then compared it with the perception of a flickering dot (200 Hz, 1 ms-on 4 ms-off) presented for 80 ms before leftward saccade. From the measured time course of mislocalisation it was suggested that the flickering dot should be perceived as an array of dots drawn from right to left, but subjects never saw such arrays. In experiment 2, two dots was flashed at 80 ms interval before leftward saccade, and subjects reported whether the latter dot was perceived at right or left of the former one. From the time course of mislocalisation it was suggested that PSE of the latter dot should shift to the right, but PSE did not shift.

These results suggest that perceived location of brief stimulus is not determined solely by the internal representation of eye position and the retinal information at the moment of stimulus onset. We must be careful in discussing the relationship between the time course of mislocalisation and the time course of internal representation of eye position.

## Eye movements and reaction times during visual search

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Classical visual search experiments analyse the reaction times required to detect a target item among a number of distracters. Visual targets and distracters are shortly presented on a video display. The measured reaction times depend on feature differences between target and distracters and the number of presented elements. Our study is focused on the additional analysis of explorative saccadic eye movements during these visual search tasks and the modelling the scanpath: This has rarely been performed and should provide further insight in

the global search strategies and in the corresponding higher level cognitive influences. In this study, young healthy volunteers participated in a number of single feature and conjunction search tasks with 0, 1, 4, or 8 targets among 40, 60, or 80 items. The features were "form" (circle, square, triangle) and "colour" (red, green, blue), presented by the Visual Stimulus Generator (VSG 2/4, Cambridge Research Systems) on a Sony 17" IIse monitor with a 100 Hz refresh rate. The objects were presented at 1.5 cd/m<sup>2</sup> on a black background. Eye movements were recorded with a highly accurate CNC scleral search coil system at 500 Hz. Subjects were asked to indicate each recognised target by a click on the left mouse button and the termination of their search by a click on the right button. Beside reaction times we analysed duration and sequences of fixations in relation to global strategies and local features. Reaction time analysis demonstrated the prominent "pop-out" effect of colour in search tasks, also in peripheral vision. The feature "form" or conjunction search tasks induced more systematic scanning eye movements across the whole scene, but were associated with longer reaction times.

### **The strategic control of gaze direction when avoiding Internet ads**

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Web page design, as well as web ad design, is still in its infant stage, more ruled by fashion and popular belief than by principles based on investigations on how users interact with the web. This is no less true of web advertisements. This study, conducted in co-operation with a web ad company, explores the use of eye tracking in web page usability testing. In this paper, we focus on the extent to which Internet users fixate Internet advertisements.

**Method:** Eight subjects, experience web users, were given the task to find answers to ten questions within 30 min, using the web. They were given seven bookmarked pages as starting points and were allowed to find their own way to the answers. They were not allowed to use the keyboard (excluding the use of search engines). Their eye movements, superimposed onto the computer screen, were recorded on videotape for analysis.

**Result:** Subjects did not look at web advertisements, not even during download when the colourful, flickering ad was the only thing on the page.

The flickering, colourful ads did not attract the overt attention of our subjects. Ad designers seem to expect that *any* moving visual object that appears on the screen during the search for relevant information will force the subjects to fixate the ad and then preferably to click it.

It is little doubt that the flickering ads disturbed the subjects. Most of them employed *avoidance strategies* against ads to achieve top-down control over their

visual attention (strategic control). They rotated the mouse cursor in the middle of the empty screen during slow downloads, so as to generate a competing motion to the ad at the top of the page.

Subjects thus wanted to exercise strategic control over both visual selection and visual attention on web pages. To their additional help, we hypothesise, our subjects had experience-based expectations (semantic frames) on the structure of web pages that told them where ads were located, so they could avoid them without fixating them.

Several observations showing the usefulness of eye tracking in web design evaluation were also made, among them:

- All subjects exhibited basically the same search pattern towards the different pages, agreeing on which parts of the page were relevant to them.
- They rather searched along vertical than along horizontal lists.
- Subjects often missed out on information inside longer texts, since they did not read, only scan, it (with the exception of a dyslectic subject who therefore solved the tasks faster than anyone else).
- Picture links were only chosen if they were clear and unambiguous, otherwise subjects looked for an unambiguous text link.
- The mouse cursor was often placed (anchored) at one of the latest points of attended task relevant information, like a flag to mark a point possibly useful to return to, while continuing visual search elsewhere.

### **The influence of an auditory accessory stimulus on saccadic responses to multiple visual targets**

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The effects of multiple visual stimuli on saccadic eye movements have been studied extensively. Saccades are systematically affected by stimulus properties such as intensity, size, and interstimulus spacing. (Findlay, 1982). The integration of auditory and visual stimuli became a topic of oculomotor research recently, since it is supposed that both modalities converge on SC. Auditory stimuli can facilitate responses to visual stimuli, particularly with both stimuli at the same spatial location (e.g., Colonius & Arndt, 1998). Most investigations on visual-auditory interaction have been restricted to situations with just one visual and one auditory stimulus. Here we investigate the influence of an auditory accessory on saccadic reaction times with multiple visual target stimuli. Subjects were instructed to make saccades toward any of two visual stimuli presented at an eccentricity of 8 deg or 24 deg to the right or left of fixation point. Additionally, via an virtual acoustic environment, an auditory stimulus (white noise) was presented at the same eccentricity of either visual stimulus and with a stimulus onset asynchrony (SOA) of -50, 0, or 50 ms. Although the

subjects were allowed to ignore the white noise, it became obvious that the auditory accessory stimulus influenced the selection of the visual target. With the visual targets in opposite hemispheres, a significant bias toward the visual target accompanied by the auditory stimulus was observed, under all SOA's. However, if the visual stimuli appeared within the same hemisphere, the auditory stimulus had no influence on the selection process when subjects selected the more central target stimulus. On the level of saccadic reaction times, the auditory stimulus always had a facilitative effect. Eye movements were the faster the earlier the auditory stimulus was presented for both visual targets. Generally, these results support the idea of an integration of visual and auditory stimuli in a joint saliency map.

### **Parallel allocation of visual attention during word recognition**

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The purpose of the two experiments reported here was to provide further evidence of lexical influence on eye-movement control during the reading of compound words and to comment on possible mechanisms by which lexical access processes influence early eye movements components. The question of a possible parallel visual attention allocation on the words is also asked.

Eye-movements were recorded during the reading of compound words which were displayed with or without the hyphen (e.g.: "rond point" ; "bloc-note"). Specific inspection patterns were found in the no-hyphen condition where two perceptual units (separated by a blank) must be grouped together in order to access the compound-word lexical entry.

In order to assess the potential influence of pre-established inspection strategies, the composition of the experimental list was varied. In the "single-word" condition, filler items were long (seven character) words, while in the "two-word" condition, there were pairs of short words (three to four characters each). This manipulation did influence the oculomotor behaviour (interaction with the hyphen vs. no-hyphen factor), suggesting that eye movement control in reading is submitted to high-level strategic effects.

The aim of the second experiment was to determine whether a pair of words like "ami aux" is likely to activate the high frequency word "amicaux", whose first three and last three letters correspond to the first and second word in the pair, respectively. Such "pseudo-compound" stimuli were compared to sequences such as "but vin" for which no single lexical entry can be found.

Again, inspection strategies were found to depend on processes developed at the lexical level. A parallel allocation of visual attention on the two words would be possible.

## The remote distracter effect in fixation durations

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Paradigms using double stimuli have revealed an effect termed remote distracter effect. When two stimuli are presented in parallel, one of which is the target and the other a distracter, a significant increase in saccadic reaction time is usually found (Lévy Schoen, 1969; Findlay, 1983), independent from prior knowledge of the target location (Walker et. al., 1995). The effect - has been ascribed to the fact that the onset of a remote distracter alters the dominance of a collicular "fixate-system" (Findlay & Walker, in press). They suppose that the balance between the two systems "fixate-move" is temporarily shifted towards fixation. This explanation relies entirely on an optomotor effect. We challenge this position, stating that it is, at least for a significant portion, caused by attentional mechanisms. We studied fixation durations during picture viewing with a gaze contingent distracter presented at 3° to the right of the gaze position. The distracter was presented at a fixed latency from beginning of the fixation of 100 ms. Probability of occurrence depended on the likelihood of a fixation duration of at least 100 ms. The results indicated a significant increase in fixation duration of those fixations during which a distracter was presented. Moreover, the distribution of fixation durations showed a considerable "lack" of fixations with a duration of distracter latency plus around 96 ms on the one hand, and a "surplus" of fixation durations yet another 120 ms. The study was replicated with distracter latencies of 100 and 300 ms, with essentially the same results. Within this second experiment, half of the visual distracters were replaced by an auditory signal of 1000 Hz. Results from this condition showed, that a similar though somewhat smaller effect was yielded by the auditory distracter: a prolongation of fixation durations, less than expected fixations with a duration of distracter latency + some 80 ms and a recovery around 120 ms later. We consider these results as an indication, that the remote distracter effect cannot solely be explained through an optomotor reflex mechanism, and suggest that the model presented by Findlay and Walker should take attentional mechanisms into account.

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### **Eye activity correlates of workload during a visuo-spatial memory task**

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Assessing and predicting human workload is an important consideration in the design process of new systems, the modification of existing systems, or for the purposes of alleviating or avoiding task overload in real time through task re-allocation or adaptive automation. Previous research has established that truly adaptive systems require information on the human operator's workload levels in real time, as it is difficult to reliably predict actual workload based upon a priori modelled estimates alone. The combination of several eye activity measures may provide a psychophysiological estimate of workload for some tasks. Pupil diameter has been shown to increase with higher cognitive workload, while blink rate and duration decline as a function of greater visual demands imposed by a task. Likewise, fixation parameters (dwell time and frequency) also show workload-related changes. Here, we demonstrate signal processing methods that make possible the identification of eye measures most sensitive to task demands. We then assess the sensitivity of non-linear and artificial neural network (NN) models using combined eye measures to predict moment-to-moment fluctuations in task workload. Eleven subjects completed four 2 h blocks of a visuo-spatial memory task in which they were required to examine and remember the classification (friend/enemy) of targets moving inward towards two ship icons presented on a computer display. Subjects were required to prosecute each target (fire upon/allow to pass) when targets passed between two range rings surrounding each ship. Between one and nine targets could be simultaneously present on the display. Eye activity measures were recorded at 60 Hz from a near infrared eye tracking system. For each participant, moving estimates of blink frequency and duration, fixation dwell time and frequency, and pupil diameter, integrated over periods of 20 s or less, were obtained every 2 s.

Eye activity measures demonstrated significant and predictable changes as a function of target density. Blink frequency, fixation frequency, and pupil diameter most characteristically defined individualised and general non-linear regression models relating eye activity to target density. A general regression model derived from all sessions produced estimates of target density that correlated well with actual workload levels ( $R = 0.55$ ). Individual non-linear regression models based upon all sessions from every subject produced individ-

ual correlations ranging from 0.39 to 0.79. Next, individualised NN models were developed through training on several sessions and subsequently tested on a different session within each subject. Cross-session validation of NN-derived estimated to actual target density yielded correlations of 0.33 to 0.85 (mean  $R = 0.68$ ).

The study demonstrates that information from multiple eye measures may be combined to produce reliable and near real-time estimates of cognitive and visual workload for some visuo-spatial tasks. The use of moving-mean estimates of pupil, blink and fixation measures with relatively brief integration times and individualised NN models represents a significant progression of eye-activity based psychophysiological assessment of workload.

### **Effects of fixation point size and attended area size on reaction time of visually guided reflexive saccades**

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It is well known that the temporal gap from extinction of a fixation point (FP) until appearance of a saccade target produces saccades having an extremely short reaction time (express saccade, Fischer, 1987, *Rev. Physiol. Biochem. Pharmacol.*, **106**: 1-35). This gap effect can be explained as that the attentional disengagement begins at saccade target appearance in no gap condition (or overlap condition), whereas the disengagement begins at FP extinction in the gap condition. Thus, the FP is a factor responsible for the saccade reaction time (SRT). In the present study, the effects of the FP size and the attended-area size on the FP was investigated in the gap and overlap conditions.

Four male students participated in the experiment as the subjects. Their heads were immobilised in complete darkness. Visual stimuli were produced using a 15-inch non-interlaced computer display. Horizontal eye positions were recorded using an infrared limbus reflection system. The experiment consisted of the gap and overlap paradigms. In the gap condition, a central FP was turned off 200 ms before appearance of a peripheral saccade target. In the overlap condition, the fixation stimulus remained visible throughout each trial. For each condition, the following four tasks were conducted: small stimulus (SS), large stimulus (LS), small attended (SA), and large attended (LA) tasks. In the SS and LS tasks, the FP diameter was 0.2 deg and 3.2 deg, respectively. In the SA and LA tasks, the FP was a concentric disc: a small disc (dia. 0.2 deg) superimposed upon a larger disc (dia. 3.2 deg). The inside and outside discs were distinguishable by their colour difference. In the SA and LA tasks, during FP fixation the subject was asked to concentrate the inside and outside discs of the FP, respectively. The saccade target (dia. 0.8 deg) was presented at one of the four positions: 4 and 8 deg to the right and left.

The results showed that the SRT's of almost all saccades elicited in the gap and overlap conditions were within the SRT range of the express saccade (100 - 125 ms) and the regular saccade (150 - 350 ms), respectively. For both gap and overlap conditions, the mean SRT in the SS task was significantly longer than that in the LS task for all subjects. In addition, the four subjects showed the common tendency that the mean SRT in the SA task was longer than that in the LA task. These results suggest that the attended-area size during fixation influences the SRT.

No researcher has described the mechanism of the disengagement of the attention before the saccade in detail. We propose the hypothesis concerning the disengagement as that the attention focused on the small area during the fixation broadens the expanse of attention during the disengagement. That is, in the case of the smaller FP or smaller attended area, more time is necessary for the saccade to be able to occur because it takes more time to widen the attended area.

### **Determination of visual angle from EOG**

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The EOG is a standard scientific method for the diagnosis of the light-dark coefficient, where the EOG voltage varies depending on the line of sight. The potential between the front and the back of the eye is estimated by measuring the voltage induced across a pair of electrodes as the eye looks from side to side fixing given points.

In our project we have to solve the reversed problem in the development of a method to compute the visual line out of the EOG signals. In order to determine the precise visual angle of the eyes a single EOG signal in the range of a few microvolts must be analysed. A communication system was developed consisting of an EOG amplifier, a microcontroller and a PC. In addition sophisticated software methods must be applied to extract the visual angle out of the EOG signal which is a function of the persons physiognomy and physiology, electrode position, light intensity, noise and artefacts.

The measurement of very small visual angles can only be carried out with suitable evaluation methods. Due to the compensation it is possible to eliminate the drift and the polarisation of the electrodes fully automatic. The noise and the artefacts are eliminated by hard- and software filters. After pre-processing, the signal is available as a digital measure which is modified into a mouse compatible data transmission. By this changes of the EOG are converted into a visible cursor movement on the screen.

The system was tested on 46 volunteers (students) with an appropriate pattern generator. We found a sensitivity around  $10 \mu\text{V}/\text{deg}$  deviation angle. Changing of the visual angle of one degree can be recognised. This is precise enough for many applications in rehabilitation (EyeWriter) or patient care. The stability of the system is under investigation to use this determination of the visual angle from the EOG. The precision of the system can put in reach other applications in eye movement like a new correction method for perimetry.

### **The development of the eye-movement response to the radiological image**

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In order to explore the initial response of the visual system to radiological images in groups of individuals with increasing degrees of radiological training and experience, the locations of fixations made during visual inspection of digitised chest radiographs were examined for 4 groups of observers: 10 experienced radiologists, 9 first-year 'novice' radiologists, 11 'trainee' radiologists in the second and third years of their training, and 7 naive controls. Each observer viewed 12 digitised chest radiographs (6 normal and 6 showing some abnormality) on a VDU for 8 s each. Eye movements were recorded throughout and observers indicated via a button box whether they thought the radiograph to be normal or abnormal. A least squares index (Mannan, Ruddock and Wooding, 1995, *Spatial Vision*, 9(3): 363-386) was utilised in order to quantify the similarity in fixation location between pairs of eye movement traces over the first 1.5 and 3 s of an inspection. The similarities thus produced were then averaged to give intra- and inter- group similarities in fixation location.

The fixation locations of experienced radiologists were found to be highly similar as a group, as were those of the novices. While the fixation locations of controls showed less similarity, it was the fixations of trainees which were the least similar (i.e. showed the most variability) within their group. The fixation locations of novices showed a greater similarity to those of radiologists than those of controls, and a decreased similarity to those of controls than those of the controls themselves. However, rather than showing that the fixation locations of individuals become increasing similar to those of radiologists as training progresses, the data show that the more variable fixation locations of trainees are the least similar to those of radiologists than those of any of the groups, even the controls.

Control observers examine every day images in a similar way (Mannan, Ruddock and Wooding, 1995, *Spatial Vision*, 9(3): 363-386) and this is also true

of radiological images. Experienced radiologists view radiological images in a similar way to each other, but their training has resulted in differences between them and controls. In becoming experienced radiologists, it appears that trainees may move through a developmental phase characterised by more idiosyncratic eye movements; their eye movements becoming less similar to controls or experienced radiologists than they were. With experience the eye movements of trainee radiologists may become more similar to both groups, but the transition of the trainee from novice to experienced radiologist is not a simple one: the change involves a period of some disorder.

### **Eye movement measuring system for 3-D virtual display with liquid crystal glasses**

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The measuring system is a set two devices. One is a brand new eye mark recorder EMR-8 by NAC Inc. The other is a display device of a DOS/V computer with a liquid crystal glasses system SB300 by SOLIDRAY Co. Ltd.

The eye mark recorder is divided into 5 parts: a head unit assembled in a baseball cap, a controller, an eye mark detecting unit, a software for eye movements analysis and an AC adapter. The head unit is a 1/4 inch colour CCD camera for recording a visual field and its weight is almost 300 gr. The eye mark detecting unit uses 1/3 inch CCD, its measuring scope is within 40 deg. The detecting method is pupil/cornea reflection and the detecting rates are 60 Hz (monocular) and 30 Hz (binocular). The controller has detection power of less than 0.2 deg, its outputs are images of visual field, signals of pupil image, and RS-232C serial data (XY co-ordinates, diameters of pupil, numbers of frames). By the supplied software, one can obtain a graph of eye marks, a graph of diameters of pupil in a time series, results from fixation points analysis, a graph of conversion angles in a time series, etc.

The display system is divided into 4 part: a DOS/V computer, a vertical synchroniser (SB300T), active liquid crystal glasses (SB300G) and a graphic software developed by us. The SB300T has signal inputs such as a frame sync (TTL), a composite video (RS-343A compatible), or separate horizontal and vertical sync, NTSC/PAL, a vertical sync. The SB300G has a more than 26% transmittance, a less than 0.5 ms close time, a less than 2.8 ms open time. Especially, we produced the graphic software for the 3-D virtual display. The software is written in the language C by use of the Open GL graphic library. A picture for the left eye can be displayed in the upper half of the CRT, and a picture for the right eye can be displayed in the lower half of it. The synchroniser makes each picture twice as large in its vertical size and then it can display the right picture when the right shutter of SB300G is opened, and can display the left picture

when the left shutter is opened. Available pictures are moving images from CCD cameras and stored computer graphic images.

When each picture has visual disparity, we can recognise the picture in the virtual 3-D space. By the system, we can compare eye movements in the virtual vision and in the real vision.

### **Auditory and visual evoked saccadic latency in multiple sclerosis**

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There has been debate regarding the origin of increased latencies of reflexive saccades in patients with multiple sclerosis (MS). In a previous investigation we demonstrated that MS patients (with predominantly cerebellar involvement) were able to reduce the latency of their predictive saccades compared to reflexive saccades to a similar degree as controls but both reflexive and predictive saccades were of significantly longer latency (about 100 ms) than controls. This finding suggested that predictive mechanisms are normal in MS but the increased latency of predictive saccades is likely due to delay in afferent visual information reaching the saccadic motor system. In other words, MS patients perceive target motion later than controls. The aim of the present study was to further investigate the hypothesis that saccadic delay in MS is due to delay in the afferent visual pathway rather than delay within cortical, transcortical or efferent pathways.

We therefore decided to examine visual and auditory evoked reflexive and predictive saccades in patients with MS and to correlate saccadic latency with visual (VEP) and middle latency auditory middle latency (MLAEP) evoked potential latency. A finding of increased latencies of visual evoked saccades but not auditory evoked saccades would support the proposal that the increase in latency of visual evoked saccades was due solely or predominantly to delay within the afferent pathway. Fifteen patients with definite MS (Poser criteria) and 15 age and sex matched controls were recruited. Eye movements were recorded with infrared scleral reflection oculography. Results were as follows:

1. VEP latency was significantly prolonged as expected in the MS group, (119.4 ms left, and 120.6 ms right) compared to controls (mean, 105.5 and 104.1 respectively,  $p < 0.03$ ).
2. Visual reflexive saccade latency was significantly increased in the MS group (mean, 218.6 ms left, 228.8 ms right) compared to controls (mean, 199.4 ms left,  $p < 0.05$ ; 201.0 ms right;  $p < 0.03$ ).

3. There was no difference in MLAEP latency between the MS (Pa mean, 31.3 ms left, and 28.8 ms right) and control groups (mean, 29.1 ms and 29.5 ms respectively).
4. There was no significant difference in auditory reflexive saccadic latencies between MS (mean, 210.4 ms left and 218.6 ms right) and control subjects (mean, 203.1 ms and 211.0 ms respectively).
5. Visual predictive saccades were of significantly longer latency than auditory predictive saccades but there was no difference between MS patients and controls for either saccade type.
6. For both MS and control groups there was no correlation between firstly, VEP and latency of visual evoked reflexive and predictive saccades or secondly, MLAEP latency and latency of auditory evoked reflexive and predictive saccades.

The observations in this study of delayed VEP and visual reflexive saccades but normal visual predictive saccades, and normal MLAEP and auditory evoked saccades, in patients with clinically definite multiple sclerosis suggest that the prolonged latencies of visually evoked saccades in this disorder are predominantly or even solely due to demyelination within the afferent pathway. Comparison studies in patients with optic neuritis are ongoing.

### **Using eye mark registration for evaluating object-oriented data within human-computer-interfaces**

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The ifab-Institute of Human and Industrial Engineering at the University of Karlsruhe works in the field of ergonomic suggestive visualisation of object-oriented data within the special research centre 346 "Computer integrated design and manufacturing of parts". In general, object-oriented databases allow to represent complex object hierarchies and associations but the available tools do not use appropriately these possibilities for their visualisation. Based on already existing results and ongoing research activities for visualising data, e.g. in hypermedia and network-oriented databases, the ifab-Institute started an investigation to verify some presumptions regarding the context between object-orientation and cognition. In order to achieve the results, different methods of evaluation, ranging from simple observations of the user's actions to experimental investigations with eye mark registration were used.

The eye mark registration with a "SMI Headmounted Eyetracking Device System" was useful to trace the spots on the interface a test person was looking at, which type of information representation he or she preferred, and if the person was working according to a specific strategy of problem solving or identifying an object. The 40 test persons were all familiar with a personal computer. They

all had to solve search and navigation problems in different visualisation forms of object-oriented data (e.g. list form, 2-dimensional presentation). The experimental design comprised independent variables like the colour representation, the number of objects and the number of associations between the objects.

For the development of an ergonomic suggestive visualisation of object-oriented data, it is necessary to explore the presentation of object quantities and their multiple associations. One result of the experiment is, that the search time for the objects increase linearly with the growing number of presented objects. The most effective coding changed from alphanumeric signs for 64 objects to symbols for more than 64 objects. 95% of the test persons mentioned that they prefer the presentation of associations in a list and not as graphical links between the objects on the display. This statement could only be verified for the presentation of more than 10 associations relating one object. When the interviews were compared with the results of the eye mark registration, aggravating failures in the self assessment of the test persons became evident.

## Index of Authors

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