The Role of Mental Load in Inattentional Blindness

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The purpose of this investigation is to determine whether the mental load of a cognitive task prevents the processing of visual stimuli, that is, whether the mental load produces inattentional blindness, and at what point in the cognitive-task processing more interference is produced. An arithmetic task with two levels of mental load was used in a dual-task situation with a visual search and detection task. An experiment was performed with 35 participants. An eye tracker system (ASL model 5000) was used to verify which targets were looked at. The results show impairment in the detection task when carrying out the two tasks simultaneously; it was higher when the arithmetic task had a higher mental load. The impairment cannot be explained by alteration in the ocular pattern. The moment at which the process or sub-process of the arithmetic task produces the greatest interference in visual detection corresponds to the purely cognitive moment of calculus, versus sub-processes with perceptive or motor components, such as listening to the stimuli or emitting responses.

The performance of a purely cognitive task, with no visual components and which involves mental load, produces impairment in the performance of a concurrent task of visual search and detection (Recarte, Pérez, Conchillo, & Nunes, 2008) and this deterioration increases with the mental load of the cognitive task. The dual-task situation used by these authors consists, however, of two continuous tasks with no evidence about which aspect or sub-process of the cognitive task produces the impairment. In a later investigation, the authors propose that the interference of the cognitive task in visual detection is of a general or unspecific nature, depending on the mental load of the cognitive task and not on the

processing code used (Pérez-Moreno, Conchillo, & Recarte, 2011). In the present work, we will attempt to confirm that mental load produces impairment of visual perception, using a procedure of discrete trials and two levels of mental load in the same cognitive task to study which processing aspects are producing the interference with visual perception.

Visual impairment can be similar to the phenomenon known as inattentional blindness. This term was coined by Mack and Rock (1998) and is defined as 'a situation in which an unattended stimulus is not perceived, even when the person is looking directly at it'(Goldstein, 2002). In the classic paradigm, one of the key aspects is that the target stimulus is unexpected, and another aspect is that both the task presented to the subject as the main (and only) task and the unexpectedly presented stimulus are visual. There is plenty of literature, however, that shows that the effect of inattentional blindness also occurs when the visual stimuli are expected (Macdonald & Lavie, 2008; Pérez- Moreno, et al., 2011; Recarte, et al., 2008).

The existing literature about the type of task (visual versus non-visual) that produces the effect of inattentional blindness is contradictory. According to Lavie (2005), whereas a high perceptive visual load decreases the processing of a distracter, thus increasing inattentional blindness, a high load in cognitive control processes increases the processing of the distracter (Lavie, Hirst, De Fockert, & Viding, 2004). Other authors, however, have found that an increase in the mental load of cognitive tasks reduces the probability of detecting a stimulus (Fougnie & Marois, 2007; Han & Kim, 2004; Oh & Kim, 2004; Recarte & Nunes, 2003; Recarte, et al., 2008; Todd, Fougnie, & Marois, 2005; Woodman & Luck, 2004).

The classic interpretation is that visual processing of a stimulus, at least that needed to achieve the level of awareness required to report it, requires attention (Noë & O'Regan, 2000). This is probably what happens in the dual-task situation: to the degree to which it requires attention, the performance of one of the tasks suppresses, for some moments, the assignment of attention to the second task, producing the phenomenon equivalent to the absence of detection, even when the person is looking directly at the target.

One of the most consistent attempts to study interference in dual-task situations and to provide explanations about the moment or process involved is found in the studies of psychological refractory period (PRP). In a typical PRP experiment, two stimuli are presented in a fast sequence. Each one requires the selection of an independent response. The main independent variable is the stimulus onset asynchrony (SOA), or time that

separates the appearance of the two stimuli. Manipulation of SOA allows the second stimulus to be presented at different moments during the processing of the first stimulus. The main result is a lengthening of the response time to the second stimulus if the SOA is very short; lengthening that decreases as the SOA increases. The principal explanatory theory is the single channel theory or bottleneck (Pashler, 1998), which occurs in the phase of response selection. The bottleneck only allows processing of the response to one stimulus at a time, so the processing of the second stimulus must wait until the processing of the first one is complete (see Sanders (1998) and Pashler (1994), for a review of the experimental results).

In our investigation, we attempted to show that occupying attention with a purely cognitive task prevents the visual processing of another task, the phenomenon currently called inattentional blindness, and tried to map the moment of processing in which the impediment occurs, under the hypothesis that the determinant factor is the mental load. We used the basic PRP paradigm but, in contrast to most of the experiments in this field, our design attempted to verify whether the interference between the tasks takes on the form of absence or attenuation of visual processing (versus prior works with PRP that analyse a delay in processing).

To reinforce the interpretation that it is the mental load itself that produces inattentional blindness, various aspects of interest were included in the design: (a) the use of a cognitive task without visual components to forestall any interpretation of the expected perceptive impairment in terms of structural or perceptual incompatibility; (b) the manipulation of the mental load, with two levels of effort required by the cognitive task, with the main hypothesis being that the higher the load required, the higher the visual impairment; and (c) participants were instructed to search and detect the visual stimulus. Moreover, the use of an ocular register system allowed us to analyse for each condition both the proportion of looked-at stimuli and among them the ones that were detected. That is, it allowed us to verify whether the mental load produced interference in the processes of target search, the processes of target identification, or both.

With regard to the tasks, we used a visual detection task that is broadly used in research on visual attention: detection of a target letter among a series of letters and an arithmetic cognitive task with auditive input and verbal response, specifically, the performance of subtractions with two levels of mental load. Although the performance of arithmetic operations is not frequent with the PRP paradigm, nonetheless examples of it do exist (Byrne & Anderson, 1998).

The characteristics of the cognitive task are different from those of the perceptive task in all the observable aspects: auditive versus visual input, mental calculus process versus detection-identification process, verbal versus motor response. Therefore, in terms of Wickens's (1984, 1992) taxonomy of processing resources, two tasks are presented that are clearly differentiated at all moments of their performance. Any interference between them should be interpreted in terms of general attentional resources.

The goal of this experiment, therefore, was to determine whether the mental load of a cognitive task prevents the processing of visual stimuli and at which moment of the processing of the cognitive task the interference is produced.

In our experiment, first we analysed the arithmetical task by itself to verify whether there really are two levels of mental load.

The verification of the two levels of load in the arithmetic task was studied by means of the performance of this task (correct responses and response times) and by measures of mental load, such as pupil dilation and subjective judgments of effort. The effect of the mental load on detection was studied by comparing performance of the visual search alone and in the dual-task situation. The hypotheses are that the higher the mental load of the cognitive task, the lower the proportion of correct responses in visual detection, the higher the proportion of false alarms (ultimately, a loss of sensitivity for detection of visual stimuli), the lower the proportion of gazes at the target stimuli, and the lower the proportion of detected stimuli among the looked-at stimuli. All these effects will be produced maximally when, by varying the SOA, the detection task coincides with the moments of greater cognitive activity. The performance of the arithmetic cognitive task has three moments that are clearly differentiated and operationally differentiable in our experimental procedure: the auditive presentation of the stimulus, the mental calculus itself, and the emission of the response. Although we do not rule out overlapping at the level of underlying processes, from the viewpoint of our theory that impairment in visual perception is produced by the cognitive effort, we assume that the effect of inattentional blindness will be more pronounced for the trials in which the presentation of the visual stimuli coincided with the sub-process of calculating the subtraction than when listening to the auditive stimuli or when emitting a response.

METHOD

Participants. In this experiment, there were 35 participants (28 women and seven men) with a mean age of 22 years (*SD* = 3.96) with normal or corrected vision. Except for four of them, all were psychology students. The participants were not familiar with experiments of this kind. All the participants were rewarded with six euros for their collaboration in a single session of about 45 minutes.

Design. The design of the experiment was within-subject. All the participants carried out all the experimental conditions. There were five experimental conditions: three simple tasks (low-load arithmetic task, high-load arithmetic task, visual search and detection task) and two dual tasks (low-load arithmetic task plus visual search and detection and high-load arithmetic task plus visual search and detection). The conditions were counterbalanced but with the restriction that the simple tasks were performed first. This decision was taken after several tests showed distortions in performance if we started with dual tasks.

Materials and Procedure. The tasks employed in the experiment were: (a) *the arithmetic cognitive task.* Pairs of numbers were presented auditively and participants were requested to subtract them as fast as possible and to state the result out loud. The stimuli were randomly presented within each block to each participant. The first stimulus of the pair (the minuend) was a number of either one or two figures. This characteristic determined the grouping of the stimuli into two blocks, which in turn corresponded to the two values of the mental load: Low Mental Load (hereafter, LML) with one-figure minuend, and High Mental Load (hereafter, HML) with two-figure minuend. Next, the other number (the subtrahend), which was always a one-figure number, was presented. For the HML condition, there was always the same number of subtractions with and without a change in the tens-column of the result in order to control for possible factors that affected the difficulty (for example, the following subtraction would change the tens-column: 34 minus 7). The auditive stimuli lasted an average of 2156 ms. The response time was counted from the end of the auditive stimulus; (b) *the visual search and detection task.* A (target) letter was presented in the centre of a circle made up of eight initially empty cells. In the condition in which the visual search task was carried out alone, the empty cells remained on the screen for 2000 ms before the letters appeared. For dual- task conditions, the empty cells remained on the screen for 2000 ms before the auditive stimulus appeared.

The eight positions were occupied by the eight letters after addition of the SOA corresponding to each trial to the presentation time of the auditive stimulus. That is, the first stimulus that appeared was always the auditive stimulus of the arithmetic task and the participants were instructed to respond to the arithmetic task before the detection task, to verify the possible obstruction of the visual stimulus processing. The visual stimuli remained visible for a different length of time for each participant. The presentation time of the letters was determined by the computer program during the experiment as the mean time to respond correctly to the visual task during the training trials. The mean presentation time of the letters during the experiment was 1295 ms (SD = 261 ms). After that time, the eight letters were masked and substituted by 8 # signs in these positions, which remained on the screen until the end of the trial. The diameter of the circle occupied 4° of the visual angle. This distance was selected after successive verifications because it is sufficiently small for the stimuli to be within the parafoveal zone, but it allowed sufficient distance between the stimuli to determine in each case which letter the participants were looking at. The stimuli occupied a visual angle of 0.5°, horizontally and vertically. The participants' task was to respond, by pressing the N key (for *No*) or the S key (for *Sí* [*Yes* in Spanish]), whether the target was among the stimuli of the circle. The stimuli selected in each trial (target and distracters), as well as the presentation location, were randomly selected from the series: W, T, F, H, L, N, Z, X, V, K, M, and Y, with the restriction that all the letters must appear as targets at least once and not more than twice over each condition, and all the distracters must appear in a location at least once and not more than twice. All the letters were angular, without any curves, which implied high similarity of the stimuli, an aspect of recognised importance in visual search tasks (Duncan & Humphreys, 1989). The target was present in half of the search trials. The response time of the visual search task was considered as from the appearance of the wheel of letters, which was the moment when the participant could respond to the task.

The experiment was carried out in a Faraday cabin. The following materials were used in the experiment: a visual tracking system (ASL 5000) that recorded gaze coordinates and pupil diameter in real time, two computers to present the conditions and collect the data, a projector to present the visual search conditions, a screen (146 x 110 cm) that subtended 35° of visual angle horizontally and 27° vertically, and two loudspeakers. The level of luminance was constant at 110 lux, thus controlling its possible effect on pupil size. A computer program (in CVI, of National Instruments) sequentially performed the five experimental conditions, allowing the participants to control the moment of starting each condition and each

stimulus. The participants' responses were recorded digitally by means of a small microphone that served as the vocal key of the responses ending the cognitive task of the corresponding trial. The program allowed simultaneous recording, at 50 Hz/s, of the eye movements at different moments of the trial, such as at the beginning of the stimuli, the participants' responses to both tasks, and the end of the trials.

At the beginning, each participant's right eye was calibrated by means of a nine-point calibration screen. The experiment began with a training stage, followed by the true experimental phase. At the end of each condition, the participants entered into the program the amount of effort, from 1 to 10, which the performance of the task or tasks they had completed had taken. There were ten trials of each one of the two conditions of arithmetic task alone (LML or HML). At the start of each trial, a cross appeared in the centre of the screen as a fixation point, and it remained until the end of the trial in order to equate the lighting conditions in all the experimental conditions. There were 20 trials of the visual search task alone (ten trials with the target present in the wheel of letters and ten trials without the target). The number of trials in this condition was equivalent to the set of trials in the arithmetic task alone. There were 24 trials of each one of the two dual-task conditions (LML and HML plus visual search task), two for each SOA level, thus ensuring a positive trial (presence of target) and a negative one (absence of target) for each condition of mental load and SOA. The twelve SOA levels (50, 250, 450, 700, 950, 1200, 1450, 1700, 1950, 2200, 2450, and 2700 ms) and the presence/absence of the target were randomised. The time range of the SOA variable met the need to make the different moments of the two tasks (arithmetic task and detection task) coincide, as their times in the response selection phase are very different. In order to select the number of SOA levels, we took into account the prior literature on PRP (Karlin & Kestenbaum, 1968).

RESULTS

For the sake of clarity, we have divided the analysis of the results into four parts: (1) verification of the two levels of mental load of the arithmetic task; (2) analysis of the effect of the mental load on the visual search and detection task; (3) analysis of the temporal aspects of processing by means of the SOA variable; (4) verification of the interference by the processes of the arithmetic task (listening, between listening and thinking, thinking, and responding) with stimulus detection.

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Verification of the Two Levels of Mental Load of the Arithmetic Task

In this first part, we verified whether the two levels of mental load of the arithmetic task produced significant differences, in simple- and dual-task situations, in order to be able to use the mental load as an independent variable in subsequent analyses. We analysed the proportion of correct responses (PCR) in the arithmetic task, reaction times (RT), pupil diameter, and the subjective effort ratings (SER) for both levels. When performing the arithmetic task of subtracting with two figures (HML), we expected the PCR to be lower, and pupil diameter, TR and SER to be higher than when we performed the one-figure subtraction task (LML).

We carried out a 2 x 2 (2 mental loads x 2 number of tasks) within-subject ANOVA for each of the above-mentioned dependent variables. Effect size and power of each analysis are reported. The results of the mean and the standard error of the mean by condition are shown in Table 1.

Table 1. Mean and standard error for the variables proportion of correct responses (PCR), reaction time (TR) to the arithmetic task, pupil diameter, and subjective effort ratings (SER) by mental load and number of tasks.

		PCR		TR (ms)		Pupil (pixels)		SER	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE
Single	LML	.97	.01	523	81	37.77	.08	3.63	.38
	HML	.83	.01	1713	81	38.34	.08	4.06	.43
	Total	.9	.01	1118	58	38.05	.06	3.84	.29
Dual	LML	.98	.01	1406	53	36.11	.05	5.83	.34
	HML	.88	.01	2667	53	36.72	.05	7.6	.25
	Total	.93	.01	2037	37	36.42	.04	6.71	.27

Note. Low Mental Load (LML) of arithmetic task; High Mental Load (HML) of arithmetic task. The proportion of correct responses refers to the arithmetic task.

The results of the ANOVA yielded statistically significant differences in the variable PCR of the arithmetic task by the variable mental load, with $F(1, 34) = 57.051$, $p < .001$, $\eta^2 = .627$, $1-\beta = 1$, indicating that at the HML

level, the PCR is lower than at the LML level. The variable PCR showed statistically significant differences for the variable number of tasks, $F(1, 34)$ = 5.525, p = .025, η^2 = .14, 1- β = .627, indicating that there is a higher PCR during dual-task performance, but note the low power of the contrast. No effects for the interaction of these variables were found.

The variable TR revealed statistically significant differences for mental load, $F(1, 34)$ = 62.94, p <.001, η^2 = .649, 1- β = 1, indicating that the responses are slower for the HML level compared with the LML level. For the variable number of tasks, there was a statistically significant difference in TR, $F(1, 34)$ = 100.3, p <.001, η^2 = .747, 1- β = 1, which indicates that when the two tasks are performed simultaneously TR is higher when the arithmetic task has a higher mental load. No significant interaction effect was found for these variables.

The results of the ANOVA yielded statistically significant differences for the variable pupil diameter by mental load, $F(1, 34)$ = 14.106, p = .001, η^2 = .293, 1- β = .954, and by number of tasks, $F(1, 34)$ = 57.953, p < .001, η^2 = .63, 1- β = 1, indicating that the diameter of the pupil is larger when performing at the HML level than at the MLM level and when performing the arithmetic task alone versus performing it simultaneously with the detection task. No interaction effects of these variables were found for pupil diameter.

Lastly, for the variable SER, statistically significant differences were found for the variable mental load, $F(1, 34)$ = 16.017, p = .001, η^2 = .32, 1- β = .973, indicating that the SER are higher for the arithmetic task in the HML condition than in the LML condition. Moreover, differences in the SER for the variable number of tasks were found, $F(1, 34)$ = 126.32, p < .001, η^2 = .788, 1- β = 1, indicating that the ratings are higher in performance of the arithmetic task with the detection task than when the arithmetic task is performed alone. The interaction of both variables was statistically significant for this variable but with a very low power, $F(1, 34)$ = 4.49, p = .041, η^2 = .117, 1- β = .539, indicating that the differences in the SER between the LML and HML conditions were more pronounced in the dual-task condition.

Effect of the Mental Load on the Visual Search and Detection Task: the Effect of Inattentional Blindness

The goal of the second part of the experiment was to verify that the performance of an arithmetic task together with a visual search and detection task deteriorates stimulus detection in comparison with the performance of the search and detection task alone. We analysed the

proportion of detected stimuli (PDS), the proportion of false alarms (PFA), the proportion of looked-at stimuli (PLS), and the proportion of detected stimuli among those that were previously looked at (PDS/PLS), the true effect of inattentional blindness. The proportions refer to the total trials where the target stimulus appeared. A target stimulus was categorised as looked-at if the coordinates of this stimulus (known beforehand) coincided with the coordinates of the gaze (synchronised in real time on the same file). We expected that performing an arithmetic task at the same time as a visual search and detection task would decrease the PDS, increase the PFA (which implies a decrease of sensitivity to the detection task), decrease the PLS, and decrease the PDS/ PLS. We expected more impairment in detection when it was performed together with the HML arithmetic task.

For each dependent variable mentioned, we conducted a within-subject ANOVA with a three-level factor (detection without arithmetic task or control, detection plus LML arithmetic task, and detection plus HML arithmetic task); the results of the mean and the standard error of the mean are shown in Table 2. The data of the effect size and the power of the analyses, as well as the significance of a Helmert contrast and of pairwise comparisons with the Bonferroni method, are included above. We also include the significance of a polynomial contrast because the existence of two levels of mental load with a control condition without mental load allows us to consider the variable mental load as an ordinal variable.

Table 2. Mean and standard error for the variables proportion of detected stimuli (PDS), proportion of false alarms (PFA), proportion of looked-at stimuli (PLS), and proportion of detected/looked-at stimuli (PDS/PLS) by mental load.

	PDS		PFA		PLS		PDS/PLS	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Detection	.9	.02	.02	.01	.52	.03	.89	.03
Detection + LML	.79	.02	.04	.01	.54	.02	.77	.03
Detection + HML	.7	.02	.05	.01	.51	.02	.75	.03

Note. Low Mental Load (LML) of arithmetic task; High Mental Load (HML) of arithmetical task.

Significant differences were found for the variable PDS by mental load, $F_{(2, 68)} = 20.157$, $p < .001$, $\eta^2 = .372$, $1- \beta = 1$. According to a Helmert contrast, there were statistically significant differences for the variable PDS ($p < .001$) between detection alone and detection plus arithmetic task, indicating that when an arithmetic task plus a detection task is performed, PDS is lower than when the detection task alone is performed. According to the binary comparisons, there were differences among the three ANOVA levels: between detecting alone and detecting plus LML arithmetic task ($p < .001$), between detecting and detecting plus HML arithmetic task ($p < .001$), and between detecting plus LML and detecting plus HML arithmetic task ($p = .004$). The linear component of the polynomial contrast was significant at $p < .001$; the higher the mental load, the lower the PDS.

For the variable PFA, no significant differences were found, $F_{(2, 68)} = 2.784$, $p = .069$, but the results follow the expected tendency; that is, the higher the mental load, the higher PFA. Moreover, according to a Helmert contrast, there were statistically significant differences ($p = .019$) between only detecting and detecting plus arithmetic tasks, which indicates that when an arithmetic task together with a detection task is performed, PFA increases in comparison with the detection task alone. According to the binary comparisons, there were only differences between detecting and detecting plus HML arithmetic task ($p = .038$). The linear component of the polynomial contrast was significant at $p = .013$; the higher the mental load, the higher the PFA.

For the variable PLS no statistically significant differences were found for the variable mental load, $F_{(2, 68)} = 0.499$, $p = .61$.

The results of the ANOVA for the variable PDS/PLS yielded statistically significant results by mental load, $F_{(2, 68)} = 6.505$, $p = .002$, $\eta^2 = .141$, $1- \beta = .897$. According to a Helmert contrast, there were statistically significant differences ($p = .001$) between detecting alone and detecting plus arithmetic task, indicating that the phenomenon of looking at a stimulus without seeing it is more frequent when an arithmetic task and a detection task are performed than when the latter task alone is performed. According to the binary comparisons, there were differences between detecting alone and detecting plus LML arithmetic task ($p = .015$), and between detecting and detecting plus HML arithmetic task ($p = .004$), but not between detecting plus LML and detecting plus HML arithmetic task. The linear component of the polynomial contrast was still significant at $p = .001$, however, which means that as the mental load increases, one is less likely to detect a looked-at target.

We recommend performing an analysis of the sensitivity and criterion indices (d' and *β*) with these data. The absence of false alarms in many trials, however, does not allow an analysis of variance without distorting the data with extreme values; therefore, we display the global or descriptive data of both indices by condition below (see Table 3).

Table 3. Sensitivity index (d´) and criterion index (β) for the variable mental load.

	d´		*β*
Detection	3.31	Detection	3.7
Detection + LML	2.5	Detection + LML	3.24
Detection + HML	2.12	Detection + HML	3.14

Note. Low Mental Load (LML) of arithmetic task; High Mental Load (HML) of arithmetical task.

The results show that detection sensitivity is higher when detection is performed alone than when performed with an arithmetic task and, in turn, sensitivity is higher when the detection task with the LML arithmetic task is performed than the HML arithmetic task. The results in the criterion show that the participants were conservative when performing the complete experiment, although, as mental load increased, it seems that they became increasingly less conservative.

Analysis of the Temporal Aspects of Processing by means of the SOA Variable

A key aspect in the PRP paradigm is the evolvement of the response times as a function of the variation of the SOA between the two processed stimuli. The single channel or bottleneck theory predicts that, as SOA increases, response time to the second stimulus should decrease, and this decrease is a linear function with a slope of -1. According to underlying

theory, the reason is that when the SOA varies, the moment of coincidence of the processing of the second stimulus with the moment of processing the first stimulus is moved over. We analysed the temporal aspects of processing. In our case, however, we were not so much interested in the variation of the response times as in the variation of the stimulus detection, because our hypothesis predicts that the processing of the second stimulus will not be delayed, but prevented. We analysed the difference in response times to both tasks (response time to detection minus response time to arithmetic task) and the PDS for each SOA level and mental load. We expected that, as SOA increased, the difference in response times to both tasks would decrease and the PDS would be higher. When the HML arithmetic task is performed, we expected that the difference between the response times would be higher and the PDS would be lower than with the LML task. The proportion was calculated with regard to the total number of trials with the target stimulus.

We conducted a within-subject 2 x 12 (2 mental loads x 12 SOAs) ANOVA for each dependent variable, the results of which can be seen in Figures 1 and 2. We also include the significance data, effect size, and power of the analyses, as well as the significance of a polynomial contrast and of pairwise comparisons with the Bonferroni method for the SOA variable.

For the differences between the response times of both tasks, the results of the ANOVA revealed statistically significant differences for the SOA, $F(11, 374) = 51.078$, $p < .001$, $\eta^2 = .589$ and $1- \beta = 1$; and for the mental load, $F(1, 34) = 118.615$, $p < .001$, $\eta^2 = .736$ and $1- \beta = 1$. The interaction between both variables was significant but with little explanatory power, $F(11, 374) = 2.756$, $p = .002$, $\eta^2 = .08$ and $1- \beta = .978$. The result of the linear component of the polynomial contrast for the SOA levels was significant ($p < .001$); as SOA between tasks increased, the difference between the response times to both tasks decreased. The pairwise comparisons showed statistically significant differences at $p \leq .001$ between practically all the pairs of SOAs, except for the temporally adjacent ones. These differences disappeared as from the 1700 ms level.
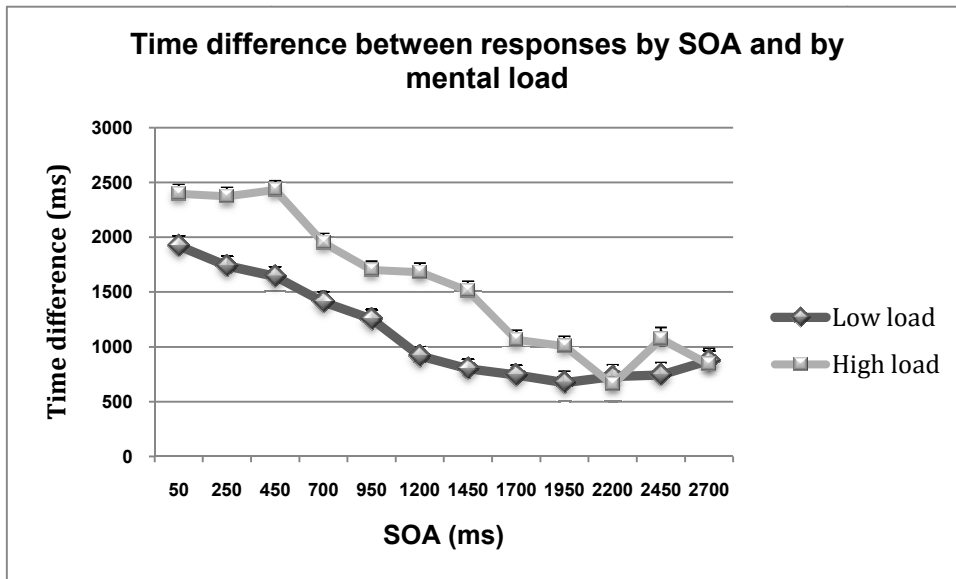
Figure 1. Mean and standard error of the mean of the variable time difference in responses by SOA and mental load.
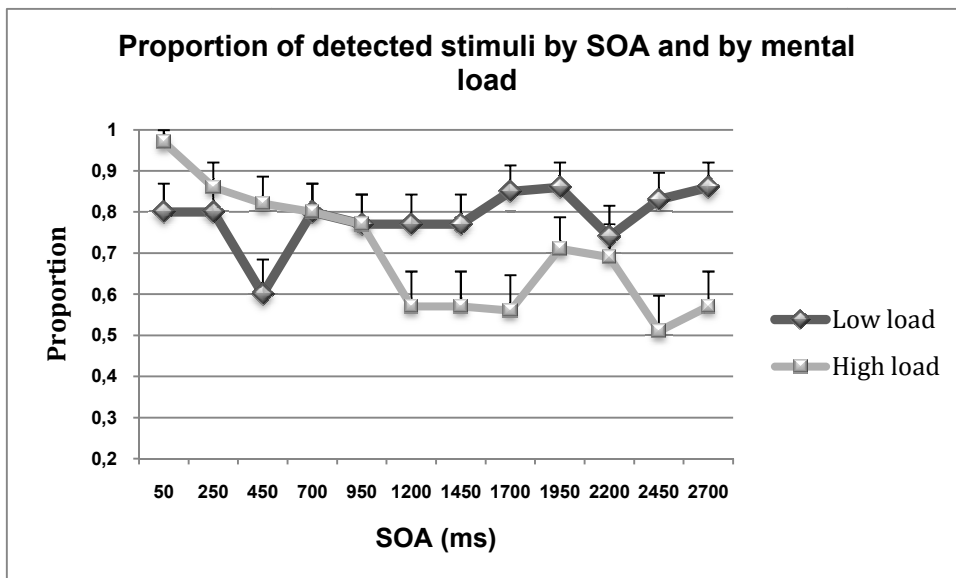

Figure 2. Mean and standard error of the mean of the variable proportion of detected stimuli by SOA and mental load.

For the PDS, the results of the ANOVA yielded statistically significant differences for SOA, $F(11, 374) = 3.267$, $p < .007$, $\eta^2 = .60$ and $1- \beta = .946$; and for the variable mental load, $F(1, 34) = 5.70$, $p = .023$, $\eta^2 = .114$ and $1- \beta = .64$. The interaction of these variables was significant, $F(11, 374) = 2.246$, $p = .047$, $\eta^2 = .507$ and $1- \beta = .809$, indicating that for low SOAs the probability of detecting a stimulus is higher in the HML condition than in the LML condition. A possible explanation is that the same SOA may coincide with different processes in HML and LML. A more detailed explanation can be found in the Discussion section. In the polynomial contrast of the SOA effect, the linear and the quadratic components were significant, $p = .002$ and $p = .041$, respectively.

Interference of the Diverse Processes of the Arithmetic Task with Stimulus Detection

The performance of the arithmetic cognitive task had three clearly differentiated and operationally differentiable moments: oral presentation of the stimulus, mental calculus (from the end of the auditive stimulus until the verbal response), and emission of the response. The analysis of PDS by SOA suggested we should conduct an analysis of PDS by processing moment, because time alone tells us nothing about the processes and it leads to great overlapping, which in turn hinders interpretation. We attempted to determine the moment of the arithmetic-task processing when the obstruction of visual detection was more pronounced. The synchronisation in real time of the data between the register of ocular movements, stimulus presentation, and participants' responses allowed us to determine, with a 20-ms accuracy, at which moment each relevant event of the experiment occurred, at which moment of the arithmetic task the visual stimulus was presented, where the participant was looking when performing mental calculus, etc.

The twelve SOA levels used for each condition allowed us to present the visual stimuli at different moments of the arithmetic task processing, thereby identifying in each trial whether the onset of the visual stimuli coincided with listening to the auditive inputs of the arithmetic task (listening), the moment of calculus of the arithmetic task (thinking), or the moment of responding, or later (responding). A condition referring to the trials in which the appearance of the visual stimuli partially coincided with listening to the auditive stimuli and partially with the moment of calculation for the arithmetic task (between) was also included.

We analysed the PDS, PFA, PLS, and PDS/PLS as a function of processing level of the arithmetic task (listening, between, thinking, and responding). From the perspective of our theory, i.e. that impairment in visual perception is produced by mental effort, we can assume that the intermediate phase, after the auditive input is over, is when the greatest mental effort is carried out. Consequently, we assume that the inattentional blindness effect will be more pronounced for the trials in which the presentation of the visual stimuli coincides with the process of calculating the subtraction (thinking) than for that of listening to the auditive stimuli of the arithmetic cognitive task, or emitting a response, or after having emitted it.

We conducted an ANOVA 4x2 (4 cognitive process x 2 mental load) for each dependent variable. The results of the means and mean standard errors by condition can be seen in Table 4. We include the significance data, effect size, and power, as well as the significance of pairwise comparisons with the Bonferroni method.

No statistically significant differences were found when we analysed PDS by cognitive load, $F_{(1, 34)} = 1.508$, $p < .226$. The results of the analysis, however, reveal statistically significant differences in the PDS for the variable cognitive process, $F_{(3, 102)} = 7.796$, $p < .001$, $\eta^2 = .138$ and $1-\beta = .988$. According to the binary comparisons, there were differences between listening and between ($p < .001$), listening and thinking ($p < .001$), between and responding ($p = .033$), and thinking and responding ($p = .014$), indicating that there is less probability of detecting stimuli when one is beginning to calculate or is calculating (.67 and .66, respectively) than when listening (.85) or responding (.79). In addition, the interaction between these variables was significant, $F_{(3, 102)} = 4.79$, $p = .004$, $\eta^2 = .157$ and $1-\beta = .888$, indicating that the differences found in the variable PDS for the diverse levels of cognitive processing were higher in performance of the HML arithmetic task than the LML task.

No statistically significant differences were found for the variable PFA, although the results show the expected tendency: PFA is higher during the HML condition than during the LML condition and higher during the processes of beginning or performing the calculus versus listening or responding.

The results of the analysis revealed no statistically significant differences in the variable PLS either by mental load, $F_{(1, 34)} = 0.004$, $p = .953$, or by cognitive process, $F_{(3, 102)} = 1.75$, $p = .16$. The effects of the interaction were non-significant, $F_{(3, 102)} = 0.821$, $p = .487$.

Table 4. Mean and standard error (SE) for the variables proportion of detected stimuli (PDS), proportion of looked-at stimuli (PLS), and proportion of detected/looked-at stimuli (PDS/PLS) by cognitive process and mental load.

		PDS		PLS		PDS/PLS	
		Mean	SE	Mean	SE	Mean	SE
LML	Listening	.78	.06	.56	.07	.81	.08
	Between	.72	.03	.53	.04	.67	.05
	Thinking	.77	.06	.46	.07	.89	.08
	Responding	.81	.04	.55	.05	.81	.06
HML	Listening	.93	.04	.49	.05	.97	.06
	Between	.62	.03	.48	.04	.66	.05
	Thinking	.55	.04	.47	.05	.57	.06
	Responding	.77	.07	.57	.08	.75	.09

Note. Low Mental Load (LML) of arithmetic task. High Mental Load (HML) of arithmetic task. Between refers to the presentation of the visual stimuli partially during the listening condition and partially during the thinking condition.

Lastly, according to the ANOVA, no statistically significant differences were found in the PDS/PLS by mental load, $F(1, 34) = 1.599$, $p = .21$, but there were statistically significant differences by the variable cognitive process, $F(3, 102) = 5.678$, $p = .001$, $\eta^2 = .125$ and 1- $\beta = .941$. According to the pairwise comparisons, the differences between the levels of listen and between were significant ($p = .001$) and between listen and think ($p = .019$), indicating that one is less likely to detect a stimulus, even if looked-at, when the visual stimuli appear at the moment of beginning to calculate or when calculating (.66 and .73 respectively) versus listening to the stimulus for the arithmetic task (.89) or responding (.78). Moreover, the interaction of these variables was significant, $F(3, 102) = 3.665$, $p = .019$, $\eta^2 = .197$ and

1- β = .764, indicating that the differences in the number of detected stimuli among those previously looked at for the conditions of cognitive processing were higher in performance of the HML arithmetic task than the LML task.

As in the previous section, Table 5 shows the global data by condition for the d' index and β.

Table 5. sensitivity index (d´) and criterion index (β) by mental load and cognitive process.

Cognitive Process	LML		HML	
	d´	β	d´	β
Listening	4.46	369.29	5.19	310.75
Between	3.84	139.06	3.51	164.54
Thinking	4.22	249.02	3.22	122.4
Responding	4.55	335.37	4.45	372.66

Note. Low Mental Load (LML) of arithmetic task; High Mental Load (HML) of arithmetical task. Between refers to the presentation of the visual stimuli partially during the listening condition and partially during the thinking condition.

Sensitivity is lower for an HML task than for an LML task. In fact, sensitivity is lower for the conditions in which the visual stimulus appears at the start or during the development of the calculus than in the conditions where it appears while participants are listening to the stimulus or responding to the arithmetic task. The criterion adopted by the participants was conservative, but it was more conservative for the conditions of listening and responding than for the conditions of starting or developing the calculus.

DISCUSSION AND CONCLUSIONS

As can be observed in the first part of the results, the two levels of mental load of the arithmetic task are justified. When the participants carried out HML operations, there was a decrease in the correct responses

for this task, and an increase in response times, pupil size, and judgments of effort.

Recarte et al. (2008) showed the efficacy and concordance of performance measures, pupil size, and subjective measures in assessing the mental load of cognitive tasks when they are carried out as simple tasks. When, however, two tasks are carried out simultaneously, a cognitive task along with a visual task, the concordance of the measures is altered; specifically, there is a discrepancy between the pupil size and the rest of the measures. The authors offer the hypothesis that the pupil size reflects the mean mental load of each task separately. Our results support this hypothesis: when the arithmetic task is carried out along with the visual search task, the reaction times and judgments of effort increase, but the pupil diameter decreases.

Once the difference in load of the two levels of cognitive task is verified, we can see how this arithmetic task affects stimulus detection. The mental load of the task affects the PDS. Considering the data from the Helmert contrasts, we can state that performance of the arithmetic cognitive task along with the visual search (versus visual search alone) produces a decrease of correct responses and an increase of false alarms. The same can be said of going from an LML to an HML task; although the differences in false alarms between LML and HML cognitive tasks do not reach significance, the results point in the expected direction. In any event, the linear component of the polynomial contrast, both for the variable PDS and for the PFA, was significant, indicating that, as the mental load increases, visual detection deteriorates. Therefore, these data support the hypothesis that the effort or mental load produces impairment in visual perceptive processing, as has been revealed in prior investigations (Recarte, et al., 2008). In contrast to the current investigation, however, these authors used continuous performance tasks in which there was no evidence about how the participants administered their attention and performance time. Another important difference with this study is that we used two levels of mental load of the same cognitive task and not different cognitive tasks with different levels of mental load, thus eliminating possible explanations in terms of different processing codes.

The descriptive analysis of our results indicates that sensitivity to the visual search task decreases when it is performed together with the cognitive task. That is, mental load produces impairment in the sensitivity to a visual detection task, and such deterioration is higher as the mental load of the task increases. With regard to the criterion, the participants are conservative throughout the diverse conditions although, as the mental load increases, they tend to be increasingly less conservative. The participants

received the instruction to press the S key only if they had seen the target and to press the N key if they had not seen the target, either because they had not had enough time to inspect the wheel of letters or because they had done so but had not located the target. We assume that these instructions could have influenced the participants' adoption of a more conservative criterion.

There are many investigations that conclude that mental load does not deteriorate visual detection (De Fockert, Rees, Frith, & Lavie, 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).

The methodology employed in our investigation (ocular register with simultaneous performance of a visual search task and a cognitive task) allows us to determine whether there is a true effect of inattentional blindness (looking at a stimulus and not seeing it because of lack of attention). Our results indicate that the simultaneous performance of both tasks does not affect the number of looked-at target stimuli. That is, the process of visual search is not affected by the simultaneous performance of a cognitive task. These results differ from those of Pérez-Moreno et al. (2011), in which the cognitive tasks altered both the ocular behaviour in the search for stimuli and the process of their identification. A possible hypothesis is that the influence of the mental load on the ocular pattern in the processes of visual search is related to the spatial and temporal uncertainty of the stimuli to be detected. In the above-mentioned investigation, the participants, not knowing when or where the target would appear, varied their ocular behaviour. In our experiment, spatial uncertainty decreased (the target could only appear in one of the eight marked positions), and the visual field to be explored also decreased (a visual angle of 4°). Moreover, in each trial (whether or not the target appeared), the participant had to respond with yes or no. These differences may have made our participants explore the same number of targets in simple and in dual tasks.

There is a clear effect of mental load on the number of stimuli detected after they had been looked at. Performing a cognitive task reduces the probability of detecting a stimulus that has been or is being looked at. This is the effect known as inattentional blindness, because we have ruled out an effect on the ocular behaviour itself (that performance of a cognitive

task implies a lower number of looked-at target stimuli). Despite the fact that in our results there were no differences between LML and HML, there was an effect in the linear component of the polynomial contrast that allows us to conclude that the higher the mental load, the less the detection of looked-at stimuli. These results support our main hypothesis that it is more likely that a looked-at target will not be recognised when the mental load of a cognitive task is high than when it is low or when there is no mental task.

The theory of the psychological refractory period predicts that, as the SOA between the two tasks increases, the response time to the second task decreases. One way of verifying these results is to calculate the difference between the reaction times for both tasks and to determine how this difference behaves across the diverse SOAs. Consequently, we can state that the third part of our results confirms the predictions of this theory when the first task is arithmetic and the second task is visual search and detection (Figure 1). We verified that, as the SOA between tasks increases, the distance between the response times decreases (the SOA explains 36% of the variance of the difference between reaction times) and this holds for both LML and HML tasks. In the HML condition, the differences between the response times were higher than in the LML condition but this difference disappears as the SOA increases because, once the arithmetic task has been calculated, the visual search task is the same in both conditions. The pairwise comparisons show statistically significant differences between practically all the SOA pairs, except for the temporally adjacent ones.

With regard to stimulus detection, there was interaction between the SOA and the mental load ($\eta^2 = .5$), revealing that, for short SOAs (up to approximately 700-950 ms), participants detected more targets in the HML condition and, with longer SOAs, they detected more targets in the LML condition. A possible explanation is that the appearance of the target stimuli coincides with a different mental sub-process depending on whether the arithmetic task is LML or HML. For example, for SOAs up to 700 ms, the appearance of the target stimulus may coincide with the moment when the subject is calculating if the task was LML, whereas the subject may still be listening if the task was HML, because the stimuli of the HML arithmetic task are longer. This would explain why the participants detected more stimuli in the HML task up to this SOA value.

One result in the PDS as a function of SOA is that, during the performance of an HML task, when the SOA is between 1200 and 1750 ms and around 2450 ms, there is an anomaly in the linear tendency. For the LML condition arithmetic task, however, this brusque decrease in stimulus detection is found at 450 and 2200 ms. A possible explanation, in the same

terms as for the interaction, is that detection is conditioned by the sub-process being performed when the target stimulus appears.

Our experimental methodology allows us to identify the process that the participant is performing when the target stimulus appears. To confirm the above-mentioned hypothesis with regard to the effect of the sub-process, we analysed the detected stimuli and the detected stimuli among those that had been looked at for four conditions: listening to the auditive input, between listening and thinking, thinking, and responding to the arithmetic task. According to our results the cognitive process that the participants are performing at the onset of the target stimulus affects their detection. The condition of having begun to calculate or to be thinking about the arithmetic task when the target stimulus appears is the one that produces the most interference in detection, in comparison with listening or responding to the arithmetic task (or having responded). Moreover, the cognitive process also determines inattentional blindness because it produces differences in the PDS/PLS, and it is the moment of starting or during the arithmetic calculus (thinking) when more blindness to the looked-at stimuli is produced. All this has shown that differences are not an effect on the process of visual search (the PLS is the same for the diverse conditions of the variable cognitive process). Another interesting result in terms of our objectives is the interaction produced between the variables mental load and cognitive process, both in PDS and in PDS/PLS, indicating that the differences found between the diverse levels of the variable cognitive process (listening, between, thinking, and responding) are higher for the HML condition than for the LML condition of the concurrent arithmetic task.

The global results of the sensitivity index again support our hypothesis: mental load produces an effect of visual impediment that is more intense during the moments of processing that involve greater mental effort.

In sum, when participants performed an arithmetic task with two levels of mental load simultaneously with a visual search and detection task, it was found that: (a) the mental load produces inattentional blindness; as the mental load increases, the PDS/PLS decreases; and (b) the effect of inattentional blindness is significantly greater when it coincides with the cognitive process of solving the arithmetic task, in comparison with processes that include a perceptive or motor component such as listening to the task input or responding verbally to it.

RESUMEN

El Papel de la Carga Mental en la Ceguera Atencional. El propósito de esta investigación es determinar si la carga mental de una tarea cognitiva impide el procesamiento de estímulos visuales, es decir, si la carga mental produce ceguera atencional, y en qué momento del procesamiento de la tarea cognitiva se produce más interferencia. Se utilizó una tarea aritmética con dos niveles de carga mental junto a una tarea de búsqueda y detección visual en situación de doble tarea. Se llevó a cabo un experimento con 35 participantes. Un sistema de registro ocular (ASL Model 5000) fue usado para comprobar qué estímulos fueron mirados. Los resultados muestran un deterioro en la tarea de detección al realizar las dos tareas simultáneamente, que es mayor cuando la tarea aritmética fue de mayor carga mental. Dicho deterioro no puede ser explicado por una alteración del patrón ocular. El momento de procesamiento o subproceso de la tarea aritmética que produce una mayor interferencia sobre la detección visual corresponde con el momento puramente cognitivo de cálculo, frente a subprocesos con componentes perceptivos o motores, como escuchar los estímulos o emitir las respuestas.

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