

# Detection and identification of information presented peripherally inside the car

Effects of driving task demands, stimulus position and direction of motion of the stimulus

*Torbjörn Falkmer, Lena Nilsson and Jan Törnros*







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<b>Title:</b> Detection and identification of information presented peripherally inside the car – effects of driving task demands, stimulus position, and direction of motion of the stimulus			
<b>Abstract</b>  The aim was to study the performance of an in-car information system relying exclusively on information presented peripherally by “running light” stimuli. The information was presented on displays placed in four different positions; upper, lower, to the right, and to the left. Four different directions of the “running light” were used; upwards, downwards, to the right, and to the left. Two levels regarding driving task demands were used. Thirty-two subjects participated in the study. A repeated-measures design was used. The study was performed in an advanced driving simulator. The subjects’ task was to report the direction of motion of the peripheral stimuli as quickly as possible. A traffic situation with high demands on the driver caused the subjects to fixate the peripheral stimulus to a lesser extent than when the driving task was less demanding. The upper display was fixated to a smaller extent than the left or the right one. However, differences in number of fixations between the displays appeared only when the demands of the driving task were high, not when they were low. No effects of the direction of motion of the stimulus on the number of fixations appeared. There were very few errors regarding the identification of the direction of the stimulus, regardless of whether the stimulus was fixated or not. The response times were short. There were differences between display positions. The response time was shortest for the right display and for the lower display, but somewhat longer for the other two displays. It was somewhat shorter when the stimulus was fixated than when it was not. Driving task demands had no effect on response time. Regarding effects of the direction of motion of the stimulus, there was only a very weak interaction with driving task demands and display position. Conclusions: Information presented peripherally in the field of vision by moving stimuli can be acquired quickly and correctly without fixation of the stimuli. An information system using this method of presenting information appears promising. Of the four display positions, the lower one seems to be preferable. It can be expected, however, that it will be more difficult to acquire the presented information under certain ambient light conditions, such as bright sunshine.			
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<b>Författare:</b> Torbjörn Falkmer, Lena Nilsson och Jan Törnros		<b>Uppdragsgivare:</b> KFB	
<b>Titel:</b> Detection and identification of information presented peripherally inside the car – effects of driving task demands, stimulus position, and direction of motion of the stimulus			
<b>Referat</b>  Syftet var att studera funktionen hos ett informationssystem som enbart använder sig av visuell information, presenterad perifert i synfältet med hjälp av ”rinnande ljus” i bilen. Informationen presenterades på displayer i fyra olika positioner; upptill, nedtill, till höger och till vänster. Fyra olika riktningar hos det “rinnande ljuset” användes; uppåt, nedåt, åt höger, och åt vänster. Två nivåer beträffande kravet hos köruppgiften användes. Trettiotvå försökspersoner deltog i studien. Designen var upprepade mätning. Studien genomfördes med hjälp av en avancerad körsimulator. Försökspersonernas uppgift var att så snabbt som möjligt rapportera rörelseriktningen hos de perifera stimuli som presenterades. En krävande köruppgift fick försökspersonerna att fixera perifert stimulus i mindre utsträckning än då köruppgiften var mindre krävande. Den övre displayen fixerades i mindre utsträckning än den vänstra och högra. Skillnader mellan displayer beträffande antal fixationer förelåg dock endast för den krävande köruppgiften, ej vid den mindre krävande. Däremot erhöles ingen effekt av stimulus’ rörelseriktning på antalet fixationer. Mycket få fel registrerades beträffande identifieringen av stimulus’ rörelseriktning oavsett om stimulus fixerades eller ej. Svarstiderna var genomgående korta. Det förelåg en skillnad mellan displaypositioner. Svarstiden var kortast för den högra och för den nedre displayen, men något längre för den övre och den vänstra displayen. Den var något längre då stimulus fixerades än när detta ej var fallet. Ingen effekt av de skilda kraven hos köruppgiften förelåg beträffande svarstider. Vad gäller effekter av stimulus’ rörelseriktning förelåg endast en mycket svag interaktion med köruppgiftens krav och displayposition. Slutsatser: Information presenterad perifert i synfältet med hjälp av av rörliga stimuli går att inhämta snabbt och med stor säkerhet utan att stimuli behöver fixeras. Ett informationssystem som använder denna metod för att presentera information tycks ha förutsättningar att fungera utmärkt. Av de fyra använda displaypositionerna ter sig den nedre vara att föredra. Emellertid kan man förvänta sig att det blir svårare att inhämta den presenterade informationen vid besvärliga ljusförhållanden såsom i starkt solsken.			
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## **Preface**

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## Definitions

### **Foveal and peripheral vision**

The visual system consists of two subsystems, foveal and peripheral vision. The foveal vision is restricted to a visual angle of approximately 1° around the fixation point. It provides the driver with high-resolution information, which supports capabilities such as recognition (Samuelsson & Nilsson, 1996). The peripheral vision enables the driver to detect changes in contrast and movements, but with decreased visual acuity. The peripheral vision supports capabilities such as the driver's spatial orientation, but without the driver being fully conscious of this process (Leibowitz, 1986). These two systems operate simultaneously and are dependent on each other.



## **Inhämtande av rörlig visuell information presenterad perifert i bilen. Effekter på uppmärksamhetsfördelning och körprestation i varierad trafikmiljö**

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### **Sammanfattning**

Studien behandlar möjligheten att använda informationssystem som enbart använder sig av visuell information som presenteras perifert med hjälp av rörliga ("rinnande ljus") stimuli i bilen. Ett syfte var att studera i vilken utsträckning sådan information påverkar foveal uppmärksamhet under olika betingelser. Ett annat syfte var att studera om informationsinhämtningen påverkas av de krav som köruppgiften ställer. Ett tredje syfte var att studera om positionen och riktningen hos perifert stimulus har betydelse i detta avseende.

Informationen presenterades på displayer i fyra olika positioner; upptill, nedtill, till vänster, och till höger. Vinkeln mellan siktlinjen och var och en av de fyra displayerna hölls konstant. Fyra olika rörelseriktningar hos det "rinnande ljuset" förekom. Två betingelser beträffande kravet hos köruppgiften användes, en med högt och en med lågt krav.

Trettiofyra försökspersoner – 16 män och 16 kvinnor, samtliga erfarna bilförare – deltog i studien. Designen var upprepade mätning. Studien genomfördes med hjälp av en avancerad körsimulator. Försökspersonernas uppgift var att så snabbt som möjligt rapportera rörelseriktningen hos de perifera stimuli.

Det visade sig att högt krav från köruppgiften fick försökspersonerna att fixera perifert stimulus i mindre utsträckning än då kravet från köruppgiften var lågt (47,2% jämfört med 61,1%).

Det förelåg även skillnader mellan displaypositioner. Den övre displayen fixerades i mindre utsträckning än den vänstra och högra (48,8% jämfört med 59,2% och 57,6%), medan antalet fixationer av den nedre displayen ej var signifikant skilt från övriga (51,0%). Vid jämförelse mellan stimuluspositioner för de två betingelserna beträffande köruppgiftens krav på föraren förelåg en skillnad endast vid höga krav; en parvis jämförelse var signifikant, den mellan den övre och den högra displayen (40,2% respektive 53,9%). Däremot erhöles ingen effekt av stimulus' rörelseriktning på antalet fixationer.

Mycket få fel registrerades beträffande identifieringen av stimulus rörelseriktning. Andelen korrekta svar varierade mellan 97,7% och 99,6% för de fyra displayerna. Andelen korrekta svar var lika stor oavsett om man fixerat stimulus eller ej.

För svarstiden hos korrekta reaktioner förelåg en skillnad mellan displaypositioner. Den var kortast för den högra (1,07 s.) och för den nedre displayen (1,08 s.), men något längre för den övre (1,19 s.) och den vänstra displayen (1,20 s.). Den var något längre då stimulus fixerades än när detta ej var fallet. Ingen effekt av de skilda kraven hos köruppgiften förelåg beträffande svarstider. Vad gäller effekter av stimulus' rörelseriktning på svarstider förelåg endast en mycket svag interaktion med köruppgiftens krav och displayposition.

Slutsatser: Information presenterad perifert i synfältet med hjälp av av rörliga stimuli går att inhämta snabbt och med stor säkerhet utan att stimuli behöver fixe-

ras. Ett informationssystem som använder denna metod för att presentera information tycks ha förutsättningar att fungera utmärkt. Av de fyra använda displaypositionerna ter sig den nedre vara att föredra. Emellertid kan man förvänta sig att det blir svårare att inhämta den presenterade informationen vid besvärliga ljusförhållanden såsom i starkt solsken.

## **Detection and identification of information presented peripherally inside the car – effects of driving task demands, stimulus position, and direction of motion of the stimulus**

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### **Summary**

The issue concerned the possibility of using in-car information systems relying exclusively on visual information presented peripherally by moving (“running light”) stimuli. One of the aims was to analyse the extent to which such information affects foveal attention under different conditions.

Another aim was to study whether the demands imposed by the driving task affect information acquisition. A third aim was to study whether the position and motion of the peripheral stimulus would be of importance in this respect.

The information was presented on displays placed in four different peripheral positions; upper, lower, to the left, and to the right. The angle between the line of sight and each of the four displays was held constant. There were four different directions of motion of the “running light” stimulus. Two conditions regarding driving task demands were used, one high and one low.

Thirty-two subjects – 16 men and 16 women, all experienced drivers – participated in the study. A repeated-measures design was used. The study was performed in an advanced driving simulator. The subjects’ task was to report the direction of motion of the peripheral stimuli as quickly as possible.

It was found that a traffic situation imposing high demands on the driver caused the subjects to fixate the peripheral stimulus to a smaller extent than when the driving task was less demanding (47.2% compared to 61.1%).

There were also differences between display positions. The upper one was fixated to a lesser extent than the left or the right one (48.8% compared to 59.2% and 57.6% respectively), with the lower display not significantly different from any of the other positions (51.0%). When comparing stimulus positions under the two different demand conditions, a difference appeared only in the high demand condition; one pairwise comparison was significant, between the upper and the right display (40.2% and 53.9% respectively). No effects of the direction of motion of the stimulus on the number of fixations appeared.

There were very few errors regarding the identification of the direction of the stimulus. The correct response rate varied from 97.7% to 99.6% for the four displays. The correct response rate was the same regardless of whether the stimulus had been fixated or not.

In regard to response time for correct identification, there were differences between display positions. Response time was shortest for the right display (1.07 s.) and for the lower display (1.08 s.), but longer for the upper (1.19 s.) and the left display (1.20 s.). The response time was somewhat shorter when the stimulus was fixated than when it was not. Driving task demands had no effect on response time. Regarding effects of the direction of motion of the stimulus on response times, there was only a very weak interaction with driving task demands and display position.

Conclusions: Information presented peripherally in the field of vision by moving stimuli can be acquired quickly and correctly without fixation of the stimuli. An information system using this method of presenting information appears promising. Of the four display positions, the lower one seems to be preferable. It can be expected, however, that it will be more difficult to acquire the presented information under certain ambient light conditions such as bright sunshine.

# 1 Introduction

New in-car information systems are being developed and introduced, highlighting the issue of information acquisition by the driver. Knowledge of how to design these systems for quick and reliable detection and interpretation of the presented information is required in order to avoid negative effects on safety and comfort.

Most support systems present visual information, relying on foveal vision. Peripheral vision is used to a very small extent for acquisition of in-car information, and it is of interest to investigate whether peripheral vision might be a resource that could be put to greater use.

The present study is based on the results from a previous driving simulator study by Nilsson, Falkmer & Samuelsson (1998, 2000), which aimed at determining whether car drivers have the capacity to acquire information presented peripherally in the car without fixating it.

The subjects were instructed not to move their foveal vision to the peripheral stimulus, i.e. to avoid fixating the stimulus. The study showed that the subjects did in fact comply with the instruction, i.e. they were capable of inhibiting their natural tendency to move foveal vision to the peripheral stimulus when instructed to do so. However, the accuracy of the acquisition of information via peripheral vision was influenced by the type of stimulus (stationary or moving), position of the display presenting the information (the displays were placed 3 cm apart from each other in a central position at the uppermost part of the windshield), and by driving speed (110 km/h and 90 km/h). A substantially larger percentage of the information was incorrectly identified with a stationary stimulus (the letter T presented correctly or upside down) than with a moving stimulus (a “running light”, either to the left or the right). Information provided by a stationary stimulus was generally correctly identified more often when presented more centrally than somewhat further out in the vertical peripheral field of view. Contrary to this, the information provided by a moving stimulus was almost always correctly identified, irrespective of display position. Higher driving speed was associated with a reduced percentage of correct identifications. Varying demands of the driving task (speed and distance control) did not, however, have any effect on the accuracy of information acquisition.

The speed of information acquisition via peripheral vision was influenced only by the type of stimulus; response times were longer with a stationary stimulus than with a moving stimulus. Display position, driving speed or varying demands of the driving task did not influence the speed of information acquisition.

In view of the promising results obtained with peripheral presentation of information with the aid of moving stimuli, it was decided to use only this method of providing information to the driver in the present study.

The previous study did not indicate the extent to which peripherally presented information would trigger the natural response to fixate the stimulus. The subjects in the present study, on the contrary, were allowed to acquire the presented information in a freely chosen manner, i.e. via foveal or peripheral vision. It was hypothesised that by increasing the demands of the driving task, the subjects would pay more attention to the traffic environment ahead and would consequently have to rely more on peripheral vision for acquiring the information presented by the peripheral stimulus (Ikeda & Takeuchi, 1975; Williams, 1982, 1985; Miura, 1985). This experimental variation might also have effects on the accuracy and/or the speed of information acquisition.

A second issue consisted of determining whether the position of the peripheral display presenting the information would have an impact on information acquisition. Four different positions were selected (within practical limits for in-car applications); an upper position, a lower position, to the right, and to the left. A literature survey by Samuelsson & Nilsson (1996) indicated that the angle between the line of sight and the position of the stimulus has an effect – the smaller the angle, the better the information acquisition. However, it was decided that this angle would be held constant for the different display positions. It was thus hypothesised that no differences between positions with respect to information acquisition would appear.

The effects of the direction of motion of the peripheral stimulus were also investigated. Four different directions were compared; upwards, downwards, to the left, and to the right. It was not hypothesised that any effects of this experimental variation would appear.

The visual task was basically the task used by Nilsson, Falkmer & Samuelsson (1998, 2000), i.e. a discrimination task, where the direction of motion of the peripheral stimulus was to be identified. A practical in-car application might concern designing a route guidance system (Alm & Berlin, 1997), which uses peripherally presented information to tell the driver which direction to take. The most relevant effect measure of this discrimination task as a measure of the quality of information acquisition is the correctness of the identifications, although the response times for the identifications are also relevant.

To sum up, the main objective of the present study was to study the extent to which drivers fixate the peripherally presented stimulus when they have a free choice to do so, and the quality of information acquisition under these circumstances. Effects of three independent variables – driving task demands, position of the peripheral stimulus, and the direction of motion of the peripheral stimulus – on fixations of the peripheral stimulus and on information acquisition, were further objectives of the study.

It was also of interest to determine whether the correctness of identifications and/or response times for identifications were related to whether the subjects fixated the peripheral stimulus or not. Finally, subjective effects of the driving task demands were investigated. It was hypothesised that the rated workload would be greater under high driving task demands.

## **2 Method**

### **2.1 Subjects**

Thirty-two subjects, sixteen men and sixteen women, aged 22 to 60 years, participated in the study. Their average age was 36.3 years (standard deviation = 11 years). They had held their driving licences for at least five years and their annual driving distances exceeded 10,000 km.

None of the subjects wore eyeglasses. The reason behind this requirement was the use of an eye movement recorder (see below), which only performs correctly when the subject does not wear glasses.

### **2.2 Driving simulator**

The VTI car driving simulator was used (Nordmark, 1990; Nordmark et al, 1986; Nilsson, 1993). The simulator has a moving base system, a wide-angle visual system, a vibration-generating system, and a sound system, all of which are controlled to interact in a way that gives the driver an impression very similar to real driving (Törnros, Harms & Alm, 1997). A temperature-regulating system is also fitted.

The noise, infrasound and vibration levels inside the car corresponded to those of a modern passenger car. The temperature inside the car cabin was +20°C. The car mock-up used in the present experiment was a front wheel drive Volvo 850 with automatic gearbox. The ambient light conditions could be characterised as those of dusk or dawn.

### **2.3 Scenario**

#### **Road**

The same rural road as in a previous study (Nilsson, Falkmer & Samuelsson, 1998) was used. This had one driving lane in each direction. The road width was 7 m with a 1 m shoulder on each side. The total distance driven was 80 km and was divided into four identical 20 km routes.

The road had smooth vertical and horizontal curves. The pavement had a high friction and corresponded to dry summer conditions.

The posted speed limit was 90 km/h.

#### **Traffic conditions – driving task demands**

On two of the four 20 km test routes, the subject was instructed to perform a car following task. The leading car varied its speed in a sine wave manner between 60 km/h and 90 km/h. This situation also featured oncoming traffic, forcing the subject to stay in the right-hand driving lane. The speed of the oncoming cars was 90 km/h, but they appeared randomly at irregular time intervals. Their lateral position also varied, but they all stayed in the opposing driving lane at all times – the distance between the left wheel and the centre of the road varied between 0.5 m and 2.0 m. The visibility distance in this situation was reduced to 50 m by fog.

On the other two test routes, there was no other traffic and no reduction in visibility distance.

## **2.4 Displays and presented information**

The peripheral visual information was presented on four identical displays. Each had a total of nine yellow light emitting diodes, which were mounted in the shape of a cross consisting of five horizontal and five vertical diodes. Each display covered an area of  $3.5^\circ \times 3.5^\circ$  of the peripheral visual field.

The four displays were mounted in four different positions, to the left, to the right, upper, and lower (Figures 1, 2). The angle between the line of sight and each of the four displays was approximately constant for each subject, but varied across subjects from  $11^\circ$  to  $22^\circ$ , with  $18^\circ$  as an average. The inconsistency of the angle was due to differences in the subjects' length and position in the driving sea. The average distance from the eye of the driver to the upper and lower displays was approximately 58 cm.

The information on each of the four displays was presented by a "running light" moving in four different directions (upwards, downwards, to the left, or to the right) (Figures 1, 2). The running light was created by the sequential lighting up of the vertical or horizontal diodes. The lighting duration of each diode was 150 ms. After the last diode in the sequence had been switched off, a period of 400 ms elapsed before the next "light wave" started. The running light stimulus was presented 64 times during the test session, distributed evenly between the four directions of motion, the four display positions, and the two demand conditions (see Chapter 2.6 Experimental design).



**Figure 1** Locations of the four displays for peripheral presentation of information to the driver, showing the four directions of motion in the low demand condition. During the experiment, the information was presented on only one display at a time.



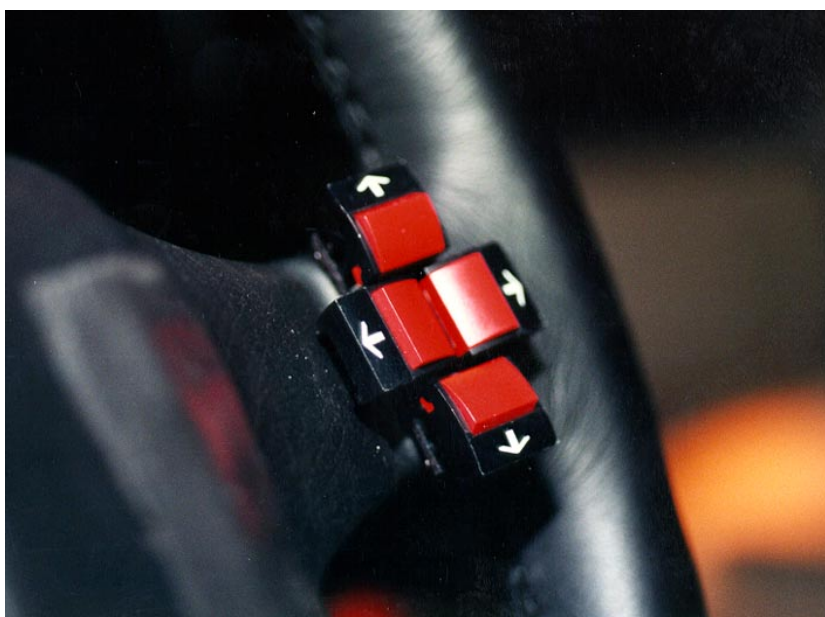
**Figure 2** Locations of the four displays for peripheral presentation of information to the driver, showing the four directions of motion in the high demand condition. During the experiment, the information was presented on only one display at a time.

## 2.5 Driving task

The subject was instructed to perform the following:

- Drive as in real traffic.
- Comply with the posted speed limit (90 km/h).
- When there was another car ahead, follow it without losing sight of it. Do not collide with the leading car, and do not overtake it.
- Report the direction of the moving stimulus presented on the displays (upwards, downwards, to the right, or to the left) by pressing the correct response button on the steering wheel as quickly as possible

Four response buttons were mounted in the form of a cradle on the right side of the steering wheel (Figure 3). The subject placed his/her right thumb in the cradle and could easily respond to the presented information without having to change grip on the wheel or look at the response buttons. Unless the driver responded within five seconds, the stimulus was turned off and a missed response was registered.



**Figure 3** *The four response buttons mounted on the steering wheel*

When the stimulus moved to the right, the correct response was to press the right-hand button, and, analogously, when it moved to the left, upwards or downwards, the correct response was to press the left-hand, upper, or lower button, respectively.

## **2.6 Experimental design**

There were three independent variables in the study: two levels of demand from the driving task, four display positions, and four directions of motion of the stimulus. All subjects were exposed to all combinations of the three independent variables during the 80 km test drive. The design was consequently a 2 x 4 x 4 factorial within-groups design. Each combination of demand x display position was presented eight times for each subject, twice for each direction of motion of the stimulus (Table 1). Consequently, each subject received 64 stimulus presentations.

**Table 1** *Experimental design. Figures in parenthesis refer to number of presentations*

High demand (32)				Low demand (32)			
Display position Upper (8)	Display position Lower (8)	Display position Right (8)	Display position Left (8)	Display position Upper (8)	Display position Lower (8)	Display position Right (8)	Display position Left (8)
Upwards (2)	Upwards (2)	Upwards (2)	Upwards (2)	Upwards (2)	Upwards (2)	Upwards (2)	Upwards (2)
Downwards (2)	Downwards (2)	Downwards (2)	Downwards (2)	Downwards (2)	Downwards (2)	Downwards (2)	Downwards (2)
To the left (2)	To the left (2)	To the left (2)	To the left (2)	To the left (2)	To the left (2)	To the left (2)	To the left (2)
To the right (2)	To the right (2)	To the right (2)	To the right (2)	To the right (2)	To the right (2)	To the right (2)	To the right (2)

Effects of presentation order were controlled through incomplete counterbalancing (McGuigan, 1968). Sixteen different randomised orders of stimulus presentation were used; one male and one female subject were exposed to each order (Appendix 1).

Four different randomised combinations of display position and direction of motion were combined with the two demand conditions in such a way that every combination appeared once and only once on each of the four 20 km test routes (two Latin square designs combined; see Appendix 1 and 2).

## 2.7 Eye movement recording

In order to determine whether the subjects fixated the stimulus or not, eye movements were recorded with an NAC 600 eye movement recorder (Kielgast, 1994). The equipment uses a cornea reflex system to measure the movement of the eyeball in the horizontal and vertical directions.

By using infra red light reflected on the cornea, movements of the eyeball are registered with an accuracy of  $\pm 0.17^\circ$  and a frequency of 30 Hz. Synchronous with the registration of eye movements, the surroundings ahead are recorded with a video camera mounted on the headset. The apparatus is shown in Figure 4.

The coordinates representing the direction of gaze are linked to the video recordings. The resulting video film tape shows the surroundings from the perspective of the subject. The recordings were analysed manually frame by frame to judge whether the subject had acquired the information via foveal or peripheral vision – i.e. to determine whether they had fixated the stimulus or not.



*Figure 4 The NAC 600 eye movement recorder mounted on the subject's head.*

## **2.8 Dependent variables**

### **Fixations**

The number of fixations of the moving stimulus was calculated.

### **Correct identifications**

The number of correct identifications of the direction of motion of the stimulus, indicated by the subject pressing the correct response button, was calculated.

### **Response time**

The response time from the onset of the moving stimulus until the subject responded by pressing one of the response buttons was measured in ms. The error of measurement was  $\pm 10$  ms.

### **Self-reported workload**

After completing each of the four test routes, the subject filled in two rating scales of mental workload, NASA-RTLX, and RSMI.

*NASA-RTLX* (Byers, Bittner & Hill, 1989) - a method of measuring six factors of subjectively estimated workload; mental demand, physical demand, time pressure, performance, effort and frustration level. For each factor, the subject rated (on a scale from 0 to 100) the workload during the preceding 20 km simulator run.

*RSMI* (Rating Scale Mental Effort) (Zijlstra & Van Doorn, 1985) – a uni-dimensional scale with a scale from 0 to 150 that measures subjectively estimated

mental effort. The subject was asked to rate the mental effort during the preceding 20 km simulator run.

## **2.9 Data analysis**

The effects of driving task demand, display position, and direction of motion of the stimulus on fixation of the moving stimulus, correct identification of the direction of motion of the stimulus, and response times were analysed. For self-reported workload, only effects of driving task demand were analysed.

Fixations and correct identifications were analysed with the non-parametric Friedman two-way analysis of variance by ranks or – when comparing only two conditions – the Wilcoxon signed ranks test (Siegel & Castellan, Jr, 1988). Separate analyses were also performed for the two demand conditions. Post-hoc tests (Wilcoxon signed ranks test) were performed when significant effects of display position appeared. In these follow-up tests, the critical significance level was adjusted as recommended by Kirk (1968);  $\alpha$  was divided evenly among the different comparisons.

Self-reported workload was analysed by the Wilcoxon signed ranks test.

Response times for correct identifications were analysed by variance analysis. Post-hoc tests (Tukey) were performed when significant main effects appeared.

Paired t-tests were used for comparing the proportion of – and response times to – correct identification of the direction of motion of the peripheral stimuli when the stimuli were fixated and when they were not.

The basic level of significance was 5% in all cases.

## **2.10 Procedure**

After arriving at VTI, the subject first read the written instructions, after which the test leader gave the instructions orally. Specifically, the subject was instructed to respond to the peripheral moving stimuli correctly and as quickly as possible, to follow the leading car and not collide with it or lose sight of it, to keep the posted speed limit, and to drive as in real traffic.

After this, the headset of the eye movement recorder was mounted on the head of the subject. The equipment was calibrated with the subject sitting in the driving simulator. The system for stimulus presentation was demonstrated and the test leader instructed the subject on how to respond to the presented information.

The subject drove a 10 km pre-test route to get used to the driving simulator and the different tasks of the study before starting the test.

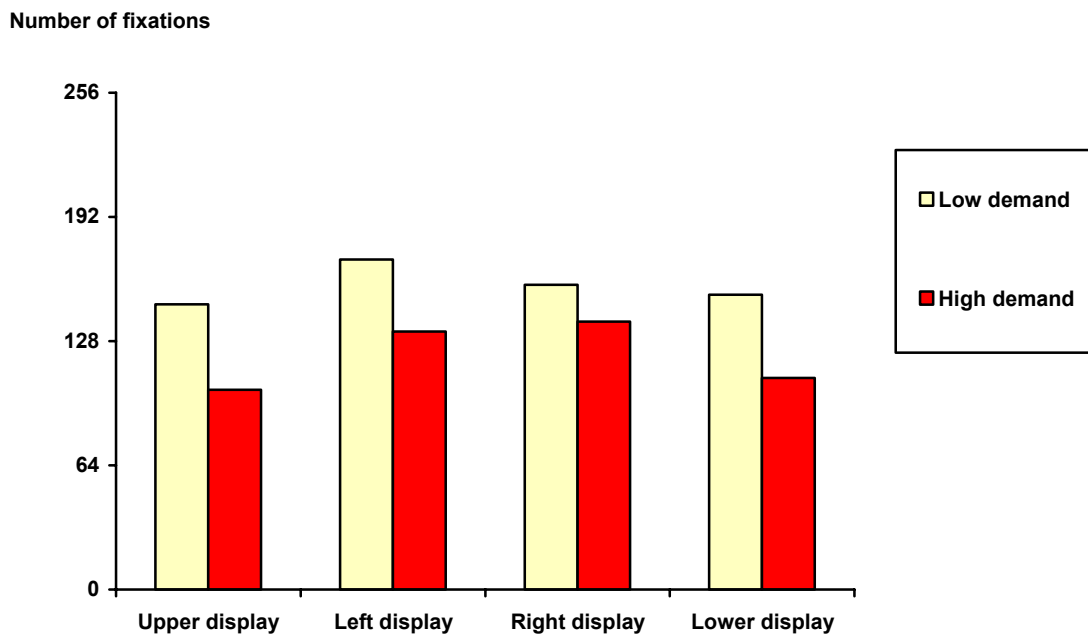
The test session then followed. The subject had a break and left the driving simulator after driving the first 20 km. The headset was removed for reasons of comfort. Before driving the next 20 km of the test road, the headset was mounted and calibrated again. The subject had another two such breaks after driving 40 and 60 km respectively.

After each of the four 20 km test routes, the subject also filled in the NASA-RTLX and RSMI forms. At the end of the test session, the subject was remunerated for his/her participation.

### 3 Results

#### 3.1 Fixations of peripheral moving stimulus

Figure 5 shows the average number of fixations of the peripheral moving stimuli for the four display positions in the low and high demand conditions. The maximal average number of fixations possible in each of the eight situations was 256. As the figure shows, there were many fixations in all conditions – the average number varied between 103 (40.2%) for presentations on the upper display under high driving task demands and 170 (66.4%) for presentations on the left display under low driving task demands. When including directions of motion, the average number of fixations and proportions in the 32 different combinations of experimental variations is presented in Appendix 3.



**Figure 5** Average number of fixations of peripheral moving stimulus.

The average number of fixations was greater with low driving task demands than with high demands; 626 (61.1%) compared to 483 (47.2%), a significant difference (Wilcoxon signed ranks test:  $z=4.26$ ;  $p<0.001$ ).

There were also differences between display positions. Presentation of information on the left display resulted in the highest average number of fixations, 303 (59.2%), followed by the right one, 295 (57.6%), the lower one, 261 (51.0%) and the upper one, 250 (48.8%). The difference was significant (Friedman two-way analysis of variance by ranks:  $\chi^2(3)=19.69$ ;  $p<0.001$ ). Pairwise comparisons (Wilcoxon signed ranks test) show that only two comparisons were significant at the required level of significance ( $p<0.05/6 = 0.0088$ ); the average number of fixations on the upper display differed from the number of fixations on both the left ( $z=3.27$ ;  $p<0.001$ ) and the right display ( $z=2.73$ ;  $p<0.01$ ).

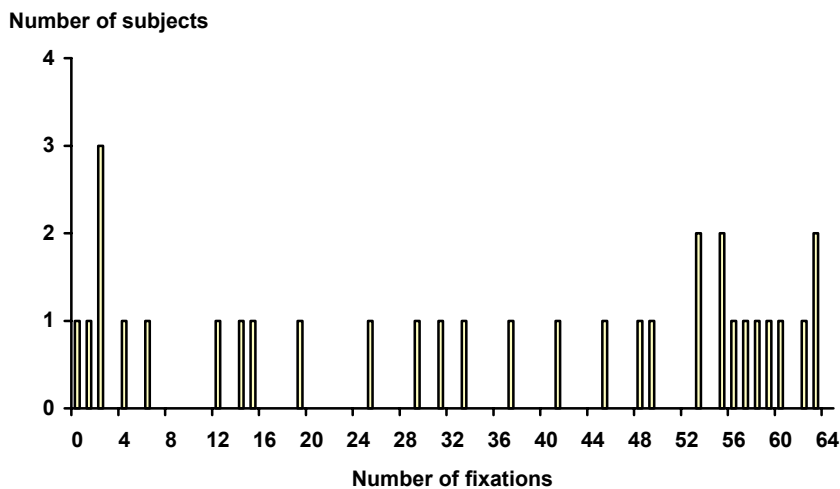
Effects of display position were also analysed in the two demand conditions separately. There was no significant difference under low driving task demands at

the required level of significance ( $p < 0.025$ ) [Friedman two-way analysis of variance by ranks:  $\chi^2(3) = 7.89$ ;  $p > 0.025$ ]. Under high driving task demands, there was, however, an effect of display position [ $\chi^2(3) = 17.20$ ;  $p < 0.001$ ]. Pairwise comparisons (Wilcoxon signed ranks test) gave the result that only one comparison turned out to be significant at the required level of significance ( $p < 0.025/6 = 0.004$ ), the average number of fixations on the upper display differed from the number of fixations on the right display (40.2% and 53.9% respectively).

Regarding effects of the direction of motion of the stimulus (Appendix 3), the highest average number of fixations was found when the stimulus moved to the right, 287 (56.1%), followed by the stimulus moving to the left, 286 (55.9%), moving downwards, 270 (52.7%), and moving upwards, 266 (52.0%). The difference was, however, not significant [Friedman two-way analysis of variance by ranks:  $\chi^2(3) = 3.98$ ;  $p > 0.05$ ].

Effects of the direction of motion of the stimulus were also analysed in the two demand conditions separately. There was no significant difference under either low driving task demands [Friedman two-way analysis of variance by ranks:  $\chi^2(3) = 2.72$ ;  $p > 0.025$ ], or high driving task demands [Friedman two-way analysis of variance by ranks:  $\chi^2(3) = 6.61$ ;  $p > 0.025$ ].

The distribution of fixations across subjects is shown in Figure 6. One subject never fixated the moving stimulus, whereas another subject fixated 63 out of the 64 stimuli presented. The variation between subjects was very large.

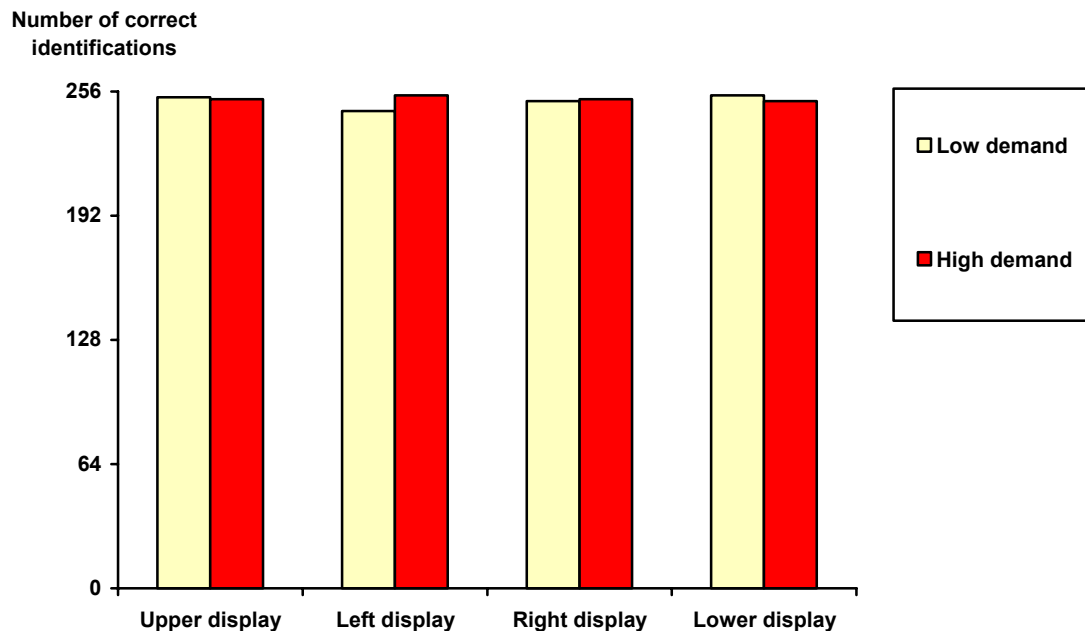


**Figure 6** Number of subjects with different number of fixations of peripheral moving stimulus

### 3.2 Correct identifications of direction of motion of peripheral stimulus

Figure 6 shows the average number of correct identifications of the direction of motion of the peripheral stimuli for the four display positions in the low and high demand conditions. The maximal average number of correct identifications possible in each of the eight conditions was 256. As the figure shows, the average number of correct identifications was very large in all conditions – varying

between 246 (96.1%) for presentations on the left display under low driving task demands and 254 (99.2%) for presentations on the left display under high driving task demands and for presentations on the lower display under low driving task demands. When including direction of motion, the average number and proportions of correct identifications in the 32 different combinations of experimental variations are as shown in Appendix 4.



**Figure 6** Average number of correct identifications of direction of motion of peripheral stimulus

The average number of correct identifications was 1009 (98.5%) under high driving task demands and 1004 (97.3%) under low driving task demands, a non-significant difference (Wilcoxon signed ranks test:  $z=1.39$ ;  $p>0.05$ ).

With respect to display position, the average number of correct identifications was 505 (98.6%) for the upper display, 500 (97.7%) for the left display, 503 (98.2%) for the right display, and 505 (98.6%) for the lower display, a non-significant difference [Friedman two-way analysis of variance by ranks:  $\chi^2(3)=2.58$ ;  $p>0.05$ ].

Effects of display position were also analysed in the two demand conditions separately. There was no significant difference under low driving task demands at the required level of significance [Friedman two-way analysis of variance by ranks:  $\chi^2(3)=6.77$ ;  $p>0.025$ ]. Similarly, there was no difference between display positions under high driving task demands [Friedman two-way analysis of variance by ranks:  $\chi^2(3)=0.95$ ;  $p>0.025$ ].

Regarding effects of the direction of motion of the stimulus (Appendix 4), the highest average number of correct identifications was found when the stimulus moved to the right, 507 (99.0%), followed by the stimulus moving to the left, 504 (98.4%), moving downwards, 504 (98.4%), and moving upwards, 498 (97.3%).

The difference was, however, not significant [Friedman two-way analysis of variance by ranks:  $\chi^2(3)=1.62$ ;  $p>0.05$ ].

Effects of the direction of motion of the stimulus were also analysed in the two demand conditions separately. There was no significant difference under either low or high driving task demands, [Friedman two-way analysis of variance by ranks:  $\chi^2(3)=2.14$ ;  $p>0.025$ ], and [Friedman two-way analysis of variance by ranks:  $\chi^2(3)=1.58$ ;  $p>0.025$ ], respectively.

### Identification errors

In all, 35 of the 2048 stimuli were identified incorrectly. Four of these errors were caused by malfunction of the apparatus. The remaining 31 human errors are presented in detail in Appendix 5.

Eighteen identification errors appeared under low driving task demands and thirteen under high driving task demands. The left display had twelve identification errors, the lower one had five, and the other two displays had seven identification errors each.

### 3.3 Correct identifications of direction of motion of peripheral stimulus with respect to fixation of the stimulus

Table 2 shows the number and proportion of correct and incorrect identifications of the direction of motion of the peripheral stimulus when the stimulus was fixated and when it was not fixated.

**Table 2** Number and proportion of correct identifications of direction of motion of the peripheral stimulus with respect to fixation of the stimulus

	Correct identification	Incorrect identification
Stimulus fixated	1092 (98.5 %)	17 (1.5 %)
Stimulus not fixated	918 (98.5 %)	14 (1.5 %)

The proportion of correct identifications was very high, and identical, regardless of whether or not the subject fixated the stimulus.

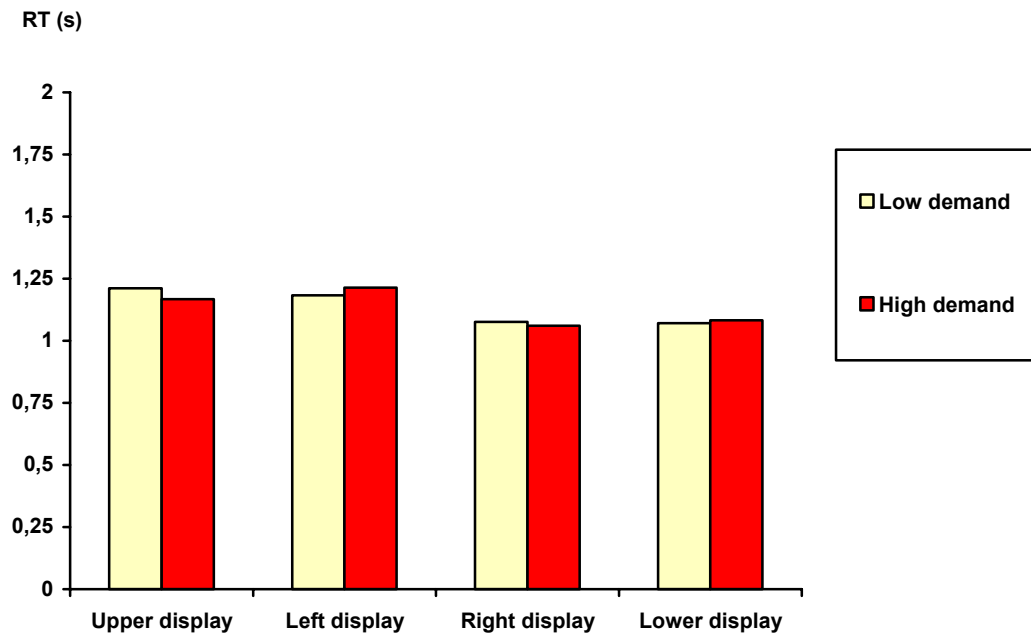
### 3.4 Response time for correct identification of direction of motion of peripheral stimulus

Only response times for correct identification were analysed.

There were a total of seven missed responses (no response within 5 s.) in the whole experiment, four of which resulted from malfunction of the apparatus. In these cases, the missed response time was replaced by the response time obtained in the other measurement for the same combination of experimental variations (demand x display position x direction of motion). The same procedure was applied in the case of response times to incorrect responses.

For one subject, both responses for one combination of demand x display position x direction of motion were incorrect. In this case, the missing value was estimated by using the average value of the individual's other correct responses for the demand x display position combination where the missing values appeared.

The results for the four displays in the low and the high demand conditions are shown in Figure 6. When including direction of motion, the average response time in the 32 different combinations of experimental variations is as shown in Appendix 6.



**Figure 6** Average response time for correct identification of direction of motion of peripheral stimulus

The variance analysis of the response time data is presented in Table 3.

**Table 3** Variance analysis of response time for correct identification of direction of motion of peripheral stimulus

Source	SS	df	MS	F	Sign.
Demand	0.005121	1	0.005121	0.080	>0.05
Error (demand)	1.975	31	0.06370		
Display position	3.798	3	1.266	13.668	<0.001
Error (display position)	8.614	93	0.09262		
Direction of motion	0.184	3	0.06134	0.962	>0.05
Error (direction of motion)	5.93	93	0.06377		
Demand x display position	0.205	3	0.06834	1.658	>0.05
Error (demand x display position)	3.834	93	0.04122		
Demand x direction of motion	0.03237	3	0.01079	0.314	>0.05
Error (demand x direction of motion)	3.194	93	0.03435		
Display position x direction of motion	0.937	9	0.104	1.772	>0.05
Error (display position x direction of motion)	16.402	279	0.05879		
Demand x display position x direction of motion	0.819	9	0.09101	2.397	<0.05
Error (demand x display position x direction of motion)	10.593	279	0.03797		

As the table shows, there were differences in response time between display positions and a triple interaction (demand x display position x direction of motion).

Regarding the effect of display position, the response time was shortest for the right (1.07 s.) and the lower display (1.08 s.), but longer for the upper (1.19 s.) and the left display (1.20 s.). Pairwise comparisons confirm these differences (Table 4).

Where effects on response time were found, the magnitude of the effect was calculated using omega<sup>2</sup> ( $\omega^2$ ). For the display factor, the result was  $\omega^2 = 0.0625$ , which, according to Keppel (1982), represents a “medium” effect. As to the triple interaction, a much smaller value was obtained;  $\omega^2 = 0.0085$ , which means that less than 1% of the total variance in response times was explained by this interaction. This was regarded as an effect with little importance and was not investigated further.

**Table 4** Response times: Pairwise comparisons for display position (Tukey)

Comparison between displays	q value	Sign.
Upper vs left	q = 0.47	n.s.
Upper vs right	q = 6.35	sign.
Upper vs lower	q = 5.89	sign.
Left vs right	q = 6.82	sign.
Left vs lower	q = 6.36	sign.
Right vs lower	q = 0.46	n.s.

### 3.5 Response time for correct identification of direction of motion of peripheral stimulus with respect to fixation of the stimulus

Table 5 shows the response times for correct identification of the direction of motion of the peripheral stimulus when the stimulus was fixated compared to when the stimulus was not fixated.

**Table 5** *Response time for correct identification of direction of motion of peripheral stimulus with respect to fixation of the stimulus*

	Response time for correct identification
Stimulus fixated	1.17 s
Stimulus not fixated	1.08 s

As the table shows, the response times were somewhat longer when the drivers fixated the stimulus than when they did not. A paired t-test performed on the response times for fixations and non-fixations gives a significant difference [ $t_{63}=4.86$ ;  $p<0.001$ ].

### 3.6 Self-reported workload

Table 6 shows the average subjective ratings of mental workload. There was a significant difference between the high and the low demand conditions for all six factors involved in the NASA-RTLX questionnaire. Also, mental effort was rated higher in the high demand condition than in the low demand condition in the RSMI questionnaire.

It can be concluded that subjective mental workload was higher under high driving task demands than under low driving task demands.

**Table 6** *Self-reported mental workload*

Instrument	Scale	Low demand	High demand	Wilcoxon signed ranks test: z value	Sign.
NASA-RTLX	Mental demand	25	44	4.23	<0.001
	Physical demand	23	36	3.69	<0.001
	Time pressure	12	22	3.39	<0.001
	Performance	73	65	2.24	<0.05
	Effort	29	49	4.01	<0.001
	Frustration level	20	44	4.40	<0.001
RSMI	Mental effort	31	50	3.91	<0.001

## 4 Discussion

Regarding *fixation* of the peripherally presented moving stimulus, more than 50% of the stimulus presentations were fixated by the subjects. The traffic situation with greater demands on the driver – imposing increased mental workload according to subjective ratings – caused the subjects to fixate the peripherally presented stimulus to a lesser extent than when the driving task was less demanding. This finding was expected and is completely in line with previous studies (Ikeda & Takeuchi, 1975; Williams, 1982, 1985; Miura, 1985).

There were also differences between display positions. The number of fixations was smaller for the upper display than for the left and the right ones. When comparing display positions in the two different demand conditions, a difference appeared only under high driving task demands; the number of fixations was smaller for the upper display than for the right display. However, no effects of the direction of motion of the stimulus were found.

There were very few errors regarding *identification* of the direction of motion of the stimulus with no effects of the different independent variables, a result that is in close accordance with the results obtained by Nilsson, Falkmer & Samuelsson (1998), who also found very high response accuracy, with no differences between driving conditions or display positions, for moving peripheral stimuli. It did not appear significant whether the stimulus had been fixated or not; the correct response rate was the same in both situations.

For *response time*, there was an effect of display position – a result that was not expected. The effect was of moderate size. The response time was shortest for the right display (1.07 s.) and for the lower display (1.08 s.), but longer for the upper (1.19 s.) and the left display (1.20 s.).

The differences in response time between display positions may be explained by differences in angle between the actual line of sight and the display positions. Even though the angle between the line of sight and the four displays was approximately the same when measured before the test drive in the stationary simulator car, the actual line of sight may very well have varied in a way that resulted in differences in angle between the actual line of sight and the four displays. It is well documented that drivers' visual search pattern are more concentrated on the right side of the road and its immediate road surroundings than the left side of the road and its surroundings (Evans, 1991), which may have caused angular differences of sufficient magnitude for the effects to appear. Regarding the other two independent variables, i.e. driving task demands and direction of motion of the stimulus, there was only a triple interaction – driving task demand x display position x direction of motion – of very small size. Finally, the response times were somewhat longer when the stimuli were fixated than when they were not.

What conclusions can be drawn from the present findings?

Firstly, the information system tested – which requires the driver to determine the motion of the peripheral stimulus moving in one of four different directions – appears to have worked satisfactorily. There were very few erroneous responses, irrespective of the driving task demands, display position, or direction of motion of the stimulus. The response times were also, generally, quite short. Hence, it appears that in-car information presented by peripheral moving stimuli can be acquired in a satisfactory way.

Secondly, satisfactory information acquisition does not appear to require the driver to fixate the peripheral stimulus – information acquisition seems to work just as well when the driver relies only on peripheral vision for acquiring the presented information.

Thirdly, the direction of motion of the peripheral stimulus seems to have no relevance with respect to information acquisition. Each direction works just as well as any other.

Fourthly, the differences in response times between display positions may be of some importance for recommendations on where in the car the information should be presented. In the absence of data on driving behaviour or performance, it seems wise to recommend positions where short response times in combination with a small number of fixations are found. It would appear positive from a safety point of view that the driver pays as much foveal attention as possible to the traffic situation ahead rather than to the in-car information system. The lower display position, i.e. at the top of the dashboard, may therefore appear to be a good recommendation for positioning the display presenting the peripheral moving stimulus. Another fact also speaks in favour of the lower position as being the most favourable one; in comparison with the right position (which also gave short response times) it does not interfere in any way with the requirement on unrestricted vision through the windshield.

It may be concluded that information presented peripherally in the field of vision by moving stimuli can be acquired in a satisfactory way without fixation of the stimuli. An information system using this method of presenting information appears promising. The method of presenting information used in the present study – peripherally with a moving stimulus – could thus be seen as an alternative way of providing in-car information to the driver when designing a route guidance system, for example.

It may be discussed whether the results of the present study can be generalised to real car driving. The few validation studies that have been performed with the VTI driving simulator, summarised by Törnros, Harms & Alm (1997), show good correspondence between driving in the driving simulator and driving in a real car on a real road regarding effects of different independent variables on basic driving behaviour, such as driving speed and lateral position. Even so, it should be mentioned that one factor of importance, the ambient light conditions, were quite different from those often appearing in real car driving. The ambient light conditions were constant during the driving session, and could be characterised as those of dusk or dawn. In real driving, on the other hand, the ambient light conditions naturally vary from darkness to bright sunshine. In the latter situation, the driver will most probably experience problems of detecting and discriminating the presented information. These problems need to be addressed if systems of the type studied, relying exclusively on visual information, are expected to function well under widely different ambient light conditions.

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## Random orders

Subject	0 – 2,000 m		2,000 – 4,000 m		4,000 – 6,000 m		6,000 - 8,000 m	
1, 17	A	1	B	2	C	3	D	4
2, 18	B	2	C	3	D	4	A	1
3, 19	C	3	D	4	A	1	B	2
4, 20	D	4	A	1	B	2	C	3
5, 21	A	2	B	3	C	4	D	1
6, 22	B	3	C	4	D	1	A	2
7, 23	C	4	D	1	A	2	B	3
8, 24	D	1	A	2	B	3	C	4
9, 25	A	3	B	4	C	1	D	2
10, 26	B	4	C	1	D	2	A	3
11, 27	C	1	D	2	A	3	B	4
12, 28	D	2	A	3	B	4	C	1
13, 29	A	4	B	1	C	2	D	3
14, 30	B	1	C	2	D	3	A	4
15, 31	C	2	D	3	A	4	B	1
16, 32	D	3	A	4	B	1	C	2

Subjects 1 – 16: men

Subjects 17 – 32: women

A – D: Road stretches of 20 km each

A, B: No other traffic, good visibility

C, D: Other traffic, reduced visibility

1 – 4: Random orders for combinations of display position and direction of motion of the stimulus according to Appendix 2



## **Random orders for combinations of display position and direction of motion of stimulus**

1\*: D1<sup>L</sup> D3<sup>U</sup> D2<sup>R</sup> D1<sup>R</sup> D4<sup>D</sup> D3<sup>L</sup> D4<sup>R</sup> D2<sup>L</sup> D1<sup>U</sup> D2<sup>D</sup> D3<sup>D</sup> D4<sup>U</sup> D3<sup>R</sup> D1<sup>D</sup>  
D2<sup>U</sup> D4<sup>L</sup>

2\*: D3<sup>U</sup> D1<sup>D</sup> D4<sup>R</sup> D3<sup>L</sup> D4<sup>U</sup> D2<sup>L</sup> D1<sup>L</sup> D2<sup>R</sup> D2<sup>U</sup> D4<sup>D</sup> D3<sup>R</sup> D1<sup>U</sup> D2<sup>D</sup> D4<sup>L</sup>  
D1<sup>R</sup> D3<sup>D</sup>

3\*: D4<sup>U</sup> D3<sup>R</sup> D1<sup>L</sup> D2<sup>D</sup> D1<sup>R</sup> D2<sup>L</sup> D3<sup>U</sup> D4<sup>D</sup> D3<sup>L</sup> D1<sup>U</sup> D2<sup>R</sup> D4<sup>R</sup> D1<sup>D</sup> D3<sup>D</sup>  
D2<sup>U</sup> D4<sup>L</sup>

4\*: D4<sup>R</sup> D2<sup>U</sup> D1<sup>U</sup> D2<sup>L</sup> D3<sup>R</sup> D4<sup>L</sup> D3<sup>D</sup> D1<sup>R</sup> D2<sup>D</sup> D4<sup>D</sup> D1<sup>D</sup> D3<sup>U</sup> D2<sup>R</sup> D1<sup>L</sup>  
D4<sup>U</sup> D3<sup>L</sup>

D1 = upper display

D2 = left display

D3 = right display

D4 = lower display

L = running light to the left

R = running light to the right

U = running light upwards

D = running light downwards

The way in which D1 – D4 (display positions) and L – D (direction of motion of stimulus) are included in the major random orders is shown in Appendix 1

- Refers to notations 1-4 in Appendix 1



## Average numbers and proportions of fixations of stimulus

Condition	Upper display	Left display	Right display	Lower display
Low demand, Stimulus motion upwards	34 (53.1%)	41 (64.1%)	37 (57.8%)	35 (54.7%)
Low demand, Stimulus motion downwards	34 (53.1%)	40 (62.5%)	42 (65.6%)	41 (64.1%)
Low demand, Stimulus motion to the left	41 (64.1%)	46 (71.9%)	36 (56.3%)	38 (59.4%)
Low demand, Stimulus motion to the right	38 (59.4%)	43 (67.2%)	42 (65.6%)	38 (59.4%)
High demand, Stimulus motion upwards	26 (40.6%)	32 (50.0%)	33 (51.6%)	28 (43.8%)
High demands, Stimulus motion downwards	20 (31.3%)	33 (51.6%)	35 (54.7%)	25 (39.1%)
High demand, Stimulus motion to the left	28 (43.8%)	36 (56.3%)	34 (53.1%)	27 (42.2%)
High demand, Stimulus motion to the right	29 (45.3%)	32 (50.0%)	36 (56.3%)	29 (45.3%)



## **Average numbers and proportions of correct identifications of direction of motion of stimulus**

<b>Condition</b>	<b>Upper display</b>	<b>Left display</b>	<b>Right display</b>	<b>Lower display</b>
Low demand, Stimulus motion upwards	61 (95.3%)	60 (93.8%)	63 (98.4%)	64 (100.0%)
Low demand, Stimulus motion downwards	64 (100.0%)	61 (95.3%)	63 (98.4%)	64 (100.0%)
Low demand, Stimulus motion to the left	64 (100.0%)	61 (95.3%)	62 (96.9%)	63 (98.4%)
Low demand, Stimulus motion to the right	64 (100.0%)	64 (100.0%)	63 (98.4%)	63 (98.4%)
High demand, Stimulus motion upwards	63 (98.4%)	64 (100.0%)	62 (96.9%)	61 (95.3%)
High demand, Stimulus motion downwards	63 (98.4%)	63 (98.4%)	64 (100.0%)	62 (96.9%)
High demand, Stimulus motion to the left	62 (96.9%)	64 (100.0%)	64 (100.0%)	64 (100.0%)
High demand, Stimulus motion to the right	64 (100.0%)	63 (98.4%)	62 (96.9%)	64 (100.0%)



## Incorrect identifications of direction of motion of stimulus

Condition	Response			
	Upper display	Left display	Right display	Lower display
Low demand, Stimulus motion upwards	To the left To the left Downwards	To the right To the right To the left No response	Downwards	-
Low demand, Stimulus motion downwards	-	Upwards To the left To the right	To the right	-
Low demand, Stimulus motion to the left	-	Downwards Downwards To the right	Upwards Downwards	Downwards
Low demand, Stimulus motion to the right	-	-	-	-
High demand, Stimulus motion upwards	No response	-	To the right To the right	To the left To the left To the right
High demand, Stimulus motion downwards	Upwards	Upwards	-	To the right
High demand, Stimulus motion to the left	Upwards No response	-	-	-
High demand, Stimulus motion to the right	-	To the left	To the left	-



## **Average response time (in seconds) for correct identification of direction of motion of stimulus**

<b>Condition</b>	<b>Upper display</b>	<b>Left display</b>	<b>Right display</b>	<b>Lower display</b>
Low demand, Stimulus motion upwards	1.19	1.23	1.08	1.10
Low demand, Stimulus motion downwards	1.17	1.18	1.10	1.10
Low demand, Stimulus motion to the left	1.21	1.18	1.01	1.08
Low demand, Stimulus motion to the right	1.28	1.15	1.11	1.00
High demand, Stimulus motion upwards	1.13	1.23	1.10	1.09
High demand, Stimulus motion downwards	1.11	1.30	1.07	1.09
High demand, Stimulus motion to the left	1.23	1.15	1.04	1.00
High demand, Stimulus motion to the right	1.21	1.18	1.04	1.15

