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The Effect of Cognitive Load and Meaning on Selective Attention

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Abstract

Nillie Lavie's Load Theory of selective attention suggests that the size of the cognitive load affects selective attention ability: the larger the cognitive load, the poorer the selective attention performance. Other authors have found that the relationship between distracting and relevant information can influence how well distractors are ignored. Our study hypothesized that a) larger cognitive load would (as previously shown) hinder reaction time on a selective attention task, b) that distractors (words) semantically related to the words being held in memory (as part of the cognitive load manipulation) would be more distracting than unrelated and neutral distracters. The findings instead showed that unrelated distractors were more distracting.

Lavie's Load Theory of selective attention suggests that the quantity of stimuli presented to a person determines how their selective attention system will function – whether they will be more or less distractible (Lavie, Hirst, de Fockert, & Viding, 2004). The Load Theory suggests that selective attention consists of two mechanisms: a passive, perceptual system, and an active mechanism of cognitive control. The perceptual system functions in line with the early selection model, where the number of stimuli modulates the effectiveness of attentional selection. When there is a low load on the perceptual system – as in a visual search task with few (1-3) items to search through – there is extra, unused perceptual capacity that involuntarily picks up other (irrelevant, distracting) environmental information, and the person is more likely to perceive distractors. In a high perceptual load condition, the opposite is true: the task uses up all attentional capacity, and extra environmental elements can't interfere. In this model, the second stage of selective attention is an *active*, cognitive process. In conditions of high cognitive load, where most of the person's cognitive capacity is consumed with a difficult working memory task, for example, the person has few cognitive resources available to resist distraction by irrelevant information. The person can better disregard distractors in a low-cognitive load condition. When the working memory (or other task) contains fewer items, there is more cognitive capacity available to focus on relevant information, while effectively weeding our perceived distractors. This cognitive system only comes into play in conditions of low perceptual load, when distractors have been perceived and need to be actively suppressed (Lavie, Hirst, de Fockert & Viding 2004; Lavie & Cox, 1997; Lavie, 1995).

Many studies have addressed the intricacies of this model, usually using simple, single letter or digit stimuli. Past studies used stimuli that are unrelated to each other and that carry as little semantic information as possible. Presumably, they do this to get at the attention issue in its purest form, with the simplest stimuli possible. Stimulus material used in past studies includes letters, numbers, colors, and simple black and white symbols. Few have examined the model in relation to the semantic, content of the stimuli. This raises the obvious questions: are distractors more distracting when they are meaningfully related to task-relevant information? Is this effect modulated by cognitive load?

Most of the work done to test Load Theory has focused on the perceptual mechanism of selective attention. Lavie and colleagues have investigated the effect of cross-modal distractor presentation in a decision task, and the possible relationship between the cognitive load resulting from task-switching between and within sensory modalities (Rees, Frith & Lavie, 2001; Brand-D'abrescia & Lavie 2008). Only Lavie's 2004 study has really addressed the effect of cognitive load on selective attention tasks. This makes sense; the question of involuntary attention grabbing by stimuli is a more direct way to study selective attention, and according to the Lavie model, the cognitive system plays only a supporting role in attention control. However, we wanted to investigate the effect of cognitive load further. The current study investigated the impact of the cognitive load on selective attention. More specifically, we examined what effect, if any, the semantic content of the information being held in working memory has on distractibility when distractors are related to the information in working memory. Lavie et al.'s 2004 study used digits to compose their memory sets, the current study used words. By using words instead of digits, the memory set words could be related to each other, and could allow for distractors to also be related (or not) to the words in the memory set. By manipulating the meaningful relationships between memory set and distractor we hoped to have an effect on distractor interference.

One study has examined the effects of distractors with semantic meaning (words) when that meaning is either task congruent or non-congruent. Fabrice Parmentier (2008) found that task-relevant and task-irrelevant novel distractor words modulated performance of a decision task in a way that suggested that the words were semantically analyzed immediately following presentation. Specifically, when an auditory distractor word (either 'left' or 'right'), presented simultaneously with a target arrow, was incongruent with the direction of a target arrow, it took longer than with a congruent distractor word for participants to identify the direction of the arrow. This suggests that task relevant information can be more distracting than task irrelevant information. It should be noted, however, that this interference did not occur when the congruent and incongruent distractors were standard distractors (presented on every trial). The authors conducted two different manipulations of the neutral:word distractor ratio, and observed interference only when a neutral distractor was used (a sinusoidal tone) on 80% of trials, and congruent and incongruent distractors each appeared in 10% of trials. This indicates that interference occurred only when the meaningful distractors were novel as well. (The current study also examined the interference caused by semantically relevant and irrelevant distractors, but in a uni-modal design. Parmentier (2008) used a bimodal design, with auditory distractor words and a visual decision task.)

Lavie and colleagues have also manipulated the similarity of the distractor and the target in a visual search task. For example, in sections of her study outlining the two-part attention model, half of the distractors would be the same as the target (X and X), and half of them would be different (X target with N distractor) (Lavie et al., 2004). These studies have shown that task non-congruent distractors cause greater interference with attention control than congruent distractors. Still, these studies used only stimuli and distractors without semantic meaning.

Lavie and Forester (2008) noted that most selective attention studies (including most of Lavie's own) utilize the same or similar stimuli as the distractor item and target item (i.e. black and white letters, numbers, symbols, etc.). Therefore, the experimenters focused on the effects of truly-task irrelevant distractors, distractors that were completely unrelated to the target stimuli. Such studies are valuable because they aim to more closely simulate real-world distraction and selective attention in a controlled clinical setting. During a visual search task, participants had to identify whether an X or an N was present. During the task standard distractors (X or N) were presented in 80% of trials, related distractors (similar to target items) were presented in 10% of trials, and unrelated distractors (images of cartoon characters) were presented in the remaining 10%. They found that these novel distractors could create more disruption of performance than standard distractors, but only when participants had a longer period of time to identify the target. When a time pressure was added to the search task—they were given 500 ms to respond rather than no time limit—the extra interference of irrelevant distractors was eliminated in high perceptual load conditions, in agreement with the Load Theory's prediction.

Belke, et al. (2008) also investigated the effects of target-similar distractor items in a visual search task. Their experimental tasks presented participants with a target, presented as a single word, followed by an array of images. In some trials the array would contain the target, and some trials would contain an item semantically related to the target (target: "shirt," related item: an image of a pair of pants). Using an eye-tracker, they found that when the target was present, even in trials where the related item was also present the participant's first fixation would fall on that target significantly more frequently than non-target items. When the target was absent, however, the first fixation would fall on the related item significantly more than the other items in the array (Belke et al., 2008). These results suggest that, when primed with a target item, the participant is more likely to look at an item related to that prime than an item unrelated to that prime.

Finally, Belke et al. (2008) found that items semantically related to a target are more attention-grabbing than unrelated items. This, along with the broad finding that task-congruent distractors are more distracting than neutral distractors (Lavie et. Al. 2004; Parmentier, 2008; Lavie & Forester 2008), and Parmentier's findings that semantic information can be obtained from novel distracters, lead us to four hypotheses. First, we hypothesized that distractors with semantic content related to the semantic content of the memory set would cause more interference (more distraction, slower RTs) than either distractors unrelated to the memory set, or neutral distractors (which should have caused the least interference). Second, we also expected to see an effect of load on distractibility compatible with the Load Theory: we expected to see greater distractibility (slower RTs) in the high cognitive load condition. Third, based on the Load Theory we hypothesized that there would be no interaction between cognitive load and distractor type; past studies produced no results that would suggest an interaction either way. Finally, we expected to see a higher rate of false positive identifications in the memory probe in the high load condition, as there should have been less cognitive capacity available to actively ignore distractor words.

Methods

Thirty-four Introduction to Psychology students from Franklin and Marshall College participated, in exchange for course credit. Participants volunteered for participation via sign up sheet. No demographic factors were recorded or controlled for.

Stimulus images were generated using Graphic Converter software, and sets of stimuli (trials) were constructed and ordered manually (although a random order was generated by computer to guide the organization of the trials). Stimulus sets were presented using Generic Psychology Lab software. All software was run on Mac OS9. Accuracy and mean reaction times for each participant were recorded by the software and analyzed using SPSS statistical software.

Each trial consisted of three phases that were presented serially at fixed time intervals: part 1, the memory set presentation, part 2, the selective attention task, and part 3, the memory probe. The memory set consisted of a small set of words the participants were asked to remember. The selective attention task was a simple decision task. Each attention task presentation consisted of a target letter (N or X) and a non-target (an O), one above the fixation point and one below. The target appeared randomly and equally in each location. The trials were also split evenly between the two target letters, each target letter appeared equally. One and only one of the two targets were present on every trial. Participants were asked to identify which of two target letters were present (X or N). During this time, a distractor presented simultaneously with the selective attention task, in the periphery of the screen aligned horizontally with the fixation point. The target and non-target stimuli (the N or X, and O) appeared, along with a flanker distractor, for 250ms. This display was followed immediately by a blank screen. Participants had from the offset of the selective attention screen (the onset of the blank screen) onward to make their response, either pressing the N key if the N was present, or the X key if the X was present. Finally, participants were shown a word, and asked if it was present in the original set.

This study had a 2x3 within subjects design: cognitive load x semantic content of distractors. Cognitive load was defined here (as in Lavie et. al. 2004) as the number of items presented in the memory set. The two conditions, high and low, were defined as memory sets containing 5 and 2 items respectively. In the low load condition, the memory set was presented for 2s and in the high load condition it appeared for 4s. These presentation times were meant to eliminate extra search/reading time from the low load condition, while still allowing enough time in the high load condition for the participant to read and process all memory set words. A similar method was used in Lavie (2004) when manipulating cognitive load. The two levels of cognitive load, as manipulated by memory set size, were presented in separate experimental blocks. Participants were assigned one of two groups at the start of the study, and group assignments alternated every-other participant. Presentation order was counterbalanced between groups.

In order to allow distractors to be semantically related (or not) to the words in the memory set, all memory sets consisted of either 2 or 5 words meaningfully related to each other. Our study's 3 distractor conditions were 1) a "neutral" distractor: a single symbol (#) without semantic meaning; 2) "related" distracters: words that are in the same semantic category as the words in the memory set; and 3) "unrelated" distracters: words that carry semantic meaning but are unrelated to the words in its trial's memory set. Words were semantically related based on broad categorization by meaning, or words were grouped under one broad category. For example, a high load memory set could consist of the words "apple, pear, grape, orange, cherry." A related distractor word would be "plum," and an unrelated distractor could be "truck."

The memory probe could have either been one of the words from the memory set (apple), or a word still related to the set, but not present (peach). While words were recycled between the two trial blocks, no words were presented more than once in the same trial block. Words were only used if they contained less than three syllables, and were easily recognizable.

In order to preserve the novelty of the meaningful distractors (which, according to Parmentier, 2008, was essential to the recognition of the distractors), a longer string of meaningless symbols (ex. #$%!?) was not used as the neutral distractor. Within each block of trials, 50% of distractors were neutral distractors (#), 25% were related, and 25% were unrelated.

Reaction times on the decision task and accuracy rates in the memory probe were collected. A 2 x 3 within subjects ANOVA (cognitive load x relatedness of distractor) was run to analyze the possible effects of our variables as they pertain to the first three hypotheses, and appropriate post-hoc tests were run as necessary. Error rates were also calculated, and a 2x2 within subjects ANOVA (presence of the memory probe x cognitive load) was run to examine any patterns regarding false positives or false negatives (as discussed in our fourth hypothesis).

Results

The 2 x 3 ANOVA (cognitive load x relatedness of distractor) results indicated a significant main effect of relatedness, $F(2,62)=16.008$, $p<.001$, partial $\eta^2=.341$. However, there was no main effect of cognitive load, $F(1,31)=.018$, $p=.894$, and partial $\eta^2=.001$. The interaction between cognitive load and relatedness was statistically significant, $F(2,62)=.028$, $p=.028$, and partial $\eta^2=.109$. Fisher's LSD post hoc test was conducted to determine which groups of relatedness were significantly different in reaction times. Results revealed that all three groups differed significantly.

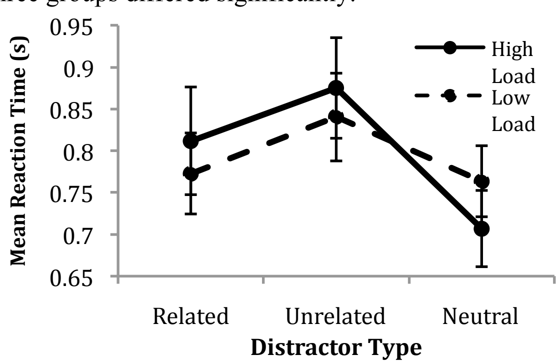

Figure 1: Mean reaction time as a function of cognitive load and distractor type.

A 2 x 2 ANOVA (presence of memory probe x cognitive load) indicated significant main effect of cognitive load, $F(1,31)=6.779$, $p=.014$, and partial $\eta^2=.179$, as well as a significant main effect of presence, $F(1,31)=30.998$, $p<.001$, and partial $\eta^2=..500$. There was no interaction between cognitive load and presence, $F(1,31)=.005$, $p=.943$, and partial $\eta^2<.001$.

Post-hoc t-tests were conducted to look at differences among related and neutral distractors in different cognitive loads. The results revealed a significant difference between mean reaction times of high related distractors and high neutral distractors, $t(31)=3.123$ and $p=.004$. There was not a significant difference between mean reaction times of low related distractors and low neutral distractors, $t(31)=.371$ and $p=.713$.

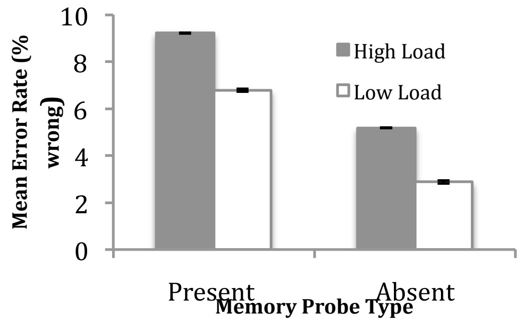

Figure 2: Mean error rate (%) as a function of cognitive load and memory probe condition.

Discussion

The first hypothesis was not supported. While a significant main effect of distractor type was found, the unrelated distractors caused more interference than related distractors. Neutral distractors caused the least interference, in line with the hypothesis. The background literature leading to this hypothesis was not cohesive, and at the time the hypotheses were written, the literature suggesting the greater interference capacity of related, rather than unrelated, distractor items was more compelling than the other findings available. Given the current findings, a second examination of the background information highlights several studies that do support the present results. As noted, Lavie et al. (2004) found that task non-congruent distractors were more distracting than task congruent distractors, Lavie & Forester (2008) found that novel, task irrelevant image distractors were more distracting than familiar or relevant distractors, and Parmentier (2008) found that task relevant items presented simultaneously with a task facilitated performance, while irrelevant items interfered.

These results might suggest a sort of priming effect. Perhaps the memory set primes some larger category or group meaning, and as a result the participant is not surprised by the presence of a related distractor; an unrelated distractor, then, is unexpected and more attention-grabbing. This is not completely satisfactory, however, because it might imply that related distractors would produce faster RTs than even neutral distractors would. This is only partially supported by our results. While in the high load condition, the neutral distractor caused significantly less interference than the related distractor, in the low load condition the two distractor categories produced mean RTs that were virtually the same. If priming were involved, we would have expected to see related distractors produce significantly faster RTs than both unrelated and neutral distractors, or very similar RTs to neutral distractors. While these results have interesting implications in the broader discussion of priming effects and working memory, further discussion of the topic is beyond the scope of this study.

Although our results are not consistent with our original predictions, they still build on the previous literature in valuable ways. All previous work cited here related their distractors only to the items in their selective attention or perceptual load tasks; the related (or unrelated) information appeared all on the same screen. The current study sought to examine relatedness between the attention task and the cognitive load, to manipulate relatedness across tasks and attention mechanisms. Because of this the results were slightly unpredictable, but valuable nonetheless.

The second hypothesis was also not supported: no main effect of cognitive load was observed. This result was unexpected, as the effect of cognitive load has been observed in past work. A trend towards significance was observed—high load RTs were slower than low load RTs—but only in the 'related' and 'unrelated' condition. This suggests that, possibly, the cognitive load manipulations were not adequate representations of 'high' and 'low' cognitive load. One possible explanation of this involves the related nature of the stimuli. Perhaps the fact that all memory set items fell under one broad category or meaning provided a strategy for remembering them: maybe participants remembered the group rather than each individual word (consciously or not) in an effort to reduce the load on the cognitive system. The results regarding our fourth hypothesis provide more evidence to this effect.

Our fourth hypothesis was supported. We observed significantly more false positives in the high load condition than in the low load condition: participants were failing to accurately remember the words in the larger memory sets. After considering the related nature of the memory set words, this result suggests that participants noted the category of the words presented along with individual words. As all memory set words, present and absent, were related to their memory set (it would have been too obvious had the probe words been unrelated) false positives indicate that participants recognized the category membership/ semantic meaning of the probe word and responded accordingly.

The results concerning the second and fourth hypotheses point to semantic grouping as a characteristic that can mitigate the effects of cognitive load in both directions. In high load conditions, it appears that semantic grouping reduces the load that would otherwise be placed on a cognitive system by trying to retain five unrelated or meaningless items. Relating memory set provides a crutch, a strategy for the participant to make remembering easier. By relating the high load memory set items to each other, we may have created a pseudo-high cognitive load, not high enough to mimic previous results. The current manipulation of low load does differ from past studies'. In Lavie et al. (2004), the low cognitive load condition contained one item: a single letter. In Belke et al.'s (2008) manipulation of cognitive load a single number was used in the low load memory sets. To compare, the current study used two one- or two - syllable words. Setting aside the extra item in our low load condition, words have meaning, single letters do not. It is possible that the combination of these two factors brought the low load condition's difficulty closer to that of the high load condition. Adding the factor of meaningfully related memory sets, seems to have knocked the significance out of the effect of cognitive load.

Our third hypothesis was, again, not supported. A significant interaction occurred between cognitive load and distractor relatedness. The relationship between the two variables was very similar between the two conditions with meaningful distractors (the 'related' and 'unrelated' conditions)**.** The interaction appears between these conditions and the neutral distractor condition: neutral distractors were more distracting in the low load condition than in the high. This is not consistent with load theory, which would predict faster RTs in the low cognitive load condition all around. Most of the background studies cited here disregard their neutral data, there isn't much in the literature to compare our results to. The degree of the difference between RTs of contentful and non-contentful distracters—the fact that the trend is reversed in the neutral condition—may indicate a different mechanism is at work when the distractor and the memory set information are presented in the same form (all words, as opposed to words and symbols). This interpretation is not fully compatible with the past findings, however. Lavie and Forester (2008) found that when target stimuli were letters and distractors were images of cartoon characters, the images were still significantly distracting (when compared to letter distractors). This study, though, did not manipulate cognitive load; the novel distractors were not novel to cognitive load content, as in the current study, they were novel to perceptual load items. Perhaps, as the current results suggest, the interaction *between* attention mechanisms is qualitatively different than that *within* mechanisms. This qualitative difference is interesting and warrants further study.

The size of the sample may have limited the study. Using additional participants was not feasible, however, and because of the within-subjects design was not essential. The software used to present stimuli, and record reaction times, responses and error rates also limited our ability to fully explore the data. A more sophisticated program like E-Prime could alleviate these technological issues.

The current study is incomplete in that it does not compare related memory sets to unrelated memory sets. Further exploration is necessary to determine whether the results seen here are truly attributable to the semantic relatedness of the memory set and the distractor, or if they are simply a product of using whole words as stimuli. Adding a third independent variable, that of memory set relatedness, would enhance the literature in this area.

More detailed data regarding error rates and the type of distractor task would shed further light on the issue of false memories: it is possible that the greater the interference of the distractor in the selective attention task, the higher the error rates would climb. If unrelated distractors are more distracting, it follows that error rates in the unrelated distractor condition would be significantly higher than those in the related or neutral conditions.

Because of technological limitations, it could be valuable to re-examine the interaction between distractor type and cognitive load. Validating the current results regarding neutral distractors could point to different mechanisms used in ignoring extraneous information.

Conclusion

A desire to better understand what interrupts or facilitates selective attention continues to drive research in cognitive psychology. While Lavie's Load Theory provides a valuable theoretical explanation of the phenomena, it is also vital that studies explore selective attention in real-world settings using real-world stimuli. The present results indicate that while the Load Theory provides a strong theoretical base, there are stimulus characteristics, like meaning and relationships between stimuli, that can alter the general pattern, but not without a cost. While it is possible that relating stimuli to one another reduces the cognitive capacity required to retain it, retention and recall suffer when such strategies are used. Knowing how attention and working memory are disrupted and aided could be particularly applicable in the field of education, and could be used to teach strategies for better retention and more effective methods of teaching and information presentation.

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