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Personal names do not always survive the attentional blink: Behavioral evidence for a flexible locus of selection ☆

Barry Giesbrecht *, Jocelyn L. Sy, Megan K. Lewis

Department of Psychology, University of California, Santa Barbara, CA 93106, USA

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Abstract

Models of the attentional blink phenomenon (AB) typically assume that unattended information is processed to the post-perceptual level prior to selection for access to consciousness. The present experiments test this assumption by manipulating the perceptual load of the first target task (T1) and whether the second target (T2) was the participant's own name or someone else's name. In three experiments, increasing T1-load increased the severity of the AB for personal names. The results suggest that selection during the AB is not fixed at the post-perceptual stage, but rather the stage at which selection occurs during the AB is flexible.

Keywords: Selective attention; Attentional blink

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1. Introduction

Coherent behavior is supported, in part, by attentional mechanisms that afford selective processing of information in the environment that is consistent with our current behavioral goals. Although selective attention has clear benefits that can be measured in terms of improved behavioral performance and enhanced neural activity evoked in response to attended stimuli (e.g., Corbetta, Miezin, Dobmeyer, Shulman, & Petersen, 1990; Heinze et al., 1994; Hillyard, Hink, Schwent, & Picton, 1973; Mangun & Hillyard, 1991; Posner, 1980; Van Voorhis & Hillyard, 1977), selective attention also has clear and measurable costs. For example, when two masked targets are presented in rapid succession in the same location, correct identification of the first target (T1) leads to impaired identification of the second target (T2). This impairment in conscious report of T2, known as the attentional blink (AB, Raymond, Shapiro, & Arnell, 1992), lasts for about 500 ms and it is generally thought to reflect the temporal distribution of the cost of selectively attending to T1, which renders T2 unattended.

The aim of the present work was to investigate the constraints on the processing of unattended information presented during the AB. Determining the extent to which unattended information is processed has been one of the fundamental issues in the attention literature (e.g., Allport, 1993) and it has been at the center of the historical debate between models of attention that posit that selection occurs early and unattended information is not processed beyond perceptual stages (e.g., Broadbent, 1958) and models of attention that suggest that selection occurs late and unattended information is automatically processed to post-perceptual stages (e.g., Deutsch & Deutsch, 1963).[1] In contrast

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* Corresponding author. Fax: +1 805 893 4303.
E-mail address: giesbrecht@psych.ucsb.edu (B. Giesbrecht).

[1] Throughout the present work we used the term selection to refer to a data reduction process by which a subset of the total amount of information available in the environment is chosen for detailed analysis (e.g., Vul, Nieuwenstein, & Kanwisher, 2008). It must be emphasized that the adoption of this generic definition does not mean to imply that early/perceptual and late/post-perceptual selection are achieved by the same mechanism. Indeed, several studies in the literature have suggested that perceptual and post-perceptual selection are not mediated by a unitary mechanism, but rather that they are likely mediated by different mechanisms (e.g., Marois et al., 2004; Vogel et al., 2005; Yi et al., 2004).

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to these classic views, more recent studies of spatial attention have demonstrated that both perceptual and post-perceptual level selection can occur, depending on task demands (e.g., Lavie, 1995, 2005; Lavie, Hirst, de Fockert, & Viding, 2004; Vogel, Woodman, & Luck, 2005; Yantis & Johnston, 1990). Although these studies offer an important reconciliation to the classic early vs. late selection debate, it is unclear whether changes in the selectivity of attention with changing task demands are a purely spatial phenomenon. Here we address this issue by using the AB as a tool to investigate the influence of task demands on the perceptual and post-perceptual processing of unattended information in the absence of shifts of spatial attention.

1.1. Evidence for post-perceptual processing during the AB

One of the most consistent findings in the AB literature is that despite the severe impairment in conscious report, T2 is processed to a post-perceptual level. Empirical evidence for extensive processing of unattended information during the AB comes from two sources. The first source of evidence is behavioral and electrophysiological studies showing that T2 is processed to the semantic level even though it cannot be reported (e.g., Luck, Vogel, & Shapiro, 1996; Maki, Frigen, & Paulson, 1997; Rolke, Heil, Streb, & Henninghausen, 2001; Shapiro, Driver, Ward, & Sorensen, 1997; Vogel, Luck, & Shapiro, 1998). The first published report demonstrating that information presented during AB is processed to the semantic level used the event-related potential (ERP) technique to measure the magnitude of the N400 ERP component evoked by T2 words (Luck et al., 1996). The N400 ERP component is thought to reflect the outcome of a comparison between current semantic representations with a previously established context and it is observed as a large negative deflection in the ERP occurring approximately 400 ms after the presentation of a stimulus that violates the established context (Kutas & Hillyard, 1980). For example, the N400 evoked by the word 'NURSE' would be larger if preceded by the word 'HORSE' relative to if 'NURSE' had been preceded by the word 'DOCTOR'. Luck et al. (1996) used the amplitude of the N400 component to measure semantic processing of T2 during the AB and found that the size of the N400 for words presented during the AB was as large as the N400 for words presented outside the AB. Luck et al. (1996) argued that the presence of the N400 during the AB indicates that T2 was processed to the post-perceptual level (i.e., fully identified) and compared to the context established by the word presented at the beginning of the trial even though the T2 word could not be reported. The second source of evidence typically offered in support post-perceptual processing during the AB comes from studies demonstrating that specific classes of high-priority information survive the AB (Mack, Pappas, Silverman, & Gay, 2002; Shapiro, Caldwell, & Sorensen, 1997). The first published report demonstrating that high-priority information survives the AB revisited the classic finding that personal names capture attention (Moray, 1959; Wolford & Morrison, 1980). Shapiro and colleagues (1997) presented the subject's own name or someone else's name as the T2 stimulus and they found that while the detection of someone else's name presented during the typical AB window was impaired, the detection of one's own name was not.

A variety of theoretical accounts of the AB have been proposed and each one differs in terms of the explanation of the processing limitation that results in impaired processing of T2. For instance, traditional accounts of the AB explain the deficit in T2 report as a capacity or resource limitation caused by attending to T1 (Chun & Potter, 1995; Duncan, Ward, & Shapiro, 1994; Jolicoeur, 1999; Marois, Yi, & Chun, 2004; Raymond, Shapiro, & Arnell, 1995; Shapiro, Raymond, & Arnell, 1994; Vogel et al., 1998). If T2 is presented during the period when resources are allocated to T1, the encoding of T2 is delayed and during this period of delay it is vulnerable to interference. More recent models have explained the AB not as a resource limitation, but rather as a failure in configuring the information processing system for the second target (Di Lollo, Kawahara, Ghorashi, & Enns, 2005), a failure in the creation of object-level representations (Raymond, 2003), or a generalized selection failure (Olivers & Watson, 2006). Despite the fundamental differences in the nature of the processing limitation proposed to be at the root of the AB, these models explain the finding that semantic information survives the AB even though conscious report is impaired by borrowing from classic late selection theories of attention (e.g., Deutsch & Deutsch, 1963). Specifically, each model assumes that the AB reflects the failure of a post-perceptual selection mechanism that permits unconstrained processing of T2 to a high-level even though conscious report is impaired (Chun & Potter, 1995; Di Lollo et al., 2005; Duncan et al., 1994; Jolicoeur, 1999; Marois et al., 2004; Olivers & Watson, 2006; Raymond, 2003; Shapiro et al., 1994; Vogel et al., 1998).

1.2. Evidence that post-perceptual processing does not always occur during the AB

While there are numerous demonstrations that T2 is processed to a post-perceptual level during the AB, recent evidence suggests that semantic processing of T2 does not always occur (Giesbrecht, Sy, & Elliott, 2007; Vachon, Tremblay, & Jones, 2007). For instance, Giesbrecht et al. (2007) manipulated T1 perceptual load using a flanker task (e.g., Eriksen & Eriksen, 1974) and measured the context-sensitive N400 event-related potential (ERP) component evoked by T2 words. When perceptual load was low, T2 evoked a robust N400 during the typical AB window despite impaired behavioral performance, thus replicating previous studies of the AB. However, when T1 perceptual load was high, the magnitude of the N400 during the AB was completely suppressed. In a similar vein, Vachon et al. (2007) recently reported that when T1 and T2 were semantically related and the tasks required a change in set, either because the targets were presented in different locations or because they required different responses, the extent to which T2 was semantically primed by T1 was reduced. The authors argued that the reduction in the semantic priming effect reflected the fact that the reconfiguration processes required to change task sets prevented post-perceptual processing of T2. When these studies showing attenuated semantic processing during the AB are considered together, they converge on the notion that T2 may not always be processed to the post-perceptual level.

Although the finding that post-perceptual processing of T2 does not always occur challenges the common view in the AB literature, the finding is consistent with studies in the spatial attention literature showing that when a task-relevant stimulus is high in perceptual load, task-irrelevant stimuli presented at nearby locations have less influence on behavioral and cortical responses relative to when the target task is low in perceptual load (e.g., Handy, Soltani, & Mangun, 2001; Lavie & Tsal, 1994; Rees, Frith, & Lavie, 1997). These findings have been explained within the context of models that propose that attention can act to select information at multiple stages of processing depending on task demands (Lavie, 2005; Lavie & Tsal, 1994; Lavie et al., 2004; Vogel et al., 2005). According to one model, known as ‘load theory’ (Lavie, 2005; Lavie & Tsal, 1994; Lavie et al., 2004), changes in the stage at which selection occurs is determined by the amount of perceptual load that is required to process task-relevant information. Specifically, if processing of the task-relevant information does not require all perceptual resources, uncommitted resources automatically ‘spill-over’ to the perceptual processing of task-irrelevant information thereby allowing this information to be processed more extensively even though it is not directly attended. In contrast, if all resources are devoted to the task-relevant information, no spare resources are available for perceptual processing of task-irrelevant information and thus the extent to task-irrelevant information is processed beyond the perceptual level is reduced. In other words, under conditions of low load, the automatic allocation of resources to task-irrelevant information means that attention effectively selects information at relatively later stages of processing, whereas under conditions of high load, attention selects information at earlier stages of processing. While the models explaining the effects of perceptual load are based on empirical studies of the distribution of selective attention over *space*, Giesbrecht and colleagues (2007) proposed that the finding that T1-load affects whether T2 is processed to a perceptual or post-perceptual level during AB suggests that perceptual load also modulates the selectivity of attention over *time*. In the present work, the proposal that T1-perceptual load modulates post-perceptual processing during the AB will be referred to as the ‘load hypothesis’.

1.3. The present study

Whereas previous studies have shown that task demands constrain semantic processing of common words during the AB, the purpose of the present study was to test the influence of task demands on the processing of high-priority information presented during the AB. If the load hypothesis is correct, then not only should T1-load influence semantic processing of common words presented during the AB as the recent evidence suggests (Giesbrecht et al., 2007; Vachon et al., 2007), but T1-load should also influence the extent to which high-priority information survives the AB. To test this prediction, we conducted three experiments that revisited the classic finding that personal names survive the AB (Shapiro, Caldwell, et al., 1997). To provide a strong test of the hypothesis, each experiment employed a different manipulation of T1-load previously used to demonstrate either the influence of T1-load on post-perceptual processing during the AB (Experiment 1) or the influence of load on the spatial selectivity of attention (Experiments 2 and 3). Regardless of the type of perceptual load, the prediction is that under conditions of low load, the present experiments should replicate the finding that personal names survive the AB. In contrast, under conditions of high load, the present experiments should reveal a robust AB for one’s own name. To anticipate the outcome, the results of each experiment demonstrate that T1-load modulates the extent to which personal names survive the AB and thus are consistent with the notion that post-perceptual processing does not always occur during the AB.

2. Experiment 1

The task used in Experiment 1 was similar to that used by Giesbrecht et al. (2007) in which participants were presented with two masked stimuli separated by a variable lag (200–800 ms). The T1 stimulus was a central arrow pointing to the left or right, flanked by task-irrelevant pairs of arrows pointing in either congruent or incongruent directions. The congruent and incongruent conditions will be referred to as the low and high-load conditions, respectively. To test whether T1-load influences the extent to which high-priority stimuli survive the AB, T2 was the participant’s own name or someone else’s name. Participants indicated the direction of the central arrow (T1) and then the gender of the name (T2). T2 accuracy in the dual-task condition was compared to a single task control where subjects reported the gender of the name only. The prediction was that personal names should survive the AB under conditions of low T1-load, but that personal names should be subject to the AB under conditions of high T1-load.

2.1. Method

2.1.1. Participants

Twenty-four University of California, Santa Barbara (UCSB) undergraduates participated in a 45-min session for class credit (mean age = 20; 12 female; all right handed).

2.1.2. Apparatus and stimuli

All stimuli were viewed from a distance of 110 cm on a 19-in. color monitor (1024 × 768; 75 Hz refresh rate) with neutral gray background. Presentation timing was controlled using MATLAB (Mathworks, Inc., Boston, MA) and the Psychophysics Toolbox (Brainard, 1997). T1 stimuli were white and consisted of a central arrow (0.4 × 0.4°) centered between two pairs of arrows (0.4 × 1.1°). The distance between adjacent arrows was 0.15°. T2 stimuli were personal names obtained from each participant at the beginning of the session and from the database of registered birth names available from the US Social Security Administration (http://www.socialsecurity.gov/OACT/babynames/). The 50 most popular male and female names were selected from the most common year of birth of our sample (1987). All names were presented in black uppercase 32 point Arial font. Each character subtended 0.4 × 0.4°. Mask stimuli were strings of black numbers and uppercase letters of the same font and the same length as the respective target.

2.1.3. Design

There were four independent variables: Number of tasks, T1-load, T2-name, and T1–T2 lag. The number of tasks was manipulated by instructing subjects to respond to T1 and T2 (dual-task) or T2 only (single-task). T1-load was manipulated by the direction of the flankers relative to the central arrow and was either low (i.e., >>>>> or <<<<<) or high (i.e., <<><< or >><>>). T2 was either the participant's own name or someone else's name. The participant's own name appeared on 25% of the trials, which matched the frequency of occurrence with previous studies showing that personal names survive the AB (Shapiro, Caldwell, et al., 1997). The temporal lag between T1 and T2 ranged from 200 to 800 ms in steps of 120 ms. The number of tasks was manipulated between subjects ($n = 12$ per condition). All other factors were manipulated within subjects. The T1-load conditions were presented in separate blocks of trials and the order was counterbalanced across subjects. The T1-load conditions were blocked primarily so that the low-load condition of the present experiment was as similar to the experiment reported by Shapiro, Caldwell, et al. (1997), but also because previous studies of the AB have shown that randomly intermixing trials with varying levels of difficulty can bias subjects to assume that all trials will be difficult, which may influence the magnitude of the AB for personal names on low-load trials (Shore, McLaughlin, & Klein, 2001). T2-name and T1–T2 lag were combined factorially and randomly intermixed within a block of trials. Participants completed 10 practice trials and then 480 trials divided into 10 blocks.

2.1.4. Procedure

The participant initiated each trial started by pressing the space bar. After a variable delay (500–1000 ms), T1 appeared and then it was masked (duration = 53.3 ms; T1-mask ISI = 53.3 ms). After the lag elapsed, T2 was presented and then masked (40 ms; T2-mask ISI = 40 ms). On half the trials T2 was a male name and on the other half it was a female name. At the end of the trial, participants were prompted to give their responses. In the dual-task condition, they indicated the direction of the central arrow (left or right) and then the gender of the name (male or female); in the single-task condition, they indicated the gender of the name only. All responses were unspeeded and typed into the keyboard. After the responses, the participant started the next trial when ready. A sample trial sequence is illustrated in Fig. 1.

2.2. Results and discussion

Mean proportion of correct T1 responses in the dual-task condition is shown in Fig. 2. Accuracy was higher in the low-load (0.96) condition than in the high-load (0.81) condition ($F(1,11) = 20.22$, $p < 0.001$). Performance on the T1 task was not affected by whether T2 was the subject's own name or someone else's name (own = 0.88 vs. other = 0.89; $F(1,11) = 1.81$, $p > 0.2$) nor the interaction between T1-load and T2-name ($F < 1$).

Mean proportion of correct T2 responses in the single and dual-task conditions is shown in Fig. 3. Mean accuracy in the single-task condition was based on all trials, whereas the mean accuracy in the dual-task condition was computed based on trials in which T1 was identified correctly. On visual inspection of the data shown in Fig. 3, one can clearly observe four main effects. First, overall accuracy was higher in the single-task condition than in the dual-task condition (single = 0.97 vs. dual = 0.88; $F(1,22) = 14.34$, $p < 0.001$). Second, increasing T1-load reduced overall T2 accuracy from 0.95 in the low-load condition to 0.90 in the high-load condition ($F(1,22) = 15.78$, $p < 0.001$). Third, T2 accuracy improved monotonically as a function of lag ($F(5,110) = 15.19$, $p < 0.001$). Finally, overall accuracy was modulated by T2-name ($F(1,22) = 62.80$, $p < 0.001$), such that observers were more likely to correctly discriminate the T2 gender when the target was the subject's own name (0.96) relative to when it was someone else's name (0.89). Importantly, visual inspec-

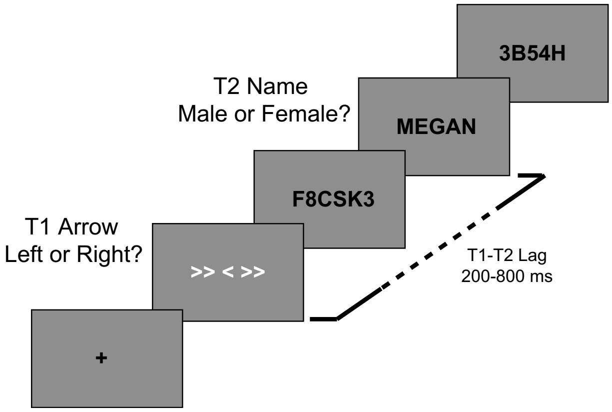

Fig. 1. A schematic representation of the trial sequence. In the trial depicted T1-load is high.

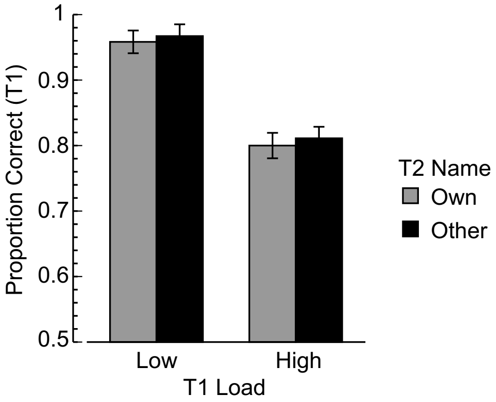

Fig. 2. Mean proportion of correct T1 responses observed in Experiment 1 plotted as a function of T1-load and T2-name. Error bars represent the standard error of the mean (Loftus & Masson, 1994).

tion of the data shown in Fig. 3 also reveals that these main effects were qualified by three significant interactions that are critical to the present hypothesis. First, there was an overall task × lag interaction, such that there was little or no effect of lag in the single-task condition, but a large effect of lag in the dual-task ($F(5, 110) = 5.22$, $p < 0.001$). This interaction is indicative of a robust AB. Second, the task × lag interaction was modulated by load, such that that the difference between the single- and dual-task conditions was largest under conditions of high load, particularly at short lags ($F(5, 110) = 3.69$, $p < 0.005$). This three-way interaction indicates that the AB was more severe under conditions of high T1-load. Finally, there was an interaction between task, load, lag, and T2-name ($F(5, 110) = 2.58$, $p < 0.04$). This interaction was such that under conditions of low T1-load, there was no difference between the single- and dual-task conditions when T2 was the subjects' own name, but a large difference when T2 was someone else's name, particularly at short lags. In contrast, under conditions of high load, single- and dual-task conditions were maximally different at short lags, regardless of T2-name.

To further clarify the influence of T1-load on the severity of the AB, we performed an analysis of AB magnitude. The computation of AB magnitude quantifies the overall severity of the decrement in T2 accuracy and controls for the differences in perceptual difficulty that are independent of the attention-dependent effect of lag. This analysis was performed using the method reported by Jackson and Raymond (2006), in which each individuals' level of performance at the lag producing the minimum level performance in the group mean is subtracted from an optimal performance baseline. In the present work this computation was done in each load condition using accuracy from the single-task control condition at the corresponding lag as the performance baseline. The results of this analysis are shown in Fig. 4. Consistent with previous studies of the AB showing that the severity of the impairment is modulated by T1 difficulty (e.g., Jolicoeur, 1998, 1999; Seiffert &

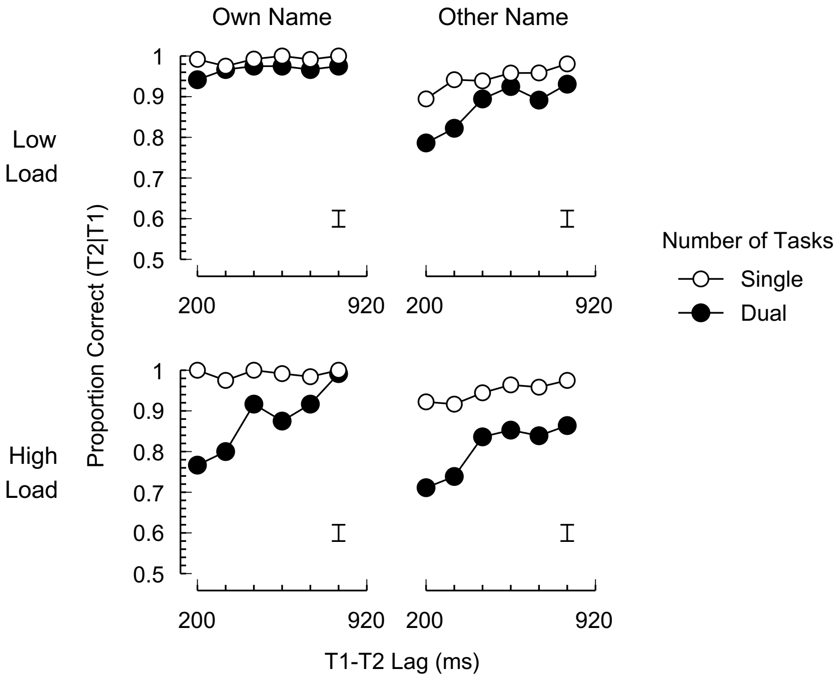

Fig. 3. Mean proportion of correct T2 responses given correct identification of T1 (T2|T1) observed in Experiment 1 plotted as a function of the number of tasks, T1-load, T2-name, and T1–T2 lag. For comparison purposes, the scale of the *x*-axis depicting T1–T2 lag is the same in all figures. For the purposes of clarity stemming from the fact that the standard error of the mean is smaller than the figure symbols, in this and subsequent line-graphs a single error bar is plotted in the lower right of each panel. This single error bar represents +/− one standard error of the mean calculated based on the ANOVA error term for highest level interaction shown in the figure (Loftus & Masson, 1994). In Fig. 3, the error bar calculation was based on the four-way interaction between the number of tasks, T1-load, T2-name, and T1–T2 lag.

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Di Lollo, 1997), the magnitude of the AB in the present work was larger when T1-load was high than when T1-load was low (0.22 vs. 0.12; $F(1,11) = 8.38$, $p < 0.02$). There was also a trend towards a larger AB in the T2-other name condition relative to the T2-own name condition (0.20 vs. 0.14; $F(1,11) = 3.78$, $p < 0.08$). More critically, there was a significant interaction between T1-load and T2-name, such that when T1-load was low, there was a robust AB for someone else's name, but not for one's own name. Indeed, a separate *t*-test revealed that the magnitude of the AB for one's own name was not significantly different than zero ($t(11) = 1.92$, $p > 0.08$). In contrast, when T1-load was high, there was a robust AB for both types of name.[2] In other words, consistent with the load hypothesis, under conditions of low load there was an AB for someone else's name, but not for one's own name; whereas under conditions of high load, there was an AB for both types of name.

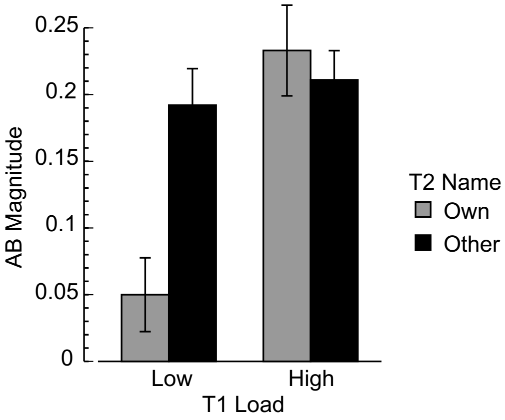

Fig. 4. Mean proportion AB magnitude in Experiment 1 plotted as a function of T1-load and T2-name.

3. Experiment 2

The purpose of Experiment 2 was to test the load hypothesis using a manipulation of T1-load directly based on models that account for the influence of perceptual load on the spatial selectivity of attention. The most prominent of these models the load theory of selective attention (for a recent review of this model see Lavie, 2005). According to this theory, one of the key determinants of perceptual load is the number of items that need to be perceptually identified.[3] In Experiment 2 we used this definition to determine the manipulation of load. Specifically, we changed the T1 task to a parity judgment task in which perceptual load was manipulated by changing the number of items that had to be identified. In the low-load condition, the T1 stimulus was a row of equals signs with a single number in the middle of the row (e.g., ==5==) and the task was to indicate the parity of the digit. In the high-load condition, the T1 stimulus was a row of equals signs with two numbers on either end (e.g., 5===4) and the task was to indicate whether the parity of the digits was the same or different. According to load theory, comparing the parity of two numbers, which requires both numbers to be identified, should be higher in perceptual load than determining the parity of a single number (e.g., Lavie, 2005). Despite this change to the T1 task, the prediction was the same as in Experiment 1: there should be an AB for one's own name under conditions of high load, but not under conditions of low load.

3.1. Method

3.1.1. Participants

Sixteen UCSB undergraduates participated in a 45-min session for class credit (mean age = 19; 12 female; 1 left handed).

3.1.2. Apparatus and stimuli

T1 was either a single digit flanked by two pairs of equals signs (e.g., ==4==) or it was a pair of digits separated by three equals signs (e.g., 8===6). The target stimulus was black and subtended 0.4 × 2.6°. T2 and the mask stimuli were created in the same manner as Experiment 1.

3.1.3. Design

The independent variables in this experiment were: T1-load, T1–T2 lag, and T2-name. T1-load was either low or high. In the low-load condition, T1 was a single digit flanked by pairs of equals signs; in the high-load condition, T1 was two digits separated by three equals signs. T1–T2 lag was either 320, 400, or 920 ms. Third, T2 was either the subject's own name or someone else's name. All variables were manipulated within subjects. The T1-load conditions were presented in different blocks of trials (order counterbalanced), whereas T1–T2 lag and T2-name were randomly intermixed within a block of trials.

3.1.4. Procedure

The procedure was similar to Experiment 1, with the following exceptions. First, subjects always responded to both T1 and T2. Because only the dual-task condition was included, the effect of T1–T2 lag will be used as an index of the AB (e.g., Chun & Potter, 1995). Second, on low-load trials subjects indicated the parity of the single digit and then the gender of the name; on high-load trials they indicated whether the parity of the two digits was the same or different and then the gender of the name. Third, to ensure T2 performance was not at ceiling, overall T2 accuracy was titrated using visual noise dots (e.g., Giesbrecht, Bischof, &

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[2] It is worth noting parenthetically that the finding that personal names are not always processed automatically is not novel. Indeed, even in Moray's (1959) original study, only one third of the subjects noticed their own name on the unattended channel, a result that has been replicated more recently by Wood and Cowan (1995).

[3] This definition perceptual load is only one of several that have been proposed by Lavie and her colleagues (e.g., Lavie, 2005; Lavie et al., 2004). The purpose of adopting this definition here is to provide a touchstone to the previous work and is not meant to imply that we are assuming that this is the only definition of perceptual load. Indeed, the concept of perceptual load has yet to be defined precisely both at the behavioral and neural level.

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Kingstone, 2003). At the start of the experiment, every T2 stimulus included 30 black dots (5 pixel diameter) randomly positioned over the name. After 24 trials, if T2 accuracy (collapsed across all conditions) was above 87.5% (21 correct out of 24), then the number of dots was increased by 10; if accuracy was below 66.7% (16 correct out of 24), then the number of dots was reduced by 10. It is important to note that because this procedure collapsed across all conditions, it is possible that some individual conditions could fall outside of the 66.7–87.5% range.

3.2. Results and discussion

Mean proportion of correct T1 responses is shown in Fig. 5a. Overall accuracy was 0.92 and participants were more accurate in the low-load condition than in the high-load condition (0.94 vs. 0.88; $F(1,15) = 13.01$, $p < 0.003$). T1-accuracy was neither affected by T2-name nor by the T1-load × T2-name interaction (both Fs < 1).

Mean proportion of correct T2 responses given correct identification of T1 is shown in Fig. 5b. There were two key results. First, performance was better at long lags than at short lags ($F(2,30) = 4.64$, $p < 0.02$). Within the context of the present experiment, in which there is only a dual-task condition, this effect of lag is indicative of a robust AB. Second, and most critically, there was a significant interaction between T1-load, name, and lag ($F(2,30) = 3.60$, $p < 0.04$), such that under conditions of low load, there was no effect of lag for one's own name, but a large effect of lag for someone else's name; in contrast, under conditions of high load, there was an effect of lag, regardless of name type. In addition to these key findings, the analysis of Experiment 2 also revealed a trend towards lower overall T2 accuracy in the high-load condition than in the low-load condition (0.74 vs. 0.77; $F(1,15) = 4.37$, $p < 0.06$) and that, as in Experiment 1, overall T2 accuracy was better in the own name condition relative to the other name condition (0.84 vs. 0.65; $F(1,15) = 35.90$, $p < 0.001$).

Again, we performed an additional analysis of AB magnitude. As in Experiment 1, AB magnitude was computed using the Jackson and Raymond (2006) method, but because there was no single target control condition, performance at the 920 ms lag served as the baseline.[4] The results of this analysis are shown in Fig. 5c. Again, this analysis clearly revealed the influence of T1-load on the severity of the AB for personal names, such that there was a significant interaction between T1-load and T2-name ($F(1,15) = 5.74$, $p < 0.04$). Consistent with the load hypothesis, this interaction was such that the AB for the participants' own name was attenuated relative to the AB for someone else's name under conditions of low load, whereas both names were subject to an AB under conditions of high load.

In addition to providing further support for the load hypothesis, Experiment 2 also rules out two alternative explanations for the pattern of results observed in Experiment 1. First, it is possible that the increased AB for personal names observed in Experiment 1 was due to subjects restricting their focus of spatial attention tightly on the location of the central arrow for the duration of the trial. While this strategy would facilitate exclusion of the distractors, it would result in much of the T2-name falling outside the focus of attention. Experiment 2 rules out this possibility because subjects could not attend to a single location, but rather they had to attend to more of the T1 stimulus in the high-load condition, permitting more of the T2 stimulus to fall inside the focus of spatial attention. Moreover, the hypothesis that a restricted focus of attention was the cause of the increased AB for personal names in Experiment 1 predicts that an increased AB for personal names should have been observed in the low-load condition of Experiment 2, where the discrimination was based on a single number at fixation. However, no such increase was observed. Second, because in Experiment 1 the flanking distractors were visually similar to the target and they mapped onto a competing response, it is unclear whether the source of interference giving rise to the AB for personal names was due to perceptual conflict, response conflict, or some combination of the two. Experiment 2 demonstrates that response conflict is not the sole source of interference because the distractors (i.e., equals signs) did not map onto a competing response. Thus, when the experiments are considered together, they provide strong evidence that the perceptual demands imposed by T1 constrain processing of personal names during the AB.

4. Experiment 3

Although load theory posits that the key determinant of perceptual load is the number of items that need to be perceptually identified (e.g., Lavie, 2005), several studies have shown that other manipulations can have similar effects on the processing of task-irrelevant or otherwise unattended information. For instance, Yi, Woodman, Widdlers, Marois, and Chun (2004) demonstrated that increasing the perceptual demands of a task using visual noise caused reductions in neural activity in areas of visual cortex that were activated by task-irrelevant information under conditions of low perceptual demand. Borrowing from this work, Experiment 3 tested the load hypothesis of post-perceptual processing during the AB by manipulating T1-load

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[4] Although the use of the longest lag in the dual-task condition as the performance baseline in the computation of AB magnitude is different than in Experiment 1, it is precisely the baseline used by Jackson and Raymond (2006). The difference in baselines between Experiments 1 and 2 is likely the cause of the overall differences in magnitude between the two experiments. For completeness, we performed an additional analysis on the results of Experiment 1, using the longest lag in the dual-task condition as the performance baseline in the computation of AB magnitude. Importantly, although the change in baseline resulted in an overall AB magnitude that was smaller than the original analysis, the magnitude in this second analysis was similar to that observed in Experiment 2 and, more importantly, despite the change in the baseline the interaction between T1-load and T2-name remained.

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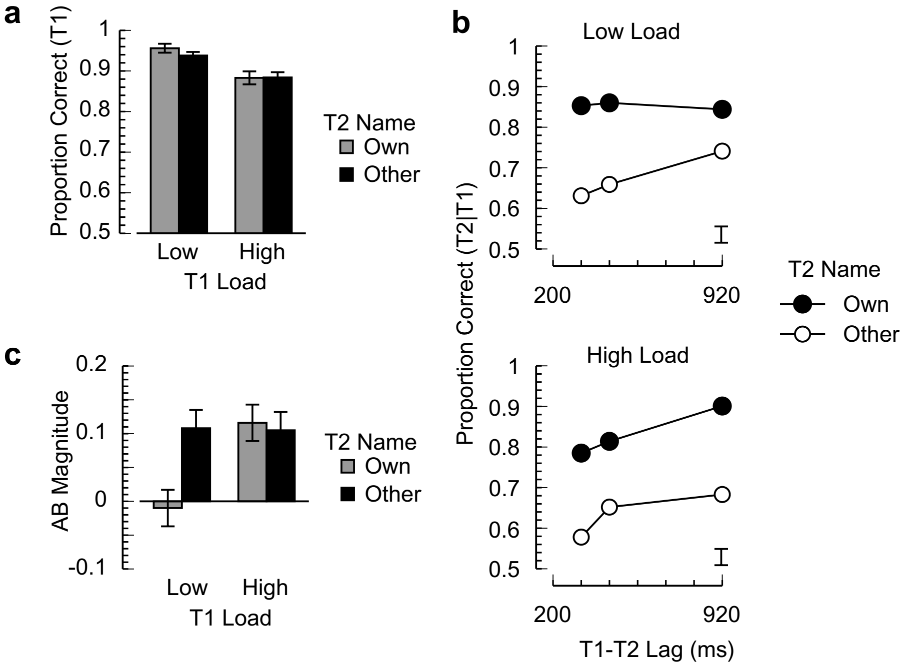

Fig. 5. Results of Experiment 2. (a) Mean proportion of correct T1 responses plotted as a function of T1-load and T2-name. (b) Mean proportion of correct T2|T1 responses in plotted as a function of T1-load, T2-name, and T1–T2 lag. (c) Mean proportion AB magnitude plotted as a function of T1-load and T2-name.

using visual noise. The T1-task was the same as the high-load condition of Experiment 2, except that T1 stimulus could be presented alone or embedded in a variable amount of visual noise. Based on the results of Experiment 2, the parity task should result in a robust AB for personal names even without visual noise. Thus, the key question in Experiment 3 is whether the additional perceptual demands caused by the noise dots will result in additional modulations in the severity of the AB for personal names.

4.1. Method

4.1.1. Participants

Fifteen UCSB undergraduates participated in a 45-min session for class credit (mean age = 20; 6 female; 13 right handed).

4.1.2. Apparatus and stimuli

T1 was a pair of digits separated by three equals signs (e.g., 8===6). The target stimulus was black and subtended 0.4 × 2.6°. T2 and the mask stimuli were created in the same manner as Experiment 1.

4.1.3. Design

There were three independent variables. First, T1-load was manipulated by presenting black noise dots (5 pixel diameter) in random locations over the T1 stimulus. There were four levels of dots: 0, 20, 40, and 60. These noise levels were selected based on the results of a pilot study in which a separate group of subjects performed the T1 task in isolation. Second, T2 was the subject's own name or someone else's name. Third, T1–T2 lags were 320, 400, and 920 ms. T1-dots, T2-name, and T1–T2 lag were combined factorially and randomly intermixed within the experimental blocks. Subjects participated in 10 blocks of 48 trials.

4.1.4. Procedure

All aspects of the procedure were the same as the high-load condition of Experiment 2.

4.2. Results and discussion

Mean proportion of correct T1 responses is shown as a function of the number of noise dots in Fig. 6a. As revealed by visual inspection of the data, T1-accuracy declined monotonically as the number of dots increased ($F(3,42) = 80.20$, $p < 0.001$). This pattern of performance was not affected by the type of name that was presented after T1 or by the interaction between T1-load and T2-name (both Fs < 1).

Mean proportion of correct T2 responses given correct identification of T1 is shown in Fig. 6b. There were three main effects. First, performance was better at long lags than at short lags ($F(2,28) = 27.17$, $p < 0.001$), indicative of a robust AB. Second, there was an effect of T2-name ($F(1,14) = 52.28$, $p < 0.001$), such that people were more accurate overall when T2 was their own name than when it was someone else's name. Critically, there was an effect of T1-load, such that performance was worse when there were more dots on T1 ($F(3,42) = 3.14$, $p < 0.04$). None of the interactions were significant.

As with the previous experiments, an analysis of AB magnitude was performed. The results of this analysis are shown in Fig. 6c. The only reliable effect was a significant increase in the magnitude of the AB for both types of name as the number of T1-dots increased ($F(3,42) = 3.94$, $p < 0.02$). Interestingly, the monotonic increase in AB magnitude that occurred as the number of T1-noise dots increased mirrored the observed monotonic decrease in T1 performance. Thus, the present experiment supports the load hypothesis that perceptual load constrains post-perceptual processing during the AB.

5. General discussion

The purpose of the three experiments reported here was to investigate the influence of T1 perceptual load on the processing of high-priority, personally salient information presented during the AB. Each experiment employed a different manipulation of T1 perceptual load and measured the resulting impact on the magnitude of the AB for personal names. In Experiment 1, T1-load was manipulated using a flanker task. The results demonstrated that under conditions of low load, there was no AB for one's own name, but that under conditions of high T1-load there was a robust AB for one's own name. In Experiment 2, T1-load was manipulated by varying the number of items that had to be identified. Again, there was an AB for personal names under conditions of high load, but not under conditions of low load. Finally, in Experiment 3 T1-load was manipulated using visual noise dots and the results demonstrated that as the amount of visual noise increased, the magnitude of the AB for personal names also increased. These experiments provide data that are consistent with the load hypothesis that posits that increased T1 perceptual load constrains processing of subsequently presented high-priority information during the AB, while at the same time replicating previous studies that reported that high-priority information can survive the AB (Mack et al., 2002; Shapiro, Caldwell, et al., 1997).

In addition to providing strong support for the hypothesis that the perceptual demands imposed by T1 limit post-perceptual processing of high-priority information during the AB, the present results dove-tail with recent studies showing that semantic and perceptual processing of more mundane stimuli can also be constrained during the AB. These studies include the finding that the N400 can be suppressed under conditions of high T1-load (Giesbrecht et al., 2007) and the finding that switches of task set reduces semantic processing of T2 (Vachon et al., 2007). As a compliment to these recent studies showing that semantic processing can be impaired during the AB, other recent ERP work suggests that stages of perceptual processing that occur prior to the extraction of meaning may, under some conditions, be delayed. These studies have focused on the N2pc (N2 posterior contralateral) ERP component, which is thought to reflect processes involved in the allocation of

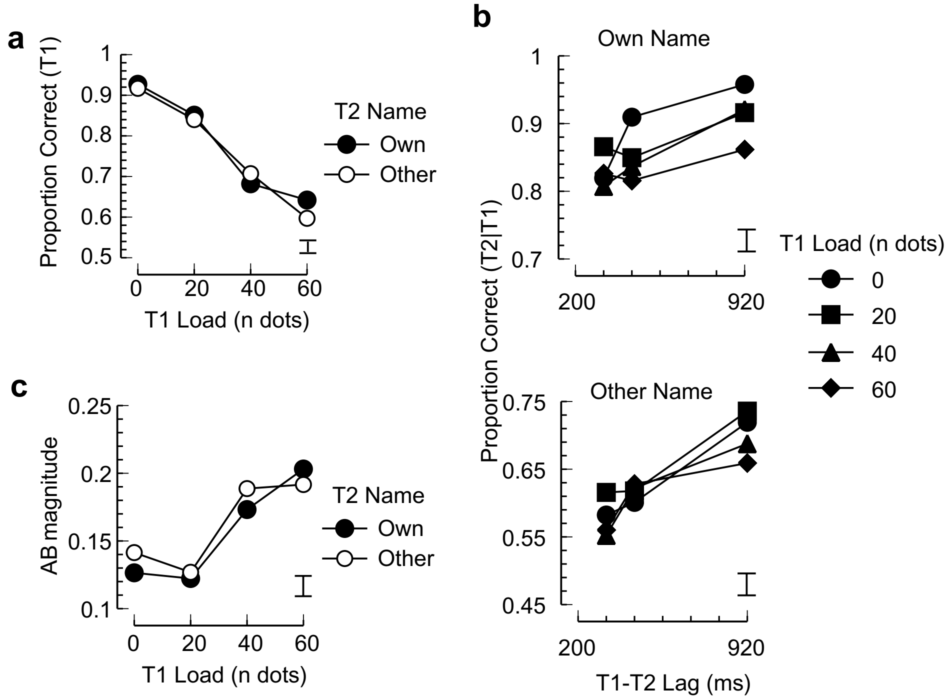

Fig. 6. Results of Experiment 3. (a) Mean proportion of correct T1 responses in plotted as a function of T1-load and T2-name. (b) Mean proportion of correct T2 responses plotted as a function of T1-load, T2-name, and T1–T2 lag. Because the main effect of name was large, but did not interact with lag or the number of dots, the *y*-axes are different, but cover the same range so as to facilitate comparison of the effect of dots and lag. (c) Mean AB magnitude plotted as a function of T1-load and T2-name.

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perceptual processing resources to facilitate selection of a target from amongst distractors (e.g., Eimer, 1996; Luck & Hillyard, 1994; Woodman & Luck, 1999). In several studies, Jolicoeur and colleagues (Dell'Acqua, Sessa, Jolicoeur, & Robitaille, 2006; Jolicoeur, Sessa, & Dell'Acqua, 2006a; Jolicoeur, Sessa, Dell'Acqua, & Robitaille, 2006b) have found that the N2pc evoked by a peripherally presented T2 during the AB is suppressed if distracting stimuli are also presented simultaneously with the target. Because the N2pc is thought to reflect relatively early (i.e., pre-semantic) stages of processing, the attenuation of the N2pc component during the AB suggests that under some conditions perceptual level processing can be compromised during the AB. Thus, the present findings showing that T1-load modulates the magnitude of the AB for personal names and the previously published findings of modulated behavioral and electrophysiological indices of semantic and perceptual processing during the AB support the conclusion that information presented during the AB is not always processed to a post-perceptual level.

Besides the convergence with other studies of the AB, the present work showing that the temporal distribution of selectivity is modulated by T1-load converges with studies in the broader attention literature showing that increased perceptual load modulates the spatial distribution of selectivity. For instance a large number of behavioral, electrophysiological, neuroimaging studies have shown that increases in task-relevant perceptual load reduces behavioral interference caused by task-irrelevant stimuli and that increases in task-relevant load are associated with reductions in neural activity in areas of cortex that represent the task-irrelevant information (e.g., Handy et al., 2001; Lavie, 1995; Lavie & Tsal, 1994; Pessoa, McKenna, Guitierrez, & Ungerleider, 2002). Importantly for the present work, these studies demonstrated modulations in the selectivity of spatial attention using a wide variety of task-irrelevant stimuli ranging from simple letters and shapes (e.g., Handy et al., 2001; Lavie, 1995; Rees et al., 1997; Vogel et al., 2005) to high-priority, personally salient information such as personal names (Harris & Pashler, 2004) and emotional faces (Pessoa, Kastner, & Ungerleider, 2002; Pessoa, McKenna, et al., 2002). The findings that the spatial and temporal distribution of post-perceptual processing of task-irrelevant or otherwise unattended information is affected by load can be explained by appealing to the load theory of selective attention (e.g., Lavie 2005). This theory assumes that the perceptual system devotes all of its available resources to sensory processing. According to this scheme, if the sensory processing demands overload the perceptual system, then attention acts to divert resources to task-relevant inputs, resulting in increased selectivity and reduced influence of task-irrelevant information. If, however, the sensory processing demands do not overload the perceptual system, then resources are allocated not only to task-relevant information, but also task-irrelevant information. Thus, under conditions of low load, task-irrelevant information has the potential to interfere with task-relevant behavior and has the potential to evoke neural responses. A secondary consideration in this scheme is that the extent to which task-irrelevant information is fully identified at the perceptual level is not only a function of the demands imposed by processing the task-relevant information, but it is also a function perceptual resources required to process the task-irrelevant information itself. Specifically, even if the system is taxed to a high degree by the task-relevant information, if the task-irrelevant stimulus happens to require fewer resources to process at the perceptual stage, as may happen if it is something with which the observer is highly experienced or that is personally salient (e.g., one's own name), then the stimulus will be more likely to interfere with task-relevant behavior or evoke neural response relative to stimuli that require more perceptual resources. Based on this scheme, we argue that while the low-load T1 tasks were sufficient to cause an AB, they did not completely deplete the perceptual resources, thereby leaving some resources available for the perceptual processing of T2. Critically, in each of the three experiments reported here, overall accuracy was higher when T2 was the subject's own name than when it was someone else's name, suggesting that either because of the repeated exposure to our own name or because of it's personal salience, or for both reasons, personal names are easier to perceptually identify than other names and presumably they require fewer perceptual resources to identify. Thus, even though the low-load T1 task taxed the system enough to cause an AB for other names, given the relatively high-level of performance, it seems likely that the resources were not completely depleted allowing some resources to spill-over to the processing of T2. Importantly, according to this scheme we also argue that the high-load condition was enough to tax the system to the extent that the perceptual resources were completely depleted, thus, regardless of name type, it would reduce the likelihood that even personal names would be fully identified during the AB.

Appealing to load theory also reconciles the present findings with previous studies showing that high-priority information survives the AB. First and foremost, we argue that T1 task used by Shapiro, Caldwell, et al. (1997) did not place a severe enough demand on perceptual selection processes. In the Shapiro, Caldwell, et al. (1997) paradigm, the T1 task was to name the identity of the single white word in the display sequence. This word was always chosen out of a set of 10 possible items and never in the course of the experiment did it appear as a distractor. The fact that only a single item was required to be identified and there were no other items presented simultaneously with T1, this task, while sufficient to cause an AB for many stimuli, would likely be enough to leave minimal resources available to process a personal name enough for detection. In a similar vein, Mack et al. (2002) reported that cartoon smiley faces survived the AB and argued that the saliency of the happy faces permitted them to be processed without attention. However, as with the Shapiro, Caldwell, et al. (1997) task, Mack et al. (2002) used a T1 task in which the stimulus was the only red item in the RSVP stream. We argue that this task is relatively low in perceptual demand and when coupled with their finding that overall discrimination of T2-faces was better than any of the other stimuli they used, suggest that enough perceptual resources remained after allocating to the T1 item to process the happy face to the point of recognition.

Although the present results are consistent with the load hypothesis, there are three important caveats that are worth noting. First, it must be emphasized that, we are not proposing that the AB itself is determined by perceptual load only. Indeed, there is no question that the AB is sensitive to post-perceptual factors (e.g., strategic, motivational, response-related, etc.). Second, we are also not proposing that perceptual load is the only factor that serves to reduce post-perceptual processing during the AB. Third, although load theory provides a general definition of perceptual load, this is only one definition. Indeed, while the results of Experiment 3 and other studies in the literature (e.g., Yi et al., 2004) show patterns that are consistent with load theory, the manipulation of load used to obtain those results (i.e., visual noise dots) is not what load theory would precisely define as perceptual load. Indeed, future work is needed to define what precisely constitutes perceptual load at the behavioral and neural level. These caveats aside, what we are proposing is that, to the extent the present manipulations of T1-load affect perceptual-level selection, the present results demonstrate that perceptual load is *sufficient* to modulate the magnitude of the AB and that perceptual load is *sufficient* to modulate the extent to which high-priority information is processed during the AB. Critically, when the present findings are considered together with previous studies showing that the AB is modulated by post-perceptual factors, they converge on the notion that the AB is not a unitary phenomenon (e.g., Kawahara, Enns, & Di Lollo, 2006) and that it can be modulated by early-stage perceptual factors, by late-stage central capacity limitations, or by a combination of the two.

5.1. Implications

A variety of models have been proposed to account for the AB. Despite their variety, the one commonality of these models is that each assumes that T2 is always processed to the post-perceptual level (Chun & Potter, 1995; Di Lollo et al., 2005; Duncan et al., 1994; Jolicoeur, 1999; Marois et al., 2004; Olivers & Watson, 2006; Raymond, 2003; Shapiro et al., 1994; Vogel et al., 1998). According to this assumption all stimuli are initially handled by a high-capacity processor that fully identifies information prior to selection and consolidation for report in a manner similar to that proposed by classic late selection models of attention (e.g., Deutsch & Deutsch, 1963). The present finding that high-priority information does not always survive the AB as well as other findings showing attenuated semantic processing during the AB challenges the common theoretical assumption that all information presented during the AB is processed to a post-perceptual level. However, all current models of the AB could be modified to handle the present results if is assumed that the resources of the initial high-capacity processor are not unlimited and that they are allocated based on the principles of load theory. In other words, if the perceptual load of the T1 task overloads the initial processing stage, then automatic post-perceptual processing of T2 would be prevented. If the initial processing stage is not exceeded, then post-perceptual processing of T2 would proceed to the extent afforded by the available perceptual resources and by the nature of the T2 stimulus. Importantly, the dynamics of this process would occur independent of the specific functional limitation implicated by each theory of the AB. As a result, the primary implication of the present work with respect to models of the AB is to more completely specify the models rather than to discriminate between them.

Beyond the scope of the AB, the finding that the extent to which personal names survive the AB depends on task demands supports theoretical frameworks that suggest that attentional selection can occur at either perceptual or post-perceptual stages of processing (Lavie & Tsal, 1994; Lavie et al., 2004; Vogel et al., 2005; Yantis & Johnston, 1990; Yi et al., 2004). These frameworks are supported by functional neuroimaging and neurophysiological studies showing that attention influences processing at almost every stage of visual processing, from high-order association areas to the lateral geniculate nucleus (Astafiev et al., 2003; Chelazzi, Miller, Duncan, & Desimone, 1993; Corbetta et al., 1990; Hopfinger, Buonocore, & Mangun, 2000; Moore & Fallah, 2004; Noesselt et al., 2002; O'Connor, Fukui, Pinsk, & Kastner, 2002). Thus, in contrast to the debate between traditional early (Broadbent, 1958, 1971) and late selection views of attention (Deutsch & Deutsch, 1963), this recent work suggests that visual attention is not fixed at either early or late stages of processing, but rather that attention is a multi-level selection process that can change flexibly depending on task demands and behavioral goals (Kastner & Pinsk, 2004; Lavie, 2005; Lavie & Tsal, 1994; Lavie et al., 2004; Vogel et al., 2005; Yantis & Johnston, 1990; Yi et al., 2004). Whereas much of the previous work offered in support of this flexible selection view has come from studies demonstrating that concurrent task demands modulate the selectivity of attention over space, the present work coupled with other emergent evidence from the AB literature (e.g., Dell'Acqua et al., 2006; Giesbrecht et al., 2007; Jolicoeur et al., 2006a, 2006b; Vachon et al., 2007) demonstrates that perceptual demands also impact the selectivity of attention over time.

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