OBSERVATIONS

Dilution: A Theoretical Burden or Just Load?
A Reply to Tsal and Benoni (2010)

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Load theory of attention proposes that distractor processing is reduced in tasks with high perceptual load that exhaust attentional capacity within task-relevant processing. In contrast, tasks of low perceptual load leave spare capacity that spills over, resulting in the perception of task-irrelevant, potentially distracting stimuli. Tsal and Benoni (2010) find that distractor response competition effects can be reduced under conditions with a high search set size but low perceptual load (due to a singleton color target). They claim that the usual effect of search set size on distractor processing is not due to attentional load but instead attribute this to lower level visual interference. Here, we propose an account for their findings within load theory. We argue that in tasks of low perceptual load but high set size, an irrelevant distractor competes with the search nontargets for remaining capacity. Thus, distractor processing is reduced under conditions in which the search nontargets receive the spillover of capacity instead of the irrelevant distractor. We report a new experiment testing this prediction. Our new results demonstrate that, when peripheral distractor processing is reduced, it is the search nontargets nearest to the target that are perceived instead. Our findings provide new evidence for the spare capacity spillover hypothesis made by load theory and rule out accounts in terms of lower level visual interference (or mere "dilution") for cases of reduced distractor processing under low load in displays of high set size. We also discuss additional evidence that discounts the viability of Tsal and Benoni's dilution account as an alternative to perceptual load.

Keywords: attention, perceptual load, dilution, distraction, response competition

Load theory of attention (e.g., Lavie, 1995; Lavie, Hirst, De Fockert, & Viding, 2004) delineates the determinants of focused attention and conversely the ability to ignore irrelevant distractions, highlighting the critical role of different types of information-processing load. The proposals of load theory and the various strands of evidence supporting these proposals have been described extensively elsewhere (for a recent review, see Lavie, 2010; see also Lavie, 2005, 2006; Lavie et al., 2004; Lavie & Tsal, 1994). Here, we concentrate on the effects of perceptual load on distractor processing and their interpretation, incorporating the recent findings of Tsal and Benoni (2010) while addressing their claims. We propose an account for Tsal and Benoni's findings in terms of the existing assumptions of load theory. We then report a

new experiment testing the novel predictions we derive from our account. The new findings confirm our predictions. We conclude that load theory can accommodate the effects of "dilution" and thus remains the most parsimonious account for a large set of data, now including those obtained in Tsal and Benoni's "dilution" conditions.

The role of perceptual load in distractor processing was derived from load theory's hypotheses that perception has limited capacity but proceeds in parallel on all items within its capacity in an involuntary, "automated" manner until it runs out of capacity. These hypotheses led to the predictions that under conditions of low perceptual load in the relevant task, spare capacity remaining from the low-load processing will involuntarily spill over, resulting in the perception of task-irrelevant and potentially distracting stimuli. Distractor processing is eliminated, however, in tasks of high perceptual load that exhaust perceptual capacity in the more demanding processing of task-relevant stimuli.

The level of perceptual load in the task can be increased either by increasing the number of different items in a perceptual task (the relevant task set size) or by increasing the number and complexity of perceptual operations that the task involves while keeping the same number of task stimuli (e.g., for the very same stimulus displays, the task may require just feature detection in the low-load conditions or a feature conjunction discrimination in the higher perceptual load conditions). Distractor processing can be measured in various ways (e.g., distractor interference effects, awareness reports, brain activity related to the distractor presence,

and so forth; see Lavie, 2010, for a recent review). Previous studies have used both types of perceptual load manipulations and a wide variety of distractor-processing measures, and their results have converged on the same conclusion: Distractor processing is reduced in tasks of higher perceptual load, irrespective of whether the load manipulation involves an increase in the number of items in the display or in the perceptual processing requirements for the same displays. The convergent evidence across many different tasks and distractor measures provides strong support for load theory predictions while ruling out alternative accounts in terms of task-specific factors for one or the other type of perceptual load manipulation, given the common findings across the different tasks.

Tsal and Benoni's (2010) claims that perceptual load effects may be accounted for in terms of *dilution* pertain only to the manipulation of perceptual load with the relevant search set size and its effect on one measure of distractor processing, namely that of distractor response competition effects. Their task and claims are based on the original demonstration of perceptual load effects in Lavie (1995, Experiment 1). Next, we focus on these specific effects and their interpretation, but before we narrow our discussion to dealing with the effects of set size on distractor response competition effects, we note that the use of the very same stimulus displays across the levels of perceptual load in many previous studies, including the original demonstrations using the response competition paradigm (Lavie, 1995, Experiments 2 and 3), sidesteps all of their concerns.

Tsal and Benoni's "Visual Dilution" Account

Lavie (1995, Experiment 1) varied perceptual load for the task by increasing set size in a central search array. An irrelevant but potentially response-competing distractor was presented in the periphery. Response competition effects from that distractor were eliminated in the high set size conditions, suggesting that the high search load exhausted perceptual capacity. In two experiments in the same Lavie (1995) study, perceptual load was varied without changing the stimulus displays. A shape was presented next to the target letter, and the responses to the target letter were to be made only if that shape had the correct feature (e.g., only if it was blue) in the low-load condition or the correct feature conjunctions (e.g., only if it was a blue square or a red circle, but not if it was a blue circle or a red square) in the high-load condition. Response competition effects were eliminated with high perceptual load in these experiments, suggesting that the effect is not due to any low-level change in the visual stimulus displays, but rather to the level of demand on perceptual capacity.

Tsal and Benoni added a condition of higher set size with a singleton colored target (e.g., a red target among black nontargets) to the low and high set size conditions in Lavie's (1995) Experiment 1. They found reduced response competition from the peripheral distractor in the added condition. Search for a target with an odd color (e.g., a red target among black nontargets) should result in a target "pop out"; thus, the search task in this condition clearly involves low perceptual load. The nontarget items in such a search do not require processing beyond their color feature. Indeed, recall that in the perceptual load model, the attention spillover under low load is assumed to be involuntary.

Tsal and Benoni do not consider the attention spillover hypothesis and therefore assume that because the search nontargets do not need to be processed beyond their low-level features, they would not be perceived any further. The elimination of distractor effects in this condition is thus attributed to an effect of early visual interference produced just by the "mere presence" of the nontarget items, an effect akin to that found in some of the Stroop "dilution" experiments (Brown, Roos-Gilbert, & Carr, 1995; Kahneman & Chajczyk, 1983), in other words, a form of distractor dilution with visual clutter.

Of course, the "mere presence" of any item cannot have any functional role if these items are not processed at any level. In a further characterization of the putative early visual interference produced by the "mere presence" of nontarget items, Tsal and Benoni suggest that the nontarget letter features "compete with those of the incongruent distractor, degrade the quality of its visual representation, thus substantially reducing the amount of lexical analysis achieved by its corresponding lexical representation" (Tsal & Benoni, p. 1646).

This account, however, remains somewhat underspecified. Specifically, given that following from Lavie's (1995) design, the distance separation of the central items and the peripheral distractor in their displays seems too great for any low-level feature interference (e.g., any lateral masking; e.g., Bouma, 1970; Wolford & Chambers, 1983), it is not clear what other mechanisms could mediate such putative low-level visual feature interference.

The Analogy With Previous Stroop Dilution Accounts

The analogy Tsal and Benoni make with the dilution effects established in the Stroop paradigm is not quite clear either, as there are some critical differences between the tasks used to establish the Stroop dilution effects and the perceptual load tasks used here. Specifically, in the Stroop dilution experiments (e.g., Brown et al., 1995; Jenkins, Lavie, & Driver, 2003; Kahneman & Chajczyk, 1983), the added "diluter" items are presented in one of the distractor locations. For example, a target item is presented at the display center and a response-competing distractor is presented either on the left or right while a diluter item is presented on the other side (e.g., on the right when the distractor is on the left).

Thus, in the Stroop dilution experiments, in the no-dilution conditions, the response-competing distractor is an attention-capturing peripheral singleton (see, e.g., Yantis, 2000), but in the dilution conditions, the response-competing distractor is no longer a singleton. Because this change in the distractor singleton status will occur with the presence of any other stimulus onset in the periphery, an explanation for the distractor dilution effects in terms of reduced attentional capture (as originally proposed in Kahneman & Chajczyk, 1983; see also Jenkins et al., 2003) can easily account for all of those findings, including those whereby the added diluters share only low-level visual features with the distractors (e.g., a row of equal signs [=] used to dilute word distractors in Brown et al., 1995; phase-scrambled object images used to dilute the effects from meaningful distractor objects in Jenkins et al., 2003).

Tsal and Benoni report only one experiment in which the diluter items were added in one of the peripheral distractor locations (Experiment 2), and a dilution account in terms of reduced attentional capture with added items in another distractor location can

clearly explain the results of that experiment. In all of the other experiments that Tsal and Benoni report and in all the perceptual load experiments that varied the display set size, the nontarget items are added to a central search array. As such, the added search nontargets should neither clutter the peripheral distractor nor change its peripheral singleton status. A dilution account in terms of low-level visual interference (e.g., on the basis of feature clutter or a change in the number of peripheral onsets) thus seems unlikely.

Moreover, the effects of Stroop dilution that originally gave rise to the visual interference account (discussed in Brown et al., 1995) were those obtained with fairly meaningless diluters that share only low-level visual features with the distractors. In contrast, the added nontarget items in Tsal and Benoni's study are letters. Their interference with the perception of another distractor letter need not resort to low-level visual feature interference accounts. Instead, the nontarget letters can directly load distractor identity perception (and thus reduce the associated congruency effects) if the identity of the nontarget letters is perceived.

Thus, one can explain both the effects of perceptual load and those of dilution in Stroop tasks in terms of reduced attentional allocation to the irrelevant distractor either because of reduced capture of attention in the Stroop dilution experiments or because of a spillover of attention to the search nontarget letters in the perceptual load experiments, as we discuss next.

Load Theory Interpretation of Tsal and Benoni's Findings: Stimulus Competition for Capacity Spillover

Load theory can offer an alternative interpretation for the pattern found by Tsal and Benoni in terms of its existing proposal that spare capacity will spill over to other items in a display under conditions of low perceptual load, including the case of a high set size with a singleton colored target. A key point to note is that in high set size conditions, there are multiple items in the display that can compete for involuntary allocation of spare capacity. These include not only the peripheral distractor from which any response competition can be measured, but also the nontarget letters within the central search array. In cases where the peripheral distractor did not receive the capacity spillover, load theory would hypothesize that the spare capacity left from the low-load task has spilled over to some of the other items in the displays (e.g., some of the search nontargets).[1] This hypothesis leads to a clear prediction: If the peripheral distractor effects were reduced in the low-load but high set size displays because of a spillover of spare capacity to some of the search nontargets instead of the peripheral distractor, then if we were to replace those search nontarget letters with response-competing distractor letters, this should restore the distractor interference effect.

We have run an experiment testing this prediction. As the conditions of high set size include six search items (plus a peripheral distractor) but capacity limits are typically estimated to encompass four to five items (e.g., Fisher, 1982; Kahneman, Treisman, & Gibbs, 1992; Yantis & Jones, 1991), we anticipated on the basis of previous research (e.g., Tsal & Lavie, 1988) that the nontarget letters nearest to the target would be those most likely to receive the spillover of spare capacity from among the rest of the search nontargets. Thus, we used the same task as that used in Tsal and Benoni's experiments, but now included in addition to the

peripheral distractors condition a new "nontarget distractors" condition, in which response competition distractor letters replaced two of the neutral search nontarget letters (while the peripheral distractors were response neutral). We presented letter–circle plus peripheral distractors search arrays. In the nontarget distractors condition, two of the five nontarget letters in the circle (those flanking the colored target on each side) were either compatible or incompatible with the target response. Whenever distractors in either the nontarget or the peripheral positions were response related (i.e., compatible or incompatible), the letters in the other positions were response neutral.

Tsal and Benoni's suggestion of reduced distractor processing due to some form of low-level visual interference (whereby the nontarget letter features compete with those of the distractor, degrade its visual representation, and therefore reduce its lexical access) should lead to the prediction of no distractor processing in either the peripheral or nontarget distractor conditions. In other words, the dilution account proposed gives no reason to suppose that the putative early visual interference due to some feature crosstalk will concern only the more remote and larger distractor letter in the periphery, leaving the search nontarget letter representations intact. In fact, if anything, the most studied cases of low-level visual interference (due to lateral masking) would lead one to predict that the nontarget letters in the circle should exert a greater visual interference on each other (as they are both nearer to each other and of the same size) than on the more remote and larger peripheral distractor letter. The spillover account in load theory leads instead to the prediction that under conditions where attention spillover favors some of the search nontarget items over the peripheral distractor, response competition effects will now be found from the nontarget distractors but not the peripheral distractors.

We tested these predictions on 12 volunteers (18–35 years old) recruited from the University College London subject pool, who participated in exchange for either payment or course credit. Each participant completed a practice block of 20 trials followed by four experimental blocks of 72 trials each. In each block of trials, we

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[1] We note that some of the factors that dictate which of multiple items (search nontarget letters and a peripheral distractor letter) will win the competition for the allocation of capacity (here spare capacity left over from the low-load search task) have been established in previous research. This has suggested relative visual salience of the different items (e.g., more foveal items are more salient than peripheral items, even when the peripheral items are cortically magnified; e.g., Beck & Lavie, 2005), task relevance (the search nontargets are presented in task-relevant locations, the response competition distractor is presented in a task-irrelevant location in the periphery), and proximity to the target, as well as perceptual grouping with the target (e.g., Baylis & Driver, 1992; Kramer & Jacobson, 1991). On the basis of these considerations, it appears as though in the displays used by Tsal and Benoni the search nontargets are more likely to win the competition and receive the spillover of capacity instead of the peripheral distractor. Specifically, the nontarget letters in these displays are task-relevant, closer to the fovea than the distractor, nearer to the target, and perceptually grouped with it into one central shape (e.g., a row or a circle). We address the determinants of stimulus competition for capacity further in another study in which we show that under some conditions that favor the peripheral distractor over the search nontargets in the competition, the peripheral distractors response competition effects are restored even under "dilution" displays (Lavie & Torralbo, 2010).

randomly intermixed the two distractor conditions: The response competition distractors were equally likely to appear either in the periphery (two identical flankers were presented, one on the left and one on the right, 3.5° away from a fixation point at the display center, in the peripheral distractors condition) or have replaced two of the search nontargets nearby the target (in the nontarget distractors condition). To ensure that the overall number of letters (overall display set size) did not vary between the different distractor conditions, we presented neutral distractors (*L*) either in the peripheral distractor locations in the nontarget distractors conditions or in the nontarget locations near the target in the peripheral distractors condition. Each display comprised six letters arranged in a circle centered at fixation (subtending a radius of 1.9° of visual angle). The circle letters subtended 0.3° × 0.6° and the peripheral distractor letters subtended 0.4° × 0.7°. Target letters and response competition letters were *X* or *Z*, and the neutral letters chosen randomly on every trial were from the set *J, H, U, I, Y, V,* and *N.* The target was always shown in green and the distractor and the neutral letters appeared in black; the background of the display was mid-gray. The factors of distractor conditions, compatibility and target location in the circle, were fully counterbalanced within block and presented in random order. Each trial began with a 500-ms presentation of a central fixation point, followed by the task displays presented for 150 ms. Participants were asked to respond to the green target letter as fast as possible and to press the *0* key for the target *X* and the *2* key for the target *Z,* using the numeric key pad. They were also emphatically instructed to ignore all of the black letters and informed that these may distract them and slow their response if they failed to ignore them.

The results are shown in Figure 1. A two-way analysis of variance (ANOVA) of the response time (RT) revealed a main effect of distractor compatibility, $F(1, 11) = 21.14$, $MSE = 256.00$, $p = .001$, $\eta_p^2 = .658$, no main effect for distractor location ($F < 1$), and an interaction, $F(1, 11) = 10.84$, $MSE = 140.07$, $p = .007$, $\eta_p^2 = .496$. As we predicted, whereas the distractor compatibility effects were not significant in the peripheral distractors condition, $t(11) = 2.04$, $p = .066$, $d = 1.23$, $M = 10$ ms, 95% CI [0.7, 21],
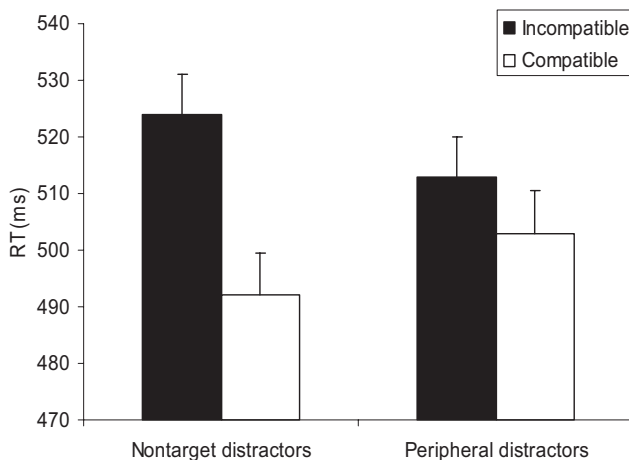
they were significant in the nontarget distractors condition, $t(11) = 5.01$, $p = .0001$, $d = 3.02$, $M = 33$ ms, 95% CI [18, 47].

These effects were replicated in the ANOVA of the percentage errors, which also revealed a main effect of compatibility, $F(1, 11) = 4.83$, $MSE = 21.7$, $p = .05$, $\eta_p^2 = .2$. Participants committed more errors on incompatible trials ($M = 10\%$) than trials than on compatible trials ($M = 7\%$). There was no effect of distractor location ($F < 1$); there was a significant interaction between distractor compatibility and location, $F(1, 11) = 6.19$, $MSE = 7.43$, $p = .03$, $\eta_p^2 = .360$. Distractor compatibility effects were not significant in the peripheral distractors condition, *M* compatibility effect = 1%, $t(11) < 1$, $d = 0.37$, $M = 1\%$, 95% CI [–2, –4], but were significant in the nontarget distractors condition, *M* compatibility effect = 5%, $t(11) = 3.3$, $p = .007$, $d = 1.99$, 95% CI [1, 8].

These results provide clear support for our load theory prediction that a spillover of spare capacity does occur in tasks of low perceptual load. In displays of high set size but low perceptual load (with a singleton target), spare capacity is allocated to the some of the nontarget letters instead of the peripheral distractor. Distractor response competition effects are restored once these can be measured for these nontarget letters. These findings provide new evidence for the capacity spillover hypothesis in load theory, demonstrating irrelevant stimulus perception in tasks of low load while ruling out an alternative account to the effects of perceptual load in terms of a low-level visual interference produced by the "mere presence of neutral elements in displays" (Tsal & Benoni, p. 1652).

Of course, data from just one experiment can be considered only as preliminary evidence. In further experiments (Lavie & Torralbo, 2010), we have also shown that the competition for capacity spillover can be biased to favor the peripheral distractor (e.g., once this is better grouped with the target) over the search nontargets, and that under such conditions, response competition effects from the peripheral distractor are restored. Thus, these effects are not specific to the nearby nontarget items but simply to those items that are strongest competitors for any spare attentional capacity that is left over in low-load tasks (see also footnote 1).

Although our new findings rule out a low-level visual interference account for the effects of perceptual load when it is manipulated through the search set size in a response competition task and emphasize spillover of capacity to nontarget items instead, we note that there are also many other previous demonstrations of the effects of perceptual load that clearly cannot be accounted for in such terms. Below we briefly discuss just a few examples that demonstrate that low-level visual interference cannot account for the effects of perceptual load in the previous research. We start with the previous studies that manipulated perceptual load through the relevant search set size but measured distraction by stimuli that have very little visual feature overlap with the added search items. As such, the distractor representations were unlikely to be degraded by their addition (cf. Tsal and Benoni's account). We then briefly describe previous studies that manipulated perceptual load by varying the perceptual processing requirements without involving any change either in the number of task stimuli or in the complexity of their visual features. Clearly, the effects of perceptual load in these studies cannot be attributed to low-level feature interference. Tsal and Benoni's claims that reduced distractor processing with high perceptual load in these tasks is explained by higher

Figure 1. Mean target response time (RT) as a function of the distractor compatibility for the peripheral distractor and nontarget distractor conditions. Error bars denote standard errors of the mean.

cognitive load do not hold either, as such load is known to increase rather than decrease distractor processing (see, e.g., Lavie & De Fockert, 2003; Lavie et al., 2004). Moreover, an alternative account in terms of cognitive load is clearly ruled out in the studies where the added perceptual requirement in the high perceptual load conditions did not affect the level of cognitive load either, as the task remained the same. We highlight those cases in the following discussion.

Perceptual Load Effects on Various Measures of Distraction: The Effects of Load Do Not Depend on Visual Feature Overlap

While the mechanisms underlying Tsal and Benoni's visual dilution account remain somewhat underspecified (and, as we discussed earlier, these are unlikely to be the same as those underlying the Stroop dilution effects), one clear tenet of their account is that reduced distractor processing in high search set sizes is attributed to some form of interaction between the visual features of the nontargets and those of the peripheral distractor. The effects, therefore, should depend on a good deal of visual feature overlap between the nontargets and distractor. However, the effects of perceptual load have generalized over many different distractor measures that involve very little feature overlap between the distractors and the stimuli added in the high-load conditions.

For example, the following studies have adopted Lavie and Cox's (1997) perceptual load task, in which subjects search for one of two target letters (e.g., X or N) in a central letter array (e.g., a circle) either among Os (low-load conditions) or among similar angular nontarget letters (high-load conditions). Note that the added Os in the low-load conditions control for any low-level changes in the stimulus displays (e.g., the number of contrasts onsets) between the load conditions. The findings indicated that perceptual load, so varied, reduces perception for various types of task-irrelevant stimuli, none of which has much visual overlap with the nontarget letters in the search task. For example, perceptual load reduces the temporal resolution of light perception: The flicker-fusion threshold assessed for a point of light presented at fixation is increased under high load (Carmel, Saker, Rees, & Lavie, 2007). Note that the temporal resolution of a light flicker does not directly interact with the number of static angular letter features. Instead, the effects of load indicate shared perceptual capacity at a higher level (i.e., attention).

Perceptual load also reduces the rates of task-unrelated thoughts reported. In other words, perceptual load reduces mind wandering (Forster & Lavie, 2009). Note that here, by virtue of definition, task-unrelated thoughts are those that do not relate to any of the task stimuli. Once again, the presence of a greater number of angular letters in the conditions of high perceptual load is unlikely to produce a dilution effect on mind wandering, nor does it produce any low-level visual interference with the task-unrelated thoughts.

Forster and Lavie (2008) extended the effects of perceptual load to a form of irrelevant distraction more akin to irrelevant distraction in daily life. They measured distraction by meaningful objects that were entirely irrelevant to the letter-search task (see also Okon-Singer, Tzelgov, & Henik, 2007, for a similar effect on processing emotional distractors). Meaningful large colorful images of cartoon characters (e.g., Superman) were infrequently presented on 10% of the experimental trials. These distractors interfered with the letter search task (slowed the search RT) in the

low- but not high-load conditions. Note that the features of the small monochromatic angular letters cannot directly interfere with those of large colorful cartoon images (whose perception is also on a different spatial frequency scale). Note also that the magnitude of modulation by load was no less than that found over the processing of response competition distractor letters (presented on 80% of the trials within the same irrelevant capture experiments), despite the far smaller feature overlap in the irrelevant capture case. Thus, the effects of perceptual load neither require nor depend on any degree of visual feature overlap between the distractors and the added high-load stimuli. The results discussed so far clearly cannot be accounted for by some form of feature interactions as Tsal and Benoni suggest in their low-level visual interference account.

Previous Research: Manipulations of Perceptual Load That Involve No Change in the Display Set Size

Tsal and Benoni claim that the great majority of studies have used display size as a manipulation of perceptual load, but in fact perceptual load has often been varied by increasing the number and complexity of perceptual operations that the task involves. It is important to note that in the latter, the perceptual load manipulation involves no change in the number of stimuli in the display. In fact, often the very same stimulus displays are used in both conditions of load. Clearly, low-level visual interference cannot account for the reduced distractor processing in this case.

As discussed earlier, Lavie's (1995) original response competition experiments demonstrated that the effects of perceptual load on distractor processing generalize across manipulations of the relevant search set size and manipulations of the perceptual task requirements (e.g., comparing feature detection and feature conjunction tasks for the same stimulus displays). Many subsequent studies have since generalized the effects of perceptual load over both types of perceptual load manipulations. For the sake of brevity, we discuss a few prominent examples (see Lavie, 2005, 2006, 2010, for a more detailed review).

Brand-D'Abrescia and Lavie (2007) demonstrated that target letter recognition was facilitated in eight-letter strings when these formed a word compared with when these formed a nonword, suggesting that lexical processing reduced the perceptual load of the letter recognition task. In line with load theory predictions, the reduced perceptual load in the word conditions resulted in greater response competition effects from an irrelevant distractor letter in the periphery, even though the same number of letters were presented in both the word and nonword conditions (see also Madrid, Lavie, & Lavidor, 2010).

Cartwright-Finch and Lavie (2006) found that the rate of awareness reports in the inattentional blindness paradigm critically depends on the level of perceptual load in the relevant task, whether this is varied through the set size of a search task or through an increase in the perceptual demands for the same target stimulus (e.g., judging either clear [low-load] or subtle [higher load] length difference between the two arms of a cross shape). Rates of awareness for a critical stimulus on the final trial were modulated to a similar extent across these different manipulations of perceptual load.

Taya, Adams, Graph, and Lavie (2009, Experiment 3) asked participants to perform a color judgment task of either low load (determining whether a central array of moving dots was a mixture

of red and green dots or a mixture of blue and yellow dots) or high load (participants determined which of the two colors was more prevalent in the central array). Motion perception for more peripheral dots surrounding the central array was reduced with higher perceptual load as indicated by a measure of the motion aftereffects.

Lavie, Lin, Zokaei, and Thoma (2009) found that measures of distractor object recognition (e.g., object naming) show reduced distractor recognition under conditions of high perceptual load. These effects were found across experiments that varied perceptual load by increasing the relevant set size in a central object search task and those that increased the perceptual demands for one target object (presented either in an upright [low-load] or inverted [high-load] orientation). Note that in all of these studies the task remained the same (e.g., always involved letter recognition, object naming, or line length or color judgments) across the load conditions. Thus, a higher perceptual load did not involve any change in the cognitive load. These address the complaint that Tsal and Benoni raise against the cognitive demand in some of the previous perceptual load manipulations.

Bahrami, Lavie, and Rees (2007) and Bahrami, Carmel, Walsh, Rees, and Lavie (2008) showed that unconscious processing and associated signal in primary visual cortex (Area V1) are modulated by the level of perceptual load in a letter stream presented at fixation. The participants monitored the very same stream of letters for targets defined either on the basis of a single feature (e.g., color, low load) or conjunction of features (color and shape, high load). The continuous flash suppression paradigm was used to assess unconscious processing. Task-irrelevant stimuli (e.g., orientations or meaningful object images) were presented to one eye, and these were rendered invisible with the continuous presentation of very bright masks to the other eye. Both the orientation adaptation aftereffects and neural response to the invisible stimuli in primary visual cortex were found to be reduced under high perceptual load in the fixated letter stream. Numerous other neuroimaging studies have also clearly established reduced distractor-related neural signal under conditions of high (vs. low) perceptual load using very similar perceptual load manipulation for a fixated stream (e.g., O'Connor, Fukui, Pinsk, & Kastner, 2002; Schwartz et al., 2005). As the very same streams were used in both of the load conditions in all of these studies, low-level visual interference cannot account for the findings.

We conclude that the abundance of evidence converging on the same effects of perceptual load, irrespective of whether or not this involves an increase in the number of items in the display, provides strong support for load theory. Moreover, as the effects of perceptual load converge across the many different manipulations of perceptual load and different distractor measures, one account for all of these effects in terms of perceptual load is clearly more parsimonious than any attempt to provide task-specific accounts for the effects in each paradigm.

How Robust Are the Dilution Effects Reported in Tsal and Benoni's Study?

Lavie's (1994) thesis included a condition of low load with a singleton colored target but high relevant set size, similar to that explored in Tsal and Benoni's experiments (see also the acknowledgments). Lavie (1994, Experiment 1) compared distractor response competition effects between conditions of either low (relevant search set size 1) or higher (relevant search set size 4) load, while also varying whether the search target had a singleton color (red among black) or not. The condition of colored target with a higher relevant set size relates to our (and Tsal and Benoni's) current interest. Distractor response competition effects were significantly reduced in the high-load condition compared with all of the low-load conditions. These included the colored target (singleton) with relevant set size 4, in support of the spillover prediction but in sharp contrast to Tsal and Benoni's results. This specific discrepancy is found under very similar task conditions and thus casts doubt on the robustness of the dilution effects.

This discrepancy also points out an additional important issue. Conditions of relevant set size 4 (used in Lavie, 1994, Experiment 1; and in Tsal and Benoni's Experiments 1 and 2) are at the borderline of capacity limits (as discussed earlier, these are often estimated as including four to five items) and are therefore likely to be unstable with respect to approaching capacity limit. Thus, depending on task-specific factors (e.g., the amount of practice), conditions of set size 4 either may take up all of the capacity or may leave some room for an additional item to be processed (the peripheral distractor in this case; e.g., Lavie & Cox, 1997; Maylor & Lavie, 1998).[2] Conditions of a relevant search set size of six items are therefore a clearer case of high perceptual load, and we focused our discussion accordingly only on these clearer cases.

We note, however, that Tsal and Benoni's effects of perceptual load even in the experiments using a higher relevant set size (of six items) are not as robust as those previously reported (e.g., Lavie, 1995). Inspection of their summary results (see their Figure 10) shows consistent numerical trends for reduced distractor effects in the high-load (relevant search size 6) compared with the low-load (relevant set size 1) conditions. These, however, reached significance in some but not all of the experiments. It is somewhat hard to reach a clear conclusion from experiments in which the numerical trends (for the effects of perceptual load) are as predicted but statistical significance is not always reached. But for the sake of clarity, we had supposed in our discussion that the effects found in Tsal and Benoni's relevant search size 6 with a color cue condition can be found even when the effects of perceptual load are clearly replicated. This, however, remains an empirical question and presently adds further doubt to the robustness of the dilution effect they report.

Reversed Load Effects: The Role of Color Discrimination

Tsal and Benoni wonder why the distractor effects are sometimes smaller in the high set size plus colored target compared with the high set size with no colored target (see their discussion of the so-called "reversed load effects"). Indeed, given that in both conditions there is an equal number of displays items, this finding cannot be predicted based on their dilution account that attributes

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[2] Inspection of Tsal and Benoni's findings in Experiments 1b and Experiment 2, in which they have used only a moderate increase in the level of perceptual load (with a relevant set size 4), suggests that their set size 4 condition did leave room for distractor processing (under their "high-load" no-color condition), consistent with previous findings (Lavie & Cox, 1997; Maylor & Lavie, 1998).

dilution to the mere presence of additional items. This finding is also the opposite of what might be expected from their claim that high-load conditions should involve effects of both dilution and attentional load. If that were the case, clearly one would expect less distractor processing in the high-load compared with the dilution condition.

Tsal and Benoni discuss the effect of reduced overall RT length in the colored target condition as a potential reason. The shorter RT in these conditions (compared with the high-load condition) provides a smaller time window for distractor processing. Although this may be a contributing factor (see also Lavie & De Fockert, 2003), Tsal and Benoni neglect the potential contribution of the color discrimination per se between the target and distractor. The effects of color discrimination per se can become clear once a factorial design is used in which color discrimination and set size are varied orthogonally. In other words, one would need to add a condition of low set size plus colored target to the design used in Tsal and Benoni's experiments.

Indeed, Lavie (1994) used such a design but her results did not point to any clear effect of color discrimination on response competition. More thorough investigations of the role of feature discrimination in the response competition paradigm (e.g., Baylis & Driver, 1992; Humphreys, 1981) have clearly established that distractor response competition effects depend also on the target distractor similarity in terms of size, color, and so forth. Thus, the color discrimination is clearly expected to have contributed to the reduced distractor response competition effects in the condition of the high set size with a colored target (see also Wilson, Macleod, & Muroi, 2008).[3]

Finally, Tsal and Benoni raise additional issues that appear to stem from various misunderstandings of load theory and in some cases misreading of the previous research. For example, they claim that the manipulations of sensory degradation reported in Lavie and De Fockert's (2003) study involved the presentation of the degraded target alone. But in fact Lavie and De Fockert's Experiment 1 manipulated sensory degradation through reduced retinal acuity for targets in more eccentric positions in displays of either low or high set size. In any case, because none of the claims raised are supported by any new data or lead to any new testable predictions, we do not dwell on these any further.

In Conclusion: "That Which Does Not Kill Us Makes Us Stronger" (Friedrich Nietzsche)

We explain the Tsal and Benoni (2010) pattern of results in terms of load theory and its existing assumptions. The present findings and discussion demonstrate that reduced distractor processing in tasks of high set size but low perceptual load can be accounted for by spillover of limited remaining capacity as originally proposed by load theory. Our new results confirm the predictions from this hypothesis in showing that when distractor processing is reduced, other nontarget items in the array are perceived instead. These results are inconsistent with lower level visual interference (cf. Tsal and Benoni's claims) and instead provide evidence for load theory extending it to low-load situations that include competition between multiple items for remaining limited capacity. Load theory thus remains the

most parsimonious account for a very large set of data obtained with various manipulations of perceptual load, including both display set size (with or without "dilution") and many other load manipulations that do not involve a change in the display set size as well as a great range of measures of distractor processing.

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[3] Tsal and Benoni's Experiments 3 and 4 included a colored target in all of the conditions. However, the target color did not serve as a selection cue in the high-load conditions. The use of color as a selection cue only in the dilution conditions can explain the small and insignificant trend for a reversed load effect in these two experiments.

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