The Spanish Journal of Psychology
2011, Vol. 14, No. 2, 556-568
http://dx.doi.org/10.5209/rev_SJOP.2011.v14.n2.4

Copyright 2011 by The Spanish Journal of Psychology
ISSN 1138-7416

Interference in Visual Perception by Verbal and Spatial Cognitive Activity

Elisa Pérez-Moreno, Ángela Conchillo, and Miguel Ángel Recarte

Universidad Complutense (Spain)

In two experiments we tested the hypothesis that cognitive processing based on spatial imagery produces more deterioration of visual perception than cognitive processing based on verbal codes. So, we studied the effect on visual perception of two cognitive tasks, one of spatial imagery and the other a verbal task. In the first one, with 30 participants, we analyzed the mental load and ocular behaviors in both cognitive tasks. In the second experiment, with 29 participants, we studied the effect of both tasks on a visual search task, using a dual-task experimental paradigm. The verbal task presented higher mental load than the imagery task when both tasks were carried out with visual search task, and there was more deterioration in stimulus detection with the verbal task. We can conclude that: (1) cognitive tasks produce important deterioration in the capacities of visual search and identification of stimuli; (2) this deterioration has two components: (a) an inefficient search, associated with alterations of the gaze patterns while performing cognitive tasks, and (b) a general interference, nonspecific to spatial codes, in the process of identification of looked-at stimuli; (3) this cognitive interference is related to the mental load or effort required by the cognitive task.
Keywords: visual search, mental load, perceptual interference, inattentional blindness.

Mediante dos experimentos hemos puesto a prueba la hipótesis de que el procesamiento cognitivo basado en imaginería espacial produce más deterioro en la percepción visual que el procesamiento basado en códigos verbales. Hemos estudiado el efecto de dos tareas cognitivas, una de imaginería espacial y otra verbal, sobre la percepción visual. En el primer experimento, con 30 participantes, analizamos la carga mental y el comportamiento ocular en ambas tareas cognitivas. En el segundo experimento, con 29 participantes, estudiamos el efecto de ambas tareas sobre una tarea de búsqueda visual, usando el paradigma experimental de doble tarea. La tarea verbal presentó mayor carga mental que la de imaginería espacial cuando ambas tareas se realizaron junto con la tarea de búsqueda visual y hubo un mayor deterioro en la detección de estímulos con la tarea verbal. Concluimos que (1) las tareas cognitivas producen un importante deterioro en capacidades de búsqueda visual e identificación de estímulos visuales; (2) este deterioro tiene dos componentes: (a) búsqueda ineficiente, asociada con alteraciones del patrón de mirada mientras se desarrollan tareas cognitivas, y (b) interferencia general, no específica de códigos espaciales, en el proceso de identificación de estímulos mirados; (3) esta interferencia cognitiva está relacionada con la carga mental o esfuerzo requerido por tareas cognitivas.
Palabras clave: búsqueda visual, carga mental, interferencia perceptiva, ceguera atencional.

This study is part of a project funded by the Spanish Ministerio de Educación y Ciencia, reference number SEJ2007-63495.

Correspondence concerning this article should be addressed to Elisa Pérez Moreno. Dpto. Metodología de las Ciencias del Comportamiento. Facultad de Psicología. Universidad Complutense de Madrid. Campus de Somosaguas. 28223 Pozuelo de Alarcón – Madrid (Spain). Phone: +34-913943061. E-mail: elisaperez@psi.ucm.es

https://doi.org/10.5209/rev_SJOP.2011.v14.n2.4 Published online by Cambridge University Press

The study of the relations between attention and visual perception has been addressed by Von Helmholtz (1924), who concluded that perception without attention does not take place, or else it is deficient. The current approach to this phenomenon prefers the label inattentional blindness. Mack and Rock (1998) found that 25% of participants failed to detect an unexpected stimulus while they carried out another visual perception task. Goldstein (2002) defines inattentional blindness as "a situation in which an unattended stimulus is not perceived, even when the person is looking directly at it." Simons and Chabris (1999) or Most, Scholl, Clifford, and Simons (2005) indicate that a large part of this phenomenon depends on whether or not the target stimulus coincides with expectations (attentional set), that is, the number of targets detected depends on whether or not they are expected. However, one wonders why surprise is considered a key factor in these studies, because the percentage of detected targets is similar in dual-task studies even when the target stimulus is expected and the participants deliberately try to detect it (Recarte & Nunes, 2003; Recarte, Pérez, Conchillo, & Nunes, 2008). However, deterioration of visual detection when it is simultaneous with another visual task leaves open the question of whether the phenomenon is purely attentional or whether it is to some degree produced because both stimuli (experimental target and surprise target) share the same visual processing modality, although Pappas, Fishel, Moss, Hicks, and Leech (2005) did not find detection of unexpected stimuli to be associated with ocular movements. Summing up, complementarily to the paradigms used in this field, which include the surprise of the stimulus to be detected and visual processing in the main task, one wonders what happens when an expected stimulus is presented and, likewise, what happens when the main task the subject is performing is cognitive but not visual.

The first issue—surprise versus selective attention—was investigated by Lavie (1995) within the framework of the perceptual load of attention theory. If the main task requires a high perceptive load, visual distractors, even if expected, will not be perceived; that is, with high perceptive load, inattentional blindness will increase (Beck & Lavie, 2005; Cartwright-Finch & Lavie, 2007; Lavie, 2006); experiments with neuroimaging (Rees, Frith, & Lavie, 1997) support this theory. Investigations of the second issue—how nonvisual cognitive tasks affect stimulus perception—yield contradictory results: according to Lavie (2005), whereas high perceptual load will eliminate processing of the distractor, high load in cognitive control processes will increase it (De Fockert, Rees, Frith, & Lavie, 2001; Lavie & De Fockert, 2005; Lavie, Hirst, De Fockert, & Viding, 2004; Macdonald & Lavie, 2008). According to Woodman, Vogel, & Luck (2001), the visual working memory load would only add a delay constant to a visual search task. However, other authors have found that an increase in the mental load of cognitive tasks reduces the probability of detecting the distractor (Han & Kim, 2004; Oh & Kim, 2004; Todd, Fougnie, & Marois, 2005; Woodman & Luck, 2004). According to the results of Fougnie & Marois (2007), both in conditions of inattention (the stimulus was unexpected) and of selective attention (the stimulus was expected), the verbal working memory induces blindness, and the effect is more pronounced when the verbal material is not only retained but also manipulated.

Recarte, et al. (2008) found that deterioration in visual perception is also produced by cognitive activity that does not require gaze or centers associated with visual processing. It would therefore seem that it is a nonspecific attentional interference. But in his taxonomy of attentional resources, Wickens (1984, 1992) maintains that, at the central processing level, the use of verbal and spatial codes triggers two different sets of attentional resources. On the other hand, Recarte and Nunes (2000) found different ocular behaviors when a driver performed a verbal task than when the task was spatial, and these different visual behaviors may explain diverse performances in a visual search task. Irwin and Brockmole (2000) found that, during saccadic eye movements, mental rotation tasks are suppressed. However, it is well documented that the processing of spatial codes such as mental images uses to a great extent the same centers as visual perception (Farah, 1985; Kosslyn, 1988; Posner & Raichle, 1994). Therefore, although the cognitive task concurrent with the visual search task is not strictly visual, it may have imagery components, and the interference produced by the cognitive load on visual processing may not be nonspecific interference, or interference with undifferentiated attentional resources, but instead specific interference, because both tasks—cognitive and visual search—partially use the same spatial processing modules. Summing up, in these dual-task situations, deterioration of visual search and stimulus identification performance can be expected to be more pronounced if the cognitive task is a spatial imagery task than if it is a verbal task, and there are two reasons for this: (a) the spatial task alters the ocular behaviors of visual search, and (b) the processing of visually perceived stimuli shares brain modules with the stimuli that are imagined during the spatial task.

The present study attempts to clarify the controversy surrounding the effect of mental load on visual search task. A visual search task involves two processes: 1) a visual search itself, where ocular movements play an important role and 2) stimulus identification process, when the stimulus is looked at. An advantage over previous research is that using an eye tracker system it is possible to know which targets are looked at and which of these looked at targets are identified while performing cognitive tasks. In other words, the use of this methodology allows to clarify if the effect of mental load is due to ocular pattern change or to differences in stimulus identification, even if that stimulus is being looked at (this would be a true inattentional blindness phenomenon). Furthermore, in the next two experiments, the issue of verbal and spatial codes and their effect on visual

https://doi.org/10.5209/rev_SJOP.2011.v14.n2.4 Published online by Cambridge University Press

search and stimulus identification is addressed. In the first one, two tasks that use both of these codes are assessed, and we expect to find that these two types of tasks produce different visual behaviors. Specifically, as Recarte and Nunes (2000) found in the context of driving vehicles, we attempt to verify whether a verbal task and a spatial imagery task, having the same mental load, differ in the duration of ocular fixations, saccadic amplitude, and gaze concentration. The confirmation of any one of these differences would allow us to state that these two types of tasks are qualitatively different regarding visual behavior. Secondly, we attempt to determine whether ocular fixation duration, saccadic amplitude, and gaze concentration, when carrying out verbal and spatial imagery tasks in the laboratory, are similar to those produced when driving a car. As driving is an activity that strongly relies on gaze, it may interact with the spatial imagery tasks and not with the verbal tasks, that is, the differences found between verbal and spatial imagery tasks may be specific to a driving context. The former verification is the basis for the second experiment, in which we attempt to determine whether these imagery and verbal tasks produce an equivalent deterioration in visual search and stimulus identification, in which case, we would have to conclude that there is a nonspecific attentional interference. But if the imagery task produces more deterioration than the verbal task, we would have to determine whether the interference is due to visual search mechanics, that is, to differences in ocular behavior, or whether it should be attributed to the use of shared specific central resources, those involved in visuo-spatial processing or identification.

In order to confirm qualitative differences of gaze in the verbal and imagery tasks, the tasks must be equal in mental load so any explanation based on load differences can be ruled out. Therefore, we shall use four measures—pupil dilation, subjective rating, blink rate and error rate of cognitive task—to assess the mental load of the verbal and imagery tasks. Pupil dilation has been considered a reliable measure of mental workload (Beatty, 1982; Hoeks & Levelt, 1993; Janisse, 1977; Kahneman, 1973). But, in addition to pupil response to mental workload, pupil dilation can be biased due to light conditions, emotional responses, or orienting reflex (Näätänen, 1992). Recarte, et al. (2008) showed that the pupil dilation is a good indicator of mental load and, in single tasks, they showed its correspondence with subjective rating of mental load and with blink rate. De Waard (1996) proposes blink rate as a mental workload measure, but also, an increase in blink rate has been considered a consistent indicator of fatigue (Stern, Boyer, & Schroeder, 1994). Recarte and Nunes (2002) found a blink rate increase attributable to the time spent driving, but they also found an even more marked increase due to the performance of cognitive tasks during the drive. Ryu and Myung (2005) concluded that the use of blink rate have to be combined with others mental workload measures. With regard to subjective ratings, some authors consider that subjective report is the best way to evaluate mental workload (De Waard, 1996). In fact, subjective ratings have been used to validate physiological measures (Iqbal, Zheng, & Bailey, 2004). Finally, a measure of each cognitive task performance (error rate) will be used to make sure both tasks have an equal level of mental workload.

Experiment 1

The goal of this experiment is to analyze visual behavior—ocular fixation duration, saccadic amplitude, and variability of spatial position gaze —when participants process verbal or spatial imagery information. Visual information is acquired during fixation, when visual processing can be performed with high acuity by the fovea. No visual information is acquired during a saccade (Leigh & Zee, 1999). The saccadic amplitude is the distance between fixations in visual angle degrees. Variability of spatial position gaze is the standard deviation between fixation positions (in pixels). Taken together, these temporal and spatial parameters (ocular fixation duration, saccadic amplitude and variability of spatial position gaze) provide a sensitive measure of processing of visual information and were thus used in the analysis. These measures have also been used by others in the analysis of visual scanning while driving. Recarte and Nunes (2000) found a higher gaze concentration, that is, a lower spatial position variability, when subjects performed a spatial task, but this could be due to a strategy of this driving situation, which involved real risk when the subject was performing another verbal or spatial task simultaneously with the driving task. Therefore, the repetition of these results in the laboratory would indicate that ocular behavior differences between the verbal and spatial imagery tasks, if present, would not be due to a specific driving strategy. We assume that, when processing spatial images, the centers involved in planning saccadic movements are occupied planning virtual movements of the images, thereby preventing physical eye movements, which would lead to longer fixations and their higher concentration or to shorter saccadic amplitude. Thus, we expect that the spatial imagery task will lead to: (1) longer fixations than the verbal task; (2) higher gaze concentration, that is a lower spatial position variability, and (3) shorter saccadic amplitude. We also expect that the mental load will be similar in both tasks.

Method

Participants

The participants of the experiment were 30 people of both sexes (21 women and 9 men), ages between 19 and 28 years, all students of the Psychology Faculty of the Universidad Complutense of Madrid.

https://doi.org/10.5209/rev_SJOP.2011.v14.n2.4 Published online by Cambridge University Press

Design

There were two experimental conditions and one control condition. In the control condition, the subjects only looked at a screen on which appeared letters in rapid sequence, without having to perform any task. In the experimental conditions, the subjects carried out a cognitive task (verbal or spatial imagery) while they looked at the same screen. Thus, the screen acted as a baseline, establishing homogeneous conditions to assess fixation duration and concentration, as well as pupil dilation. The verbal task, called *linked words*, consisted of the production of words with the constraint that each word had to start with the last syllable of the previous word. The spatial imagery task, called *nine rooms*, consisted of performing a mental trajectory on a plan that represented nine interconnected rooms and that had previously been shown to the subject, who had to verbalize the trajectory with up, down, left and right. Thus, the tasks were equivalent insofar as both of them required discrete verbal outputs, but the first task maximized lexical search (verbal) and the second task maximized image representation. The design was within-subject, counterbalancing the three conditions—control, verbal, and spatial.

The dependent variables were the measures of mental load (pupil size, subjective rating of effort, blink rate, and error rate of cognitive task) and the ocular measures (fixation duration, fixation spatial position variability, and saccadic amplitude).

Material and Procedure

The experiment was carried out in a Faraday cabin of the laboratories of the Faculty of Psychology of the Universidad Complutense of Madrid. The following materials were used: Ocular Recording System at 50 Hz/s (Eye Tracking System, Model 5000. Control Unit, A. S. L.), a computer with specific software to control the experiment, and a 146 x 110 cm screen.

The visual background observed by the participants during the experiment was the projection of 16 (1º x 1º visual angle, with a separation of 3º between them) uppercase black letters (0, 0, 0 RGB) on a grey background (176, 176, 176 RGB). Each letter remained on the screen for 2 seconds and was then substituted by another letter, with a change rate of 125 ms. The letters and the place where they appeared on the screen were randomized. The luminance of the screen was maintained constant at 110 lux.

The participants were seated centered at a distance of 230 cm from the screen, so that the screen subtended a horizontal visual angle of 35.23º and a vertical visual angle of 26.90º. In front of the subjects, on a table at a distance of 94 cm, was a camera, which recorded the ocular movements without interfering with the subject's gaze line to the screen. The head position was maintained stable by the shape of an anatomical chair.

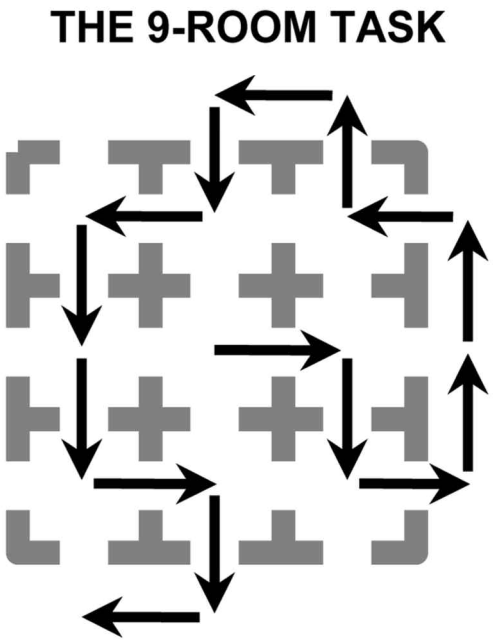


Figure 1. The plan of a house that the subjects had to memorize in the imagery task and an example of possible mental movements they could carry out.

The experiment began with a training session of two cognitive tasks: in the verbal task, participants orally produced the series of linked words, without repeating words, and if at any time they did not know how to continue, they could change the preceding word and then continue to produce words. In the spatial imagery task, they were shown a plan (Figure 1) that had nine interconnected cells (rooms). Participants memorized this figure and mentally moved through the cells, saying out loud the movement—left, right, up and down—that they were performing. Training time was variable, as much as each subject needed. After the training session, participant's right eye was calibrated, instructions were given, and immediately afterwards, the letters were projected onto the screen, thus beginning the experimental conditions. Each condition lasted one minute (3000 data lines per person and condition for mental load and ocular measures). After the performance of each task, participants had to rate on a 1-to-10 scale the effort required for their performance.

Results

For each of the dependent variables used (pupil size, judgment of effort, blink rate, error rate of cognitive task, fixation duration, horizontal and vertical gaze variability, and saccadic amplitude) a repeated measures ANOVA was performed with SPSS version 15, indicating effect size and power. In each case, we also carried out a Helmert contrast, comparing the control condition (no task) with the two experimental conditions (verbal and imagery task) conjointly. We also carried out all

https://doi.org/10.5209/rev_SJOP.2011.v14.n2.4 Published online by Cambridge University Press

the binary comparisons with the Bonferroni adjustment. A table with the mean and mean standard error is presented for each dependant variable (see Table 1).

Measures of mental load: pupil size, subjective judgment of effort, blink rate and error rate of cognitive task.

Pupil size: The repeated measures ANOVA indicated a strong influence of task on pupil size, $F(2,58) = 43.15$, $p < .0001$ ($\eta^2 = .598$, *power* = 1). The Helmert contrast showed that this effect was significant only between performing and not performing the task, $F(1,29) = 89.43$, $p < .0001$. Moreover, in the pairwise comparisons, there were significant differences between the control task (no task) and each one of the cognitive tasks ($p < .0001$), but there was no difference between the verbal and the spatial imagery task.

Subjective judgments: The ANOVA indicated a statistically significant effect of task on the subjective judgments of mental load, $F(2,50) = 198.14$, $p < .0001$ ($\eta^2 = .888$, *power* = 1). This effect was totally due to the difference between performing and not performing the task, $F(1,29) = 368.60$, $p < .0001$, an effect that was also observed when comparing the control condition (no task) with each one of the tasks separately. But when comparing the two tasks, the difference between the verbal and the spatial imagery task was nonsignificant.

Blink rate: There was a statistically significant effect of task on blink rate, $F(2,62) = 13.147$, $p < .0001$ ($\eta^2 = .298$, *power* = .997). The significant differences were between performing the task and the control condition (no task), $F(1,29) = 13.65$, $p = .001$, between the control condition and the verbal task, $p = .001$, and between the verbal task and the spatial imagery task, $p = .004$, but there were no differences between the control task and the spatial imagery task.

Table 1
Mean and standard error for the variables pupil size, subjective judgments, blink rate, error rate, fixation duration, horizontal and vertical variation and saccadic amplitude by tasks during experiment 1. Significance data, effect size and power for main analysis are also included

Variable		M	SE	s	η^2	1-β
Pupil				<.001**	.598	1
	No task	22.86	0.42			
	Verbal	26.46	0.56			
	Imagery	26.41	0.66			
Judgments				<.001**	.888	1
	No task	0.46	0.16			
	Verbal	6.35	0.32			
	Imagery	5.73	0.27			
Blink rate				<.001**	.298	.997
	No task	17.47	2.16			
	Verbal	32.06	3.53			
	Imagery	23.44	2.49			
Error rate				.147		
	Verbal	0.8	.14			
	Imagery	0.56	.12			
Duration				<.001**	.229	1
	No task	273	14			
	Verbal	223	10			
	Imagery	300	18			
Var. X				<.001**	.318	.997
	No task	41.03	1.85			
	Verbal	33.87	2.81			
	Imagery	25.13	2.43			
Var. Y				.77		
	No task	34.43	3.41			
	Verbal	28.27	2.34			
	Imagery	24.90	3.39			
Amplitude				<.001**	.408	1
	No task	4.70	0.18			
	Verbal	3.70	0.22			
	Imagery	2.81	0.28			

https://doi.org/10.5209/rev_SJOP.2011.v14.n2.4 Published online by Cambridge University Press

Error rate of cognitive task: There was not a significant effect of task on error rate (number of errors per minute) of cognitive task, $F(1,29) = 2.22$, $p = .147$, supporting the results of previous variables and indicating that there were no differences between the performance of verbal and spatial imagery task assessed as number of errors.

Measures of ocular movements: fixation duration, fixation concentration (horizontal and vertical variability), and saccadic amplitude.

Fixation duration: There was a general effect of task on ocular fixation duration, $F(2,58) = 8.60$, $p < .001$ ($\eta^2 = .229$, *power* =1). The significant difference was between the verbal and the spatial imagery task, $F(1,29) = 20.47$, $p < .001$, and also between the control task and the verbal task, $p = 0.01$, but not between the control task and the spatial imagery task. As shown in Table 1, while carrying out a spatial imagery task, the fixations are almost 80 ms longer than while carrying out a verbal task.

Fixation concentration: it was measured using the horizontal variability and the vertical variability of the fixations. Significant differences were observed on the horizontal axis between the conditions, $F(2,58) = 13.51$. $p < .001$ ($\eta^2 = .318$, *power* = .997). These differences occurred between performing and not performing the cognitive task, $F(1,29) = 19.77$, $p < .001$, between the verbal and the spatial imagery task, $F(1,29) = 7.78$, $p = .009$, and between the control condition (no task) and the spatial imagery task , $p < .001$, but not between the control condition and the verbal task. Gaze mobility on the vertical axis followed the same pattern as for the horizontal axis, as seen in Table 1. Nevertheless, neither the ANOVA nor the Helmert nor Bonferroni contrasts yielded any statistically significant difference.

Saccadic amplitude: we calculated in degrees the distance that separates the mean points of two consecutive fixations, that is, the saccadic amplitude from one fixation to the next. Results showed shorter saccades with than without cognitive task and also shorter saccades with spatial imagery task than with verbal task. The ANOVA showed a statistically significant effect for task on saccadic amplitude, $F(2,58) = 20.00$, $p < .0001$ ($\eta^2 = .408$, *power* = 1). The differences were produced between performing and not performing the task, $F(1,29) = 23.42$, $p < .0001$, and between all possible comparisons: verbal task with spatial imagery task, $p = .001$; control with verbal task, $p < .005$; control with spatial imagery task, $p < .0001$.

Discussion of Experiment 1

With regard to the measures of mental load, pupil size and subjective rating indicate that there are no differences between the verbal task and the spatial imagery task, and that both tasks involve more mental load than the control condition, in which the subject only watched the screen without performing any task. The engagement of both types of cognitive task was the same, as it is shown in the result of number of errors in cognitive task. Both tasks are correctly done, with the same level of error rate. A particular case is the blink rate, which, according to Recarte, et al. (2008), has a differentiated behavior depending on whether or not the mental load has a visual component; blink rate decreases (inhibition) when the task demands visual resources, whereas it increases (disinhibition) when the task demands nonvisual cognitive resources. These results corroborate the previous ones, revealing significant differences between the verbal task and the spatial imagery task in the foreseen direction: more blinks in the verbal task, which requires fewer visual resources. The difference found between the verbal task and no task, where the subject just watched the screen, would be interpreted in the same way.

With regard to the measures of ocular movements, the results indicate that the two tasks used, verbal and spatial imagery, reveal qualitative differences in the ocular behaviors. The differences found are observed in two aspects: a) the use of spatial image codes produces longer fixations than the use of verbal codes. These results agree with those of Recarte & Nunes (2000), obtained with other tasks and in driving conditions, although the differences between the control task and the spatial imagery task are not replicated; (b) while cognitive tasks are carried out, gaze mobility is reduced and this reduction is more pronounced in a spatial imagery task than in a verbal task. This decrease is seen in two aspects: the lower variability of the horizontal position of the fixations and the shorter saccadic amplitude. Irwin and Brockmole (2000) found that the longer the saccadic amplitude, the greater the interference with performance of a spatial task. Our results support the interference between spatial task and ocular movements, in general, but now, the performance of a spatial imagery task decreased the saccadic amplitude, which could be explained by the different instructions in both studies. Moreover, in our case, the ocular differences found between verbal task and spatial imagery task cannot be attributed to differences in mental load, because the pupil size, the judgments of effort and error rate indicate that both tasks are equal in mental load.

Experiment 2

The differences in ocular movements between verbal tasks and spatial imagery tasks found in Experiment 1 led to the second experiment, in order to determine whether tasks that use spatial imagery codes produce more deterioration than verbal tasks in the search and identification of stimuli. If this deterioration exists, our hypothesis is that it could be due to: (1) the differences described in ocular behavior; (2) spatial imagery tasks use brain areas that are common to visual processing; (3) both explanations. But if deterioration in the search and identification produced by both tasks—verbal and spatial imagery —were the same, then we should conclude that, despite the obvious differences in visual behaviors between both tasks, the deterioration

https://doi.org/10.5209/rev_SJOP.2011.v14.n2.4 Published online by Cambridge University Press

observed is due to a general interference, nonspecific to the task. Note than in macro-tasks like those used in Experiment 1, there are no pure processes, because some people can generate images from the written word, and the spatial imagery task has some verbal components at the level of response emission. Therefore, we can only refer to the predominance of one or the other code. Within this limitation, the purpose of Experiment 2 is to determine whether the processing of spatial codes, which in Experiment 1 produced gazes with different characteristics than the processing of verbal codes, also produces different results in a visual search task. In more general terms, the purpose is to determine whether the mental load of spatial images produces more perceptual deterioration than the mental load of verbal content. Our ocular movement recording system allows us to separate the visual search itself (the stimuli at which the gaze is aimed) from the stimulus identification (verification of whether or not a stimuli that is looked at is the proposed target). With regard to our hypothesis, we can establish that: (1) if interference of the spatial imagery task is produced because it alters the ocular behaviors (shorter saccadic amplitudes, more time spent gazing at the same place, lower gaze dispersion), then fewer stimuli will be looked at when performing the spatial imagery task than when performing the verbal task; but once a stimuli is looked at, its recognition as a target should be similar in both tasks. (2) In contrast, if its recognition is worse in the spatial imagery task (lower proportion of detected targets among those looked at), we could conclude in favor of Wickens' theory, in the sense that there is a specific interference due to the fact that the visual search task and the spatial imagery task are using, partially, common brain areas, that is, the same attentional resources. (3) If the deterioration is produced by both aspects—alteration of ocular behaviors and shared use of brain areas—then there should be fewer targets looked at and also fewer targets detected (among those looked at) when performing the spatial imagery task than when performing the verbal task.

Method

Participants

Participants in the second experiment were 29 people of both sexes (22 women and 7 men), ages between 19 and 33 years, students of the Psychology Faculty of the Universidad Complutense of Madrid.

Design

The independent variables in Experiment 2 were the same as in Experiment 1: performance of a cognitive task with three levels (no cognitive task or control, verbal task and spatial imagery task). The cognitive tasks were also the same as in Experiment 1: linked words and the nine rooms. But now the tasks were performed simultaneously to a continuous visual search task. Thus, the three experimental conditions were: visual search task (VS), VS + verbal task, and VS + imagery task. The first will be referred to as a single task and the other two as dual tasks. All the subjects performed all three conditions, the order of which was counterbalanced. The dependent variables were those of Experiment 1: measures of mental load (pupil dilation, subjective rating of effort, blink rate, and error rate of cognitive task); measures of ocular behavior (duration and variability of fixations and saccadic amplitude). In addition, we analyzed the visual search task (detected target stimuli, target stimuli looked at, and target stimuli detected among those looked at) and we compared performance in the cognitive tasks (verbal and spatial imagery) in both experiments, as proportion of responses per minute.

Materials and procedure

The materials used, as well as the experimental environment, were the same as in Experiment 1, with some differences: we maintained the dynamic nature of the display of stimuli but we replaced the letters with a more homogeneous set of stimuli: six uniform figures that only differed in the position or degree of rotation (Figure 2). Only one of the six orientations was the target, which corresponded to the square in the horizontal position. The distractors were the same figure rotated 15º, 30º, and 45º to the left or right, resulting in a total of five distractors. In each of the conditions, subjects had to detect the target from among 16 stimuli on the screen (15 distractors plus the target, or 16 distractors without the target).

The subjects responded to the visual search task by pressing the Enter key on a keyboard. Each stimulus (target and distractors) remained on the screen for two seconds,

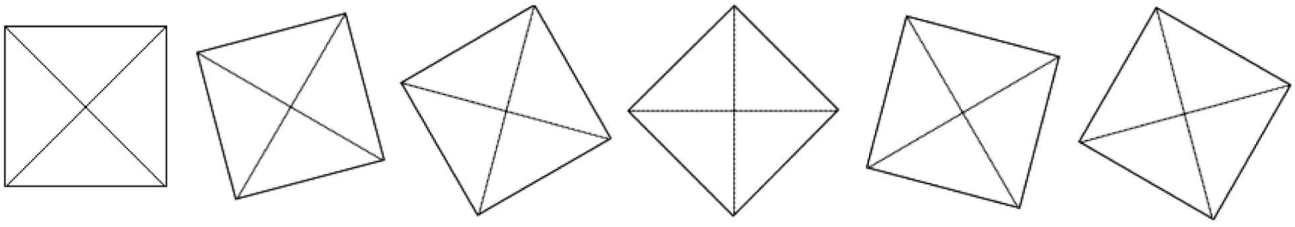


Figure 2. Stimuli used during the continuous search and detection task. The first stimulus (horizontal position) corresponds to the target.

https://doi.org/10.5209/rev_SJOP.2011.v14.n2.4 Published online by Cambridge University Press

and there was a stimulus change every 125 ms. There were twelve targets for each experimental condition, with spatial and temporal uncertainty. The temporal and spatial position of the distractors on the screen was randomized (each stimulus could appear in 100 different positions), and that of the targets was pseudo-randomized, because we restricted it to specific areas in order to control the number of times it appeared in the center, in the periphery, and in an intermediate area. Temporally, the separation between target stimuli was between 3 and 7 seconds, thus guaranteeing that the responses to any of them would not be confused with responses to the preceding or the following stimulus. Each stimulus had a visual angle of 1.57º x 1.57º at the center of the screen. If the stimulus appeared in the periphery, this number decreased by 0.07º. The color of the stimuli and the background were the same as in Experiment 1. Each experiment began with a training stage and right-eye calibration, followed by the instructions and the experimental trials. Each condition lasted 2 minutes and 3 seconds (no targets appeared in the first three seconds), that implied 6150 data lines per person and condition for mental load and ocular measures. At the end of each experimental condition, the subject valued, from 1 to 10, how much effort had been needed to perform the task.

Results

For each of the dependent variables, a repeated measures ANOVA (SPSS, version 15), a Helmert contrast, and pairwise comparisons with Bonferroni adjustment were carried out. The effect size and power are also reported. The mean and standard error of the mean are presented in Table 2 and 3.

Measures of mental load: pupil size, subjective judgment, blink rate, and error rate of cognitive task (see Table 2).

Pupil size: the repeated measures ANOVA indicated statistically significant differences, $F(2,56) = 37.13$, $p < .0001$ ($\eta^2 = .57$, *power* = 1). The significant difference was between single task (only visual search task) and dual tasks (VS + verbal or VS + imagery task), according to the Helmert contrast, $F(1,28) = 47.31$, $p < .0001$; the pairwise comparison with Bonferroni adjustment indicated that the differences between all the pairs were significant ($p < .01$).

Subjective judgment: the judgment of effort produced very similar results to those of pupil diameter, once again confirming the equivalence of both measures. The ANOVA yielded significant differences among the conditions, $F(2,56) = 16.19$, $p < .0001$ ($\eta^2 = .373$, *power* = 1); the differences occurred between single task and dual tasks, $F(1,28) = 36.55$, $p < .0001$, between visual search task and VS + verbal task, $p < .0001$, and between visual search task and VS + imagery task, $p = .018$; but the difference between VS + verbal task and VS + imagery task did not reach significance.

Blink rate: the ANOVA indicated significant differences between the conditions, $F(2,56) = 35.68$, $p < .0001$ ($\eta^2 = .56$, power = 1). The differences occurred between single task and dual tasks, $F(1,28) = 64.85$, $p < .0001$ and in all the binary combinations, $p < .01$.

Error rate of cognitive task: There was a significant effect of task on error rate (number of errors per minute) of cognitive task, $F(1,28) = 4.89$, $p = .035$ ($\eta^2 = .149$, *power* = .57), supporting again the results of previous mental load variables and indicating that the dual task condition introduces a change: performing the verbal task simultaneously with a visual search task produces higher mental load than performing the spatial imagery task (with the same mental load in single task condition) with the same visual search task.

Measures of ocular movements: fixation duration, fixation concentration (horizontal and vertical variability), and saccadic amplitude (see Table 2).

Fixation duration: The fixation duration followed the same pattern of results as in Experiment 1, but no effect was statistically significant.

Horizontal variability of fixations: statistically significant differences were observed between the conditions, $F(2,52) = 11.64$, $p < .001$ ($\eta^2 = .152$, *power* = .8). These differences were between single task and dual tasks, $F(1,26) = 19.86$, $p < .001$ (fixation variability was higher only when performing visual search task), and between visual search task with each of the dual tasks, $p < .001$; but no differences were observed between VS + verbal task and VS + imagery task.

Vertical variability of fixations: Statistically significant differences were observed among the conditions, $F(2,52) = 12.08$, $p < .001$ ($\eta^2 = .299$, *power* = .993). These differences were between single task and dual tasks, $F(1,26) = 22.16$, $p < .001$, and between visual search task and each one of the dual tasks separately, $p < .01$; but there were no differences between VS + verbal task and VS + imagery task.

Saccadic amplitude: there were significant differences among the conditions, $F(2,56) = 24.015$, $p < .0001$ ($\eta^2 = .462$, *power* = 1), between single task and dual tasks, $F(1,28) = 25.14$, $p < .0001$, and between all the pairwise comparisons, $p < .01$.

Measures of visual search and stimulus identification: detected target stimuli, looked-at target stimuli, and detected target stimuli among those looked at (see Table 3).

Proportion of detected target stimuli: results show that fewer stimuli were detected in the dual task conditions (visual search task + cognitive task) than in the single task (only visual search task). This can be seen in the ANOVA, $F(2,56) = 34.34$, $p < .001$ ($\eta^2 = .551$, *power* = 1), and in the Helmert contrast, indicating that the difference between visual search task alone (single task) and VS + cognitive task (dual tasks) was significant. The pairwise comparisons indicated that the differences between single and each one of the dual tasks were significant, $p < .001$; but the difference between the two dual tasks was nonsignificant.

https://doi.org/10.5209/rev_SJOP.2011.v14.n2.4 Published online by Cambridge University Press

Table 2
Mean and standard error for the variables pupil size, subjective judgments, blink rate, error rate, fixation duration, horizontal and vertical variation and saccadic amplitude by tasks during experiment 2. Significance data, effect size and power for main analysis are also included

Variable		M	SE	s	η^2	1-β
Pupil				<.001**	.57	1
	VS	25.91	0.62			
	VS+Verbal	27.97	0.66			
	VS+Imagery	27.41	0.64			
Judgments				<.001**	.373	1
	VS	6.53	0.2			
	VS+Verbal	8.31	0.19			
	VS+Imagery	7.45	0.29			
Blink rate				<.001**	.56	1
	VS	14.21	2.05			
	VS+Verbal	45.72	4.55			
	VS+Imagery	34.79	3.36			
Error rate				.035*	.15	.57
	VS+Verbal	1.74	0.24			
	VS+Imagery	1.2	0.15			
Duration				.071		
	VS	184	6			
	VS+Verbal	178	7			
	VS+Imagery	190	7			
Var. X				<.001**	.152	.8
	VS	46.86	1.07			
	VS+Verbal	40.79	1.77			
	VS+Imagery	40.28	1.75			
Var. Y				<.001**	.299	.99
	VS	36.46	2.24			
	VS+Verbal	30.69	1.88			
	VS+Imagery	30.02	1.31			
Amplitude				<.001**	.462	1
	VS	6.29	0.43			
	VS+Verbal	5.28	0.25			
	VS+Imagery	4.28	0.23			

Note. VS refers to Visual Search Task.

Proportion of looked-at target stimuli: as there are two possibilities of deterioration of visual search task, one due to alteration of the ocular patterns of visual search and the other to overlapping of brain areas involved in the processing, it is interesting to know whether the target stimuli were looked at fewer times in the VS + cognitive task conditions than in the task of visual search alone.

The ANOVA indicated significant differences among the conditions, $F(2,56) = 6.79$, $p = .002$ ($\eta^2 = .195$, *power* = .9). There were differences between single task and dual tasks, $p < .001$, and between visual search task with each one of the dual tasks ($p = .006$ with VS + verbal task and $p < .001$ with VS + imagery task), but not between the two dual tasks. In Table 3, it can be observed that many more stimuli were looked at than the number of stimuli that were detected. That fewer stimuli were looked at with dual task may be due to the fact that fixation variability is lower with cognitive task, and the saccadic amplitude is also shorter; ultimately, a smaller area is explored per time unit while a cognitive task is performed than while only visual search task is performed. But if the proportion of stimuli detected among those looked at were lower with dual task, it could not be attributed to this cause, but to an impediment that occurs in the central processing stage (looking and not seeing). Therefore, it is interesting to know this datum: how many of the stimuli among those looked at are actually detected.

Proportion of detected target stimuli among those looked at: there were significant differences among the experimental conditions, $F(2,71) = 21.37$, $p < .001$ ($\eta^2 = .376$, *power* =

https://doi.org/10.5209/rev_SJOP.2011.v14.n2.4 Published online by Cambridge University Press

.999). The differences were between single task and dual tasks, $p < .001$, and in all the pairwise comparisons. Fewer target stimuli were detected in the dual tasks than in the visual search task alone, and comparing the dual tasks, more target stimuli were detected with the spatial imagery task than with the verbal task.

Comparison of measures of cognitive task performance between both experiments: as the cognitive tasks used in both experiments are the same, a (2 x 2) mixed ANOVA can be conducted— within-subject for the variable cognitive task (verbal and imagery) and between-subject for the variable number of tasks (single task and dual task). The dependent variable is the number of responses/ minute produced in each task. The mean and standard error for each condition are presented in Table 4.

The results showed differences between the two cognitive tasks, $F(1,52) = 367.21$, $p < .0001$ ($\eta^2 = .876$, *power* = 1), in the sense that, when performing the spatial imagery task, more responses per minute were produced than during the verbal task. There were also significant differences, $F(1,52) = 7.3$, $p = .009$ ($\eta^2 = .123$, *power* = .755) between single and dual task, in the sense that more responses were produced when performing the single task than during the dual task. The interaction was not statistically significant.

Discussion of Experiment 2

With regard to the measures of mental load, all four coincide in indicating that the performance of dual task involves an additional effort compared with the performance of visual search task alone. Three of the measures (pupil, blink and error rate) indicate that the spatial imagery task involves less effort than the verbal task when both tasks are carried out with visual search task, and the fourth measure (subjective judgments) points in the same direction, although it does not achieve the conventional level of significance. With regard to blink, the results again replicate those of Recarte, et al. (2008), that is, a decrease in blinks while carrying out a visual search task and an increase while performing a nonvisual cognitive task.

Regarding the ocular measures, neither fixation duration nor gaze concentration (horizontal and vertical gaze spatial position variability) shows any differences between the verbal task and the spatial imagery task when both are simultaneous with visual search task. Our interpretation is that searching for the target on the screen, with rapid presentation of stimuli, has forced fixations of short duration and lower concentration, attenuating the differences between verbal task and spatial imagery task that appeared in Experiment 1. Saccadic

Table 3

Mean and standard error for the variables proportion of detected target stimuli (PDS), proportion of looked-at target stimuli (PLS), proportion of detected target stimuli among those looked at (PDS/PLS) by tasks. Significance data, effect size and power for main analysis are also included

Variable		M	SE	s	η^2	1-β
PDS				<.001**	.551	1
	VS	.31	.02			
	VS+Verbal	.11	.02			
	VS+Imagery	.17	.02			
PLS				.002**	.195	.9
	VS	.75	.02			
	VS+Verbal	.64	.02			
	VS+Imagery	.59	.02			
PDS/PLS				<.001**	.376	.99
	VS	.41	.03			
	VS+Verbal	.17	.03			
	VS+Imagery	.29	.03			

Note. VS refers to Visual Search Task.

Table 4

Mean and standard error for the variable performance of cognitive task in proportion of responses per minute produced by tasks and number of tasks

		Mean	SE
Single task	Verbal task	17	0.97
	Imagery task	46	2
Dual task	Verbal task	13	0.97
	Imagery task	41	2

https://doi.org/10.5209/rev_SJOP.2011.v14.n2.4 Published online by Cambridge University Press

amplitude is the only measure that differentiates between verbal and spatial imagery task in the expected direction: spatial imagery task reduces the saccadic amplitude.

Even so, it is clear that, while cognitive tasks are carried out, visual search task deteriorates by more than 50%, and there are no differences between verbal and imagery task in this deterioration. Thus, in the first place, we can state that cognitive activity impairs visual perception, but our hypothesis about the differential effect of verbal and spatial code, with more deterioration in the spatial imagery task, was not confirmed.

One wonders whether the interference observed in visual perception is really cognitive, or is it due to the fact that, while carrying out cognitive tasks of any kind, ocular behaviors (fixation duration, less gaze mobility) are altered so that fewer target stimuli are detected simply because fewer target stimuli are looked at. Therefore, our analysis of the looked-at targets and the targets detected from among those looked at is important. In effect, we found that, while performing cognitive tasks, significantly fewer targets are looked at than during visual search task with no cognitive task, and we also observed that among the looked-at targets, the number of targets detected is considerably lower in both the task conditions than in the no-task condition. Therefore, when performing tasks, subjects frequently do not perceive the stimulus they are seeking, even if they are looking at it (inattentional blindness, properly speaking); that is, there is a cognitive obstruction, not merely a visual one. Thus, both hypotheses are confirmed: fewer target stimuli are detected because they are looked at less, and this seems to be due to the alteration of ocular parameters but, in turn, among the looked-at target stimuli, fewer are detected, which would be due to attentional interference, not to differences between ocular behaviors.

With regard to the possible differences between verbal task and spatial imagery task, not only did the differences foreseen by Wickens' theory not appear, but an unexpected difference appeared: among the looked-at target stimuli, detection was superior when performing the spatial imagery task than when performing the verbal task, which can be attributed to the fact that, in this dual-task condition, verbal task presents a higher mental load. In addition, upon analyzing cognitive task performance (responses per minute), it is worse in the dual-task conditions, coinciding with Woodman and Luck (2004), but more deterioration for spatial imagery task is not confirmed, as would be expected if there were more interference with visual search task due to sharing visual processing centers. In fact, the statistically nonsignificant interaction indicates that the decrease in performance is the same for both tasks, verbal and spatial imagery. Moreover, taking into account that the spatial imagery task involves less effort than the verbal task (in the dual-task condition), these results reinforce the argument that deterioration has to do with the mental load and not with qualitative aspects of the codes processed, in contrast to the postulations of Macdonald and Lavie (2008) about the specificity of the perceptive capacity of conscious detection.

General Discussion

In two experiments, we attempted to test the hypothesis that cognitive processing produces a deterioration of visual perception and this deterioration is higher when the cognitive processing is based on spatial imagery codes than when the cognitive processing is based on verbal codes. First part of the hypothesis (cognitive processing affects visual perception) is based in the general assumption of conscious perception required attention (Noë & O'Regan, 2000) and the conclusions of previous research about how mental load of cognitive tasks impairs visual search and stimulus identification (Fougnie & Marois, 2007; Recarte & Nunes, 2003; Recarte, et al., 2008). However, the role of mental load in visual perception leads to contradictory results. Some previous investigations of inattentional blindness concluded that stimuli will not be perceived when the task processing requirements involve a high level of perceptual load (Lavie, 1995) and working memory load does not affect the perception of stimuli unrelated to the search task (Macdonald & Lavie, 2008). Others defend that working memory load helps the processing of competing distractor stimuli (De Fockert, et al., 2001; Lavie & De Fockert, 2005; Lavie, et al., 2004). We attempted to clarify if mental load of a cognitive task impairs a simultaneous visual search task. The second part of the hypothesis (deterioration is higher when the cognitive processing is based on spatial imagery codes than when the cognitive processing is based on verbal codes) is based on two sets of facts: (a) image processing leads to visual behaviors that are differentiated from those of verbal processing, behaviors that make visual search task less efficient, at least in conditions of rapid presentation of multiple stimuli in changeable places. These visual behaviors are: fixations of longer duration and higher gaze concentration (Recarte & Nunes, 2000). (b) Spatial image processing shares more brain areas or modules with visual processing than does verbal processing (Farah, 1985; Kosslyn, 1988; Posner & Raichle, 1994). Therefore, more interference of visual search task is expected when performing spatial imagery tasks (the reciprocal relation is also expected, that is, poorer performance in the spatial imagery task than in the verbal task when they are carried out simultaneously with visual search task). According to these two facts, deterioration of visual search task can occur either because of performing a less efficient visual search or because of poorer cognitive processing of the looked-at stimuli, or because of both. In the first case, the target stimuli should be looked at less frequently while performing a cognitive task, and less frequently when performing a spatial imagery task than a verbal task. In the second case, fewer targets should be identified among those looked at while carrying out a cognitive task, and fewer with a spatial imagery task than with a verbal task.

In the first experiment, we attempted to find two tasks, a verbal and a spatial imagery task, that were equal in mental

https://doi.org/10.5209/rev_SJOP.2011.v14.n2.4 Published online by Cambridge University Press

load and to verify that they differ in the ocular behaviors found by Recarte & Nunes (2000) in the context of an investigation with real driving. The results confirm all of this: the cognitive tasks are equal in three measures of mental load (pupil size, subjective judgments and error rate of cognitive task), and they differ in ocular behavior, specifically, in fixation duration, gaze variability, and saccadic amplitude. In the second experiment, we combined these same cognitive tasks with a visual search task in a dual-task paradigm, using as control the visual search task carried out as a single task. In this second experiment, the results of the cognitive tasks were different from to those obtained in Experiment 1. This is not at all surprising, as we had assumed that cognitive tasks interact with the visual search task, which is very demanding visually. All the measures indicate that, in Experiment 2, the spatial imagery task required less effort than the verbal task. But, in view of this unexpected result, it is interesting that the performance of the visual search task match this difference: there is less visual search task deterioration with the spatial imagery task than with the verbal task, against our initial hypothesis. Regarding the ocular characteristics: in Experiment 2, the fixations are considerably shorter than in Experiment 1, which is explained because in Experiment 1, subjects only had to look at the screen, whereas in Experiment 2, they had to search for a target on the screen among other rapidly changing distractors. This causes the fixation in each particular position to be shorter. In turn, this shortening of the fixations partially causes a floor effect, so the differences between tasks, although maintaining the same pattern as in Experiment 1, do not reach statistical significance. The difference between the verbal task and the spatial imagery task regarding gaze concentration also disappears, compared with Experiment 1. Only saccadic amplitude maintained the differences between the conditions of the cognitive tasks, and the spatial distance between fixations was shortest when carrying out the imagery task versus the verbal task. This lack of differences seems to be due to the exploratory behaviors required for an efficient search in the described visual task.

Beyond these differences between spatial and verbal task, results of the second experiment indicate that when a cognitive task is performed, a visual search task is impaired. This is because performing a cognitive task alters both, ocular behavior and general attentional resources invested. That is, the performance of a purely cognitive task, with no visual components and which involves mental load, produces deterioration in the performance of a concurrent task of visual search and stimulus identification. There are many investigations that conclude that mental load does not deteriorate visual perception (De Fockert, et al., 2001; Lavie, 2005; Lavie & De Fockert, 2005; Lavie, et al., 2004; Macdonald & Lavie, 2008), but instead that the mere perceptual load is what deteriorates perception (Beck & Lavie, 2005; Cartwright-Finch & Lavie, 2007; Lavie, 2006). Our results, however, coincide with those of other authors who conclude that, as cognitive task demands increase, the probability of detecting a stimulus decreases (Fougnie & Marois, 2007; Han & Kim, 2004; Oh & Kim, 2004; Todd, et al., 2005; Woodman & Luck, 2004).

We can conclude: (1) cognitive tasks produce important deterioration in the capacities of visual search and identification of stimuli; (2) this deterioration has two components: (a) an inefficient search, associated with alterations of the gaze patterns while performing cognitive tasks, and (b) a general interference, nonspecific to spatial codes, in the process of identification of looked-at stimuli; (3) this cognitive interference is related to the mental load or effort required by the cognitive task and not to the type of code employed in its processing, versus Macdonald and Lavie (2008).

References

Beatty, J. (1982). Task-evoked pupillary responses, processing load, and the structure of processing resources. *Psychological Bulletin, 91*(2), 276-292. doi:10.1037/0033-2909.91.2.276

Beck, D. M., & Lavie, N. (2005). Look here but ignore what you see: Effects of distractors at fixation. *Journal of Experimental Psychology: Human Perception and Performance, 31*(3), 592-607. doi:10.1037/0096-1523.31.3.592

Cartwright-Finch, U., & Lavie, N. (2007). The role of perceptual load in inattentional blindness. *Cognition, 102*(3), 321-340. doi:10.1016/j.cognition.2006.01.002

De Fockert, J. W., Rees, G., Frith, C. D., & Lavie, N. (2001). The role of working memory in visual selective attention. *Science, 291*, 1803- 1806. doi:10.1126/science.1056496

De Waard, D. (1996). *The measurement of drivers´ mental workload* (Doctoral thesis). Retrieved from http://dissertations.ub.rug.nl/FILES/faculties/gmw/1996/d.de.waard/09_thesis.pdf

Farah, M. J. (1985). Psychophysical evidence for a shared representational medium for mental images and percepts. *Journal of Experimental Psychology: General, 114*(1), 91-103. doi:10.1037/0096-3445.114.1.91

Fougnie, D., & Marois, R. (2007). Executive working memory load induces inattentional blindness. *Psychonomic Bulletin and Review, 14*(1), 142-147. doi:10.3758/BF03194041

Goldstein, E. B. (2002). *Sensation and perception*. Belmont, CA: Wadsworth.

Han, S. H., & Kim, M. S. (2004). Visual search does not remain efficient when executive working memory is working. *Psychological Science, 15*(9), 623-628. doi:10.1111/j.0956-7976.2004.00730.x

Hoeks, B., & Levelt, W. J. M. (1993). Pupillary dilation as a measure of attention: A quantitative system analysis. *Behavior Research Methods, Instruments & Computers, 25*, 16- 26. doi:10.3758/BF03204445

Iqbal, S. T., Zheng, X. S., & Bailey, B. P. (2004). Task- evoked pupillary response to mental workload in human- computer

https://doi.org/10.5209/rev_SJOP.2011.v14.n2.4 Published online by Cambridge University Press

interaction. *CHI´04* (pp. 1477- 1480). New York, NY: AMS Press. Retrieved from http://portal.acm.org/citation.cfm?id =986094

Irwin, D. E., & Brockmole, J. R. (2000). Mental rotation is suppressed during saccadic eye movements. *Psychonomic Bulletin and Review, 7*(4), 654-661.doi:10.3758/BF03213003

Janisse, M. P. (1977). *Pupillometry: The psychology of the pupillary response.* New York, NY: Wiley.

Kahneman, D. (1973). *Attention and effort*. Englewood Cliffs, NJ: Prentice Hall.

Kosslyn, S. M. (1988). Aspects of a cognitive neuroscience of mental imagery. *Science, 240*, 1621-1621. doi:10.1126/science. 3289115

Lavie, N. (1995). Perceptual load as a necessary condition for selective attention. *Journal of Experimental Psychology: Human Perception and Performance, 21*(3), 451-468. doi:10.1037/0096-1523.21.3.451

Lavie, N. (2005). Distracted and confused?: Selective attention under load. *Trends in Cognitive Sciences, 9*(2), 75-82. doi:10.1016/j.tics.2004.12.004

Lavie, N. (2006). The role of perceptual load in visual awareness. *Brain Research, 1080*(1), 91-100. doi:10.1016/j.brainres.2005. 10.023

Lavie, N., & De Fockert, J. W. (2005). The role of working memory in attentional capture. *Psychonomic Bulletin and Review, 12*(4), 669-674. doi:10.3758/BF03196756

Lavie, N., Hirst, A., De Fockert, J. W., & Viding, E. (2004). Load theory of selective attention and cognitive control. *Journal of Experimental Psychology: General, 133*(3), 339-354. doi:10.1037/0096-3445.133.3.339

Leigh, R. J., & Zee, D. S. (1999). *The neurology of eye movements*. New York, NY: Oxford University Press.

Macdonald, J. S. P., & Lavie, N. (2008). Load induced blindness. *Journal of Experimental Psychology: Human Perception and Performance, 34*(5), 1078-1091. doi:10.1037/0096-1523. 34.5.1078

Mack, A., & Rock, I. (1998). *Inattentional blindness*. Cambridge, MA: MIT Press.

Most, S. B., Scholl, B. J., Clifford, E. R., & Simons, D. J. (2005). What you see is what you set: Sustained inattentional blindness and the capture of awareness. *Psychological Review, 112*, 217-242. doi:10.1037/0033-295X.112.1.217

Näätänen, R. (1992). *Attention and brain function*. Hillsdale, NJ: Erlbaum.

Noë, A., & O'Regan, J. K. (2000). Perception, attention, and the grand illusion. *Psyche, 6*(15), 6-15.

Oh, S. H., & Kim, M. S. (2004). The role of spatial working memory in visual search efficiency. *Psychonomic Bulletin and Review, 11*(2), 275-281. doi:10.3758/BF03196570

Pappas, J. M., Fishel, S. R., Moss, J. D., Hicks, J. M., & Leech, T. D. (2005). An eye-tracking approach to inattentional blindness. In *Proccedings of the Human Factors and Ergonomics Society* (Vol. 49, pp. 1658-1662). Orlando, FL: HFES.

Posner, M. I., & Raichle, M. E. (1994). *Images of mind*. New York, NY: Scientific American Library.

Recarte, M. A., & Nunes, L. M. (2000). Effects of verbal and spatial-imagery tasks on eye fixations while driving. *Journal of Experimental Psychology Applied, 6*(1), 31-43. doi:10.1037/1076-898X.6.1.31

Recarte, M. A., & Nunes, L. M. (2002). Parpadeo durante la conducción: efectos de la carga mental y del tiempo conduciendo [Blink during driving: mental load and time driving effects]. *Vigilia y sueño, 14*, 161-167.

Recarte, M. A., & Nunes, L. M. (2003). Mental workload while driving: Effects on visual search, discrimination, and decision making. *Journal of Experimental Psychology Applied, 9*(2), 119-133. doi:10.1037/1076-898X.9.2.119

Recarte, M. A., Pérez, E., Conchillo, A., & Nunes, L. M. (2008). Mental workload and visual impairment: differences between pupil, blink, and subjective rating. *The Spanish Journal of Psychology, 11*(2), 374-385.

Rees, G., Frith, C. D., & Lavie, N. (1997). Modulating irrelevant motion perception by varying attentional load in an unrelated task. *Science, 278*, 1616- 1619. doi:10.1126/science.278.5343.1616

Ryu, K., & Myung, R. (2005). Evaluation of mental workload with a combined measure based on physiological indices during a dual task of tracking and mental arithmetic. *International Journal of Industrial Ergonomics, 35*(11), 991-1009. doi:10.1016/j.ergon.2005.04.005.

Simons, D. J., & Chabris, C. F. (1999). Gorillas in our midst: Sustained inattentional blindness for dynamic events. *Perception, 28*, 1059-1074. doi:10.1068/p2952.

Stern, J. A., Boyer, D., & Schroeder, D. (1994). Blink rate: a possible measure of fatigue. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 36*(2), 285-297.

Todd, J. J., Fougnie, D., & Marois, R. (2005). Visual short-term memory load suppresses temporo-parietal junction activity and induces inattentional blindness. *Psychological Science, 16*(12), 965-972. doi:10.1111/j.1467-9280.2005.01645.x

Von Helmholtz, H. (1924). *Treatise on physiological optics*. Rochester, NY: Optical Society of America.

Wickens, C. D. (1984). Processing resources in attention. In R. Parasuraman & R. Davies (Eds.), *Varieties of attention* (pp. 63- 102). New York, NY: Academic Press.

Wickens, C. D. (1992). *Engineering Psychology and human performance*. New York, NY: HarperCollins.

Woodman, G. F., & Luck, S. J. (2004). Visual search is slowed when visuospatial working memory is occupied. *Psychonomic Bulletin and Review, 11*(2), 269-274. doi:10.3758/BF03196569.

Woodman, G. F., Vogel, E. K., & Luck, S. J. (2001). Visual search remains efficient when visual working memory is full. *Psychological Science, 12*(3), 219-224. doi:10.1111/1467-9280.00339.

Received April 21, 2010
Revision received October 25, 2010
Accepted December 2, 2010

https://doi.org/10.5209/rev_SJOP.2011.v14.n2.4 Published online by Cambridge University Press