EFFICIENT SELECTION MODULATED BY IMPLICIT INTER-TRIAL PATTERNS: CONVERGENT DISSOCIATIONS FROM PERCEPTUAL LOAD

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Abstract

Efficiency of selection was assessed when low or high perceptual load blocks of trials were impoverished or enriched with recurrent inter-trial implicit patterns of visual information discerning targets from non-targets. Types of implicit inter-trial information were defined as stable patterns of stimuli sizes, color and positions. We hypothesized that implicit recurrent patterns can facilitate selection and dispel congruency effects in visual search. Perceptual load theory predicts that the level of perceptual load inflicted by a task is inversely proportional to congruency effects (Lavie, 1995, 2005; Lavie & Tsal, 1994). In two experiments those findings were replicated and reversed. Six convergent manipulations of different kinds of inter-trial patterns modulated the size of congruency interferences as predicted. Results suggest that 1) congruency effects stem from involuntary use of all visual information available, even when counterproductively, and 2) perceptual load is a poor predictor of efficient selection.

One of the most influential theories of attention during the last 15 years has been the perceptual load theory (Lavie, 1995; 2005; Lavie & Tsal, 1994). Its chief proposition contends that when a task imposes a perceptual load higher than the cognitive resources available, early selection occurs. Conversely, late selection prevails as long as the available resources are not exhausted. It assumes that there exists a minimum quota of attentional resources to be spent in any visual selection task. If a certain task demands less than the minimum quota, subjects will accomplish the relevant selection and then proceed to irrelevant processing of irrelevant stimuli. This proposition is unique in two aspects: Firstly, it is the only largely accepted model that proposes a *minimum* obligatory quota of resources to be spent in a selection task. Secondly, contrary to virtually all alternative interpretations of visual selection, it claims that irrelevant stimuli are processed *after* the targeted stimulus is selected.

Inefficient selection observed in studies adopting the perceptual load approach has been interpreted as a misuse of surplus attentional resources towards the processing of task-irrelevant stimuli (see Lavie, 2005, for review). These studies in general lead to the conclusion that for extremely simple visual tasks, subjects are hardly able to deploy their attentional resources according to the relevance of the visual information presented.

The current study, on the other hand, suggests that in those studies, subjects not only deployed their resources according to the visual information provided, but also took into account much more information than researchers had been aware or willing to provide. It is suggested here that in experiments fulfilling the perceptual load predictions, a crucial amount of inter-trial information – unnoticed by researchers and implicit to subjects – was recurrent across trials, and that precisely this information was the critical factor determining the deployment of attentional resources in each trial. Our present objective is to demonstrate how the manipulation of different types of inter-trial patterns can effectively modulate selection efficiency, irrespective of the level of perceptual load inflicted on the perceptual system.

The most quoted study supporting the perceptual load theory, Lavie (1995), employed in its first experiment a version of the Flanker paradigm (Eriksen & Eriksen, 1974). Lavie's experiment has been replicated and quoted more than any other experiment supporting the perceptual load hypothesis. In that experiment – and its corollaries – subjects were asked to press one key whenever a certain letter (X) appeared anywhere along the central row of the display, or press a second key whenever a second target letter (Z) appeared within the same area. An additional letter (the distractor) simultaneously appeared either above or below the central row of the display. Subjects were explicitly instructed to disregard the distractor, which could be *congruent* (identical to the target), *incongruent* (Z for a target X, or X for a target Z), or *neutral* (the letter P).

There were two critical conditions: Either a block of low-load trials, where the target letter appeared alone within the central row or a block of high-load trials where the target appeared flanked by additional neutral letters. It was found that an incongruent distractor interfered more when the target letter appeared alone (low-load displays), than when it appeared flanked by additional neutral letters (high-load displays).

According to the perceptual load reasoning, when the target appears alone, its selection is easy (low perceptual load) and thus consumes less resources than the minimum quota allotted for the task. In such a case, after accomplishing the target's selection, subjects continue to process irrelevant stimuli (including the distractor) until the minimum attentional quota is exhausted. Conversely, when the target appears within a string of letters (high perceptual load) the search for the target utilizes more than the minimum quota. In this case, after the target is selected there remains no surplus of resources and the subjects do not continue to process irrelevant stimuli.

Here we suggest a more parsimonious and possibly wider-ranging explanation for these effects. In high-load displays subjects can promptly discern between the relevant object to be attended to (a large string of 5 letters) and the irrelevant object to be ignored (a small single-letter object). Conversely, this immediate advantage is absent in low-load displays, where both objects share the same size. We propose that in high-load blocks subjects are provided with effective and recurrent information to promptly filter out the irrelevant object, whereas in low-load blocks this kind of information is absent. The critical element is not a mere visual discriminability between the objects within each trial, but the recurrence of the same attribute for the same object across trials. That is, the object to be attended is always large, and the object to be disregarded in always small. In such a sequence of trials, once the system can predict the respective objects' sizes, it can invest its resources on the large object as fast as it can recognize a large and a small object, much before it begins to process the identity of the letters that form the objects. We hypothesize that the more discriminating information is provided, the faster the resources are effectively allocated, the less an irrelevant stimulus is processed.

We have thus predicted that if subjects are deprived from stable information about the relative sizes of the objects within high-load displays, their capacity to swiftly filter out the irrelevant object – and hence disregard the distractor – would be subdued. By the same token, if subjects are provided with sufficient information discriminating relevant from irrelevant objects during low-load blocks, they would be able to effectively disregard the distractor, and thus dispel congruency effects. Furthermore, we predicted that, apart from objects' sizes, different types of recurrent information (e.g., color) could be effectively used to promptly discern and filter out irrelevant stimuli.

In resume, the present study assesses 1) the possibility that perceptual load has been systematically confounded with recurrent visual discriminability between relevant and irrelevant stimuli and 2) the extent to which different types of inter-trial implicit patterns are able to modulate selection efficiency. In the two experiments presented below, the relevance

of inter-trial patterns was manipulated across low-load and high-load blocks, such that, irrespective from the the load imposed, information-enriched conditions were expected to enable prompt filtering and effective selection, whereas information-impoverished conditions were expected to curb it.

EXPERIMENT 1

Experiment 1 comprised five conditions of low-load displays. In each condition a different kind of inter-trial information was manipulated. In the *replication* condition the target appeared randomly in one of seven positions along the central row of the display. A slightly larger distractor (X, Z or P) randomly appeared in one of four equidistant positions relative to the target: above-left, above-right, below-left or below-right. In the *much-larger-distractor* condition the size of the distractor was twice the size of the target. In the *5-letters-distractor* condition the distractor was cloned into a string of five identical letters (either Xs, Zs or Ps).In the *fixed-color* condition the distractor and the target were presented in different colors (black or red) fixed along each entire block. In the *fixed-position* condition the distractor appeared in only one of the four positions vis-a-vis the target. While the absolute location of both letters together varied randomly across the display, the relative disposition of the two objects was kept fixed along each entire block.

Method

16 Psychology undergraduates from the Tel Aviv University participated in a single experimental session of 50 minutes each. The fixation cross was a 0.4º X 0.4º plus sign (+). The target subtended 1º in height and 0.7º in width. All distractors (above or below the central row) subtended 1.14º in height and 0.8º in width. In the much-larger-distractor condition, the distractor subtended 2º in height and 1.4º in width. In all conditions, the center of the letters was anchored in one of the positions within a grid of seven horizontal columns and 3 rows. The grid subtended 4.5º in height and 7º in width. The targets were X or Z. The distractors were X, Z or P. The neutral flankers were A, E, R, T, U, S, D, F, H, K, L, V, B and N. The distractor appeared randomly in one of four positions equidistant from the target: above-left, above-right, below-left or below-right. Each session comprised 10 experimental blocks of 200 trials each. Each condition was presented twice. Each trial began with a fixation cross (400 ms), followed by a blank white screen (300 ms), followed by the the stimuli, which remained on screen until response.

Results and Discussion

An overall 2-way analysis of variance for repeated measures showed a significant differences between the five conditions, between the three congruencies and a significant interaction between conditions and congruencies. Analyses of error rates mirrored the patterns observed for RT measurements.

Two measures of distractor interference were calculated for each condition: the congruency interference (CI) is the difference between the mean RT for incongruent trials and the mean RT for neutral trials. The congruency effect (CE) was calculated as the difference between the mean RT for incongruent trials and the mean RT for congruent trials. A contrast between the CI in the replication condition and the CIs in the four information-enriched conditions revealed a significant drop in distractor interference in the information-enriched conditions. An equivalent drop occurred for the CE.

The perceptual load main claim predicts is a negative correlation between overall RTs (assumed to reflect the level of load inflicted) and congruency effects. For assessing this prediction, which we deem central to the current study, we have performed a trend analysis of the five conditions combined. Counter to the perceptual load prediction, a significant positively correlated linear trend was revealed for both measures (CI and CE) while quadratic, cubic and quartic components remained highly insignificant. In resume, along the five independent manipulations of experiment 1, the higher the load imposed, the larger the congruency effect observed (see Figure 1).

EXPERIMENT 2

This experiment was consisted of three conditions of high-load displays. The *replication* condition was expected to reproduce the absence of congruency effects as usually observed in high-load blocks. In each trial, the target letter (X or Z) randomly appeared within a string of five letters in one of its five alternative positions. The four other letters were neutral letters (neither X nor Z). A slightly larger distractor (X, Z or P) randomly appeared in one of four positions relative to the central letter of the 5-letters string: above-left, above-right, below-left or below-right. In the *5-letters-distractor* condition, both target and distractor bore the same size. The distractor was a string of four identical letters (either Xs, Zs or Ps) and a letter N in the second position. The target was flanked by four neutral letters. In the *separated-letters* condition the target appeared within a 3-letters string that were distanced from each other by a blank space. We assumed that instead of perceiving the 3-letters string as one object, subjects would perceive three separate single-letter objects, such that expectations about the objects' sizes would become useless.

Method

12 undergraduates from the Tel Aviv University participated in a single experimental session of approximately 40 minutes each. All letters subtended 1º in height and 0.7º in width. In the replication condition, the distractor subtended 1.14º in height and 0.8º in width. Each session comprised 6 blocks of 220 trials each. All remaining procedures were identical to experiment 1.

Results and Discussion

An overall 2-way analysis of variance for repeated measures revealed significant differences for conditions, congruencies and the interaction between them. Analyses of error rates mirrored the RT patterns. A contrast between the CI in the replication and the CIs in the two information-impoverished conditions revealed a significant raise of CIs in the impoverished conditions. The 5-letters condition resulted in null CEs, such that all subsequent analyses of CE became irrelevant. A trend analysis of the three conditions of experiment 2 revealed a significant linear trend between overall RT (load) and CI. Additionally, a trend analysis of the CI of the six non-replicant conditions of experiment 1 and 2 combined, revealed a significant positively correlated linear trend between overall RT and CI, whereas the quadratic component remained highly insignificant (see Figure 1).

General Discussion

By controlling the relevance of inter-trial patterns recurrent along a block, convergent dissociations between the predictions of the perceptual load theory and the behavior observed were attained. In experiment 1, all four types of low-load information-enriched conditions significantly reduced congruency interferences (CI) and congruency effects (CE) in relation to the replication condition. In experiment 2, the two types of high-load information-impoverished conditions resulted in significant congruency interferences, but only the separated condition attained significant congruency effects.

The only operational anchor proposed hitherto for assessing the level of the perceptual load imposed by a given task has been the overall mean RT observed, which, needless to say, is the dependent variable itself. Since the CI/CE are measures derived from the same dependent variable, it follows that the perceptual load hypothesis, in its strongest form, cannot defend more than a simple correlation between RT and CI/CE. Specifically, it argues for a negative correlation between the two; the higher the RT (assumed to reflect perceptual load), the lower the CI/CE (assumed to reflect distractor processing). All the six non-replicant conditions in both experiments provided robust and convergent evidence to the very opposite: Perceptual load and CI were positively and strongly correlated (see Figure 1). Similarly, five of the six non-replicant conditions produced a significant positive linear correlation between perceptual load and CE.

By separately manipulating six independent variables the relationship between RT and CI/CE was propelled and reversed according to a priori predictions. We then conclude that any relationship between RT and CI/CE does not reflect an inherent characteristic of the human cognitive system, but rather the values chosen for the independent variables in experiments fulfilling perceptual load predictions. It seems that in those studies, although subjects were explicitly instructed to disregard the distractor, implicit recurrent information spurred the cognitive system to pay attention to certain visual patterns, within which the distractor was also included.

In our experiments subjects were explicitly instructed to search for an X or a Z within the central row of the display and to disregard all stimuli outside the central row. Nevertheless, it is clear that information about the form, disposition, size and color of the stimuli outside the central row was perceived, calculated across trials and, most important, compared to the corresponding information about the stimuli within the central row. We conclude that the perceptual apparatus is relentlessly attuned to any eventual recurrent pattern across trials and that whenever such a pattern is identified, it is automatically incorporated as a variable within the equation governing selection and response.

In sum, we conclude that 1) The perceptual system is sensitive and adaptive to any piece of recurrent information that is relevant for discerning between targets and non-targets. 2) The more implicit or explicit information available, the more efficient the selection. We hypothesize that the more discriminating information available, the faster the resources are reallocated from irrelevant to relevant stimuli. The faster the reallocation, the less a distractor is processed. 3) perceptual load is neither a critical determinant nor a reliable predictor of selection efficiency.

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