Psychonomic Bulletin & Review (2018) 25:2037–2046
https://doi.org/10.3758/s13423-018-1444-7

THEORETICAL REVIEW

Can automaticity be verified utilizing a perceptual load manipulation?

Hanna Benoni[1,2]

Published online: 8 February 2018

Abstract
A variety of studies tried to examine the fundamental question of whether specific processing is "automatic," that is, occurs without attention, by manipulating attention toward stimuli via the set-size manipulation of perceptual load. The present paper invites re-extermination of this common methodology of altering the perceptual load of a relevant task to manipulate attention toward peripheral stimuli. Four main arguments that propose alternative interpretations to the notion of automaticity in this line of studies are discussed, suggesting that automaticity cannot be verified utilizing manipulation of load, and outlining a plan for moving forward.

Keywords Automaticity · Perceptual load · Visual attention

Introduction

Whether specific processing is automatic (i.e., occurs without requiring attention) or whether it requires attentional resources is a fundamental question. It is the focus of many studies in various fields of cognitive psychology, such as visual attention, face perception, emotion, social cognition, and more. A common tool that researchers utilize to examine this general question of evaluating automaticity is the set-size manipulation of perceptual load (Lavie, 1995), which was initially used to test the predictions of perceptual load theory (Lavie, 1995; Lavie & Tsal, 1994).

Perceptual load theory of selective attention (Lavie, 1995; Lavie & Tsal, 1994) postulates that the processing load of the relevant task determines the extent to which irrelevant distractors are processed. If target processing does not exhaust attentional resources (with low perceptual load), leftover attentional resources will inevitably spill over to process-irrelevant distractors, thereby producing interference. However, when target processing depletes all attentional resources (with a high perceptual load), distractor processing can be prevented. In a typical manipulation of perceptual load, participants are presented with a target letter that appears either alone (low perceptual load) or embedded among a number of non-target neutral letters (high perceptual load). The efficacy of selection is measured by the effect of an incongruent relative to congruent distractor appearing somewhat remotely from the target ("flanker effect"). Typically, substantial interference is observed under the low-load condition, but it is either markedly reduced or completely eliminated under high-load displays. This reduced interference under the high-load condition (the "load effect") has been interpreted as supporting load theory by assuming that reduced interference under the high-load condition occurs because a significant amount of attentional resources is required for searching the target among neutral items, leaving no spare resources to process the irrelevant distractor.

Currently, there is a growing body of research which manipulates perceptual load, not to test the predictions of load theory but rather to test whether specific processing is "automatic" (i.e., occurs without attention; Shiffrin & Schneider, 1977) (e.g., Bishop, Jenkins, & Lawrence, 2007; Catmur, 2016; Fox, Yates, & Ashwin, 2012; Lavie, Ro, & Russell, 2003; Okon-Singer, Tzelgov, & Henik, 2007; Ro, Friggel, & Lavie, 2009). The premise of these studies is that in high-load conditions attention is exhausted by the search for the target among neutral items, thus any interference by the distractor is an indication of automatic processing.

The present paper questions the use of perceptual load manipulation to manipulate the amount of attention that is

✉ Hanna Benoni
BenoniH@colman.ac.il

1 Department of Psychology, The College of Management, Academic Studies, Rishon LeZion, Israel

2 Department of Computer Science and Applied Mathematics, The Weizmann Institute of Science, Rehovot, Israel

directed toward stimuli. The bulk of this paper discusses four main arguments that strongly suggest that the notion of automaticity cannot be verified by manipulations of load.

Each of the first three arguments begins with a description of one problem concerning the core assumptions of load theory, and is then expounded upon with a concise review of relevant studies. In the second part of each argument, I raise a question or flaw in the study of automaticity that is derived from the first caveat concerning load theory, proposing an alternative interpretation to the conclusion of automaticity in this line of studies. In the fourth argument I discuss alternative interpretations to automaticity within the framework of load theory while accepting the core tenets of this theory. Finally, this paper outlines future suggestions that may be helpful in reducing the discussed limitations.

It is important to note that the literature review in this paper does not exhaustively review and assess the tenets of load theory and all its advantages and disadvantages. Other reviews have done this (Benoni & Tsal, 2013; Khetrapal, 2010; Murphy, Groeger, & Greene, 2016). The aim of this critical review is, rather, to raise a novel comprehensive discussion about the use of the manipulation of perceptual load to test automaticity. Therefore, the focus of this review is to provide a closer look at the studies that test automaticity. For this purpose, only relevant literature about load theory and alternative accounts that are relevant to the assessment of automaticity processes are discussed.

Alternative interpretations to automaticity that derive from the problem of circular reasoning

This section discusses a general methodological concern of circular reasoning that challenges the rationale of the studies that use perceptual load manipulations to test automaticity. The first paragraphs of this section introduce relevant studies that test automaticity via load manipulations. Following these descriptions, I discuss the methodological concern of manipulating and testing attention via the same manipulation of load. Finally, a general alternative interpretation of automaticity that derives from this problem is discussed.

Many studies have manipulated load to test whether the perception of unique stimuli like emotional and threat-related stimuli (e.g., Bishop et al., 2007; Fox et al., 2012; Norberg, Peira, & Wiens, 2010; Okon-Singer et al., 2007) or objects belonging to a person's field of expertise (e.g., Ro et al., 2009) require attention. These studies have utilized typical load manipulations but have used unique stimuli as distractors. For example, Ro et al. (2009) tested a group of expert musicians with a musical instrument-classification task, during which irrelevant images of musical instruments were presented as visual distractors under varying conditions of perceptual load. Unlike non-musicians, in the musicians group the irrelevant images of musical instruments produced interference even under conditions of high perceptual load, in which distractors are presumed to be unattended. Ro et al. (2009) suggested that musical instruments are processed automatically, and without capacity limits, in subjects with musical expertise.

Another recent example is a study by Catmur (2016). Catmur manipulated load to test whether imitation requires attention. The psychological function unique to imitation is the ability to match the visual representation of another's action onto the observer's own motor program for that action (Heyes, 2001). In Catmur's study, participants performed a letter-classification task in which peripheral images of finger movements were presented as distractors. Responses to the target-letter stimuli were performed via finger movements that were imitatively compatible with the distractor movements (requiring the same finger movement) or imitatively incompatible (requiring the opposite finger movement). Attention to the distractor movements was manipulated by altering perceptual load through increasing the number of non-target letter stimuli. The results demonstrated that irrelevant finger movements influenced response times regardless of the level of perceptual load (Experiment 4). These data were found to support the notion that imitation can occur without attention.

All the studies described above share the same generic rationale: If the specific distractor is processed automatically without attention, then it is expected to produce interference, irrespective of the level of perceptual load in the task. If, however, distractor processing requires attention, then perceptual load is expected to reduce distractor interference. The rationale underlying this line of studies is problematic because it produces circular reasoning (see Benoni & Tsal, 2013; Lamy, Leber, & Egeth, 2013, for related criticism). The basic assumption of these studies is that the distractors are attended in low-load conditions and are unattended in high-load conditions. The problem is that this assumption cannot be stated a priori, because it serves as the *hypothesis* and as the end product of the investigation of load theory, and also because load theory uses the *same manipulations* of load to *test* this assumption. In other words, we cannot manipulate attentional resources and test attentional resources using the same manipulation of load.

A process that does not require attention versus findings inconsistent with the predictions of the perceptual load theory

The aforementioned problem produces an alternative interpretation to the notion of automaticity. That is, if manipulating the load of a relevant task does not affect distractor interference, it may indeed suggest that the processing of this distractor is not affected by attention. However, this same result can alternatively suggest that this finding is inconsistent with perceptual load theory.

Indeed, the "load effect" is not obtained in all configurations and experiments which examine the "flanker effect" when manipulating load via set size; several studies found significant distractor interference under high perceptual load (e.g., Benoni, Zivony, & Tsal, 2014; Marciano & Yeshurun, 2011; Theeuwes, Kramer, & Belopolsky, 2004; Roper & Vecera, 2013; Tsal & Benoni, 2010a, Experiments 2 and 4; Yeshurun & Marciano, 2013). These studies suggest that we can't assume a priori that the distractor in high load condition is unattended.

An illustration can make this point clearer. In a recent study by Lleras, Chu, and Buetti (2017), the authors followed the procedure employed by Forster and Lavie (2008a). In this manipulation, as in typical manipulations of load, participants were asked to find a target letter (N or X) in two levels of perceptual load: low and high. However, distractibility was assessed by comparing trials in which an entirely irrelevant cartoon appeared (distractor trials), compared with trials in which a distractor does not appear at all (non-distractor trials). In their study, distractor interference was obtained in the low load condition, and eliminated in the high load condition, only in an exact replication of the original experiment by Forster and Lavie. However, when they conducted experiments with the same manipulation of load, but with minor methodological differences, like changing the proportion of distractor trials from 20 to 33% (Experiment 1), or the presentation time from 100 to 200 ms (Experiment 2), distractor interference was also obtained in high load presentation. Since in that study the authors manipulated load to test the predictions of load theory, they found these results to be inconsistent with load theory and concluded that perceptual load theory may not be a useful framework for predicting distractor interference in many situations.

By the same token, one could have used the set of experiments that were conducted by Lleras and collages (2017) to test whether irrelevant cartoon distractors are affected by attention by *assuming* that the distractors in high load conditions do not receive attention. Accordingly, the results that also demonstrate distractor interference in high-load conditions, would have generated the conclusion that the process of cartoons does not require attention (i.e., is automatic), instead of inferring that there is a problem in generalizing the conclusions of load theory.

Hence, with similar distractor interference in high- and low-load conditions in the studies that manipulate load to test automaticity, one ought to be cautious and ask: does it reflect automatic processing of the distractor or does it simply provide inconsistent evidence with load predictions?

Alternative interpretations to automaticity that derive from questioning the idea that "load effect" depends on changes in attentional resources

Studies that manipulate perceptual load to test whether specific processing is automatic or resource-demanding rely on the idea that the distractor is attended in the low-load condition and unattended in the high-load condition, and as a result the "load effect" emerges. That is, the idea that "load effect" depends on changes in *attentional resources*. However, this idea has been challenged several times. Some researchers have proposed that the typical "load effect" may be the outcome of different processes in the *pre-attentive* perceptual stage (e.g., Fitousi & Wenger, 2011; Mevorach, Tsal, & Humphreys, 2014; Tsal & Benoni, 2010) or the *post-attentive* perceptual stage (e.g., Kyllingsbæk, Sy, & Giesbrecht, 2011; Roper & Vecera, 2013). These suggestions are also in agreement with accounts that argue that the "flanker effect" may be independent of spatial attentional resources (e.g., Cohen et al., 1995; Gronau et al., 2009).

This section reviews relevant studies that challenge the basic notion that "load effect" depends on changes in attentional resources and suggest that "load effect" depends actually on pre- or post- attentive process. Following this review, alternative interpretations to automaticity that derive from these criticisms are discussed.

The role of pre-attentive processes It has recently been argued (Benoni & Tsal, 2010, 2012; Benoni, Zivony, & Tsal, 2014; Tsal & Benoni 2010a, b; Wilson, Muroi, & Macleod, 2011) that the reduction of distractor interference under high-load conditions in set-size manipulations need not be attributed to increases in load or task difficulty resulting from the need to search for the target among neutral letters. Instead, it could be due to the *dilution* of the distractor by the presence of neutral items characterizing high-load presentations. These neutral items may play an important role in competing with the distractor for neuronal representation, irrespective of load or task difficulty. Indeed, several different studies (e.g., Benoni & Tsal, 2010, 2012; Tsal & Benoni, 2010a; Wilson et al., 2011) distinguished between the possible effects of load and dilution by introducing dilution displays. These displays contained neutral letters (as in high-load conditions) capable of diluting the distractor. Yet, either the stimulus or processing requirements allowed for a low-load processing mode. For example, participants were presented with the same multicolor row of letters containing a target and five neutral letters in both the dilution and high-load conditions. In the high-load condition, the row of letters had to be searched thereby necessitating a high-load processing mode. In the dilution condition, the target color was known in advance thus they were easy to find, allowing for a low-load processing mode (Benoni &

Tsal, 2010, Experiment 2). In all the experiments that used a variety of converging operations, distractor processing was either completely eliminated for these new displays or markedly reduced compared to the original low-load condition, thereby supporting the conclusion that the elimination of distractor interference under the high-load condition, repeatedly attributed to load, is accounted for by dilution.

Although it is still unclear in which stage of processing dilution occurs, and although the exact mechanism underlying dilution is still somewhat vague, it has been proposed that dilution occurs in the pre-attentive stage (e.g., Tsal & Benoni, 2010a; Mevorach et al., 2014). Mevorach and colleagues (2014) demonstrated that patients with unilateral neglect showed dilution effects from neutral items in their contralesional neglected field, even though these items were supposed to be unattended. They thereby proposed that dilution occurs in the pre-attentive early visual stage ("perceptual dilution"). In a recent study, Fitousi and Wenger (2011) used more powerful measures, such as the hazard function of the response-time distribution (Townsend & Ashby, 1978; Wenger & Gibson, 2004), along with signal-detection theory, to test the hypothesis that perceptual load induces attentional resources. They found that contrary to the assumptions of load theory, perceptual load also induces data limitations and affects the stimuli discriminability. Their findings provide support for the notion that in high-load presentations, neutral letters degrade the quality of the distractor's visual representation.

Additional support to the notion that distractor suppression under the high-load condition may be determined by degradation of distractor's visual representation, may also be driven from the *neural competition interpretation* by Diane Beck and colleagues (e.g., Scalf, Torralbo, Tapia, & Beck, 2013; Torralbo & Beck, 2008). According to this account, competition for representation in the visual cortex may underlie perceptual load. In high-load presentations, the neural representation of the target is diminished by local competitive interactions among cells in the visual cortex that represent the target and the nearby additional neutral items. To overcome this target impairment in high-load presentations, a strong top-down bias is invoked to resolve the competition in favor of the target. This strong top-down bias results not only in the enhancement of the target in the visual cortex, but also in the suppression of all the other items in the display (Desimone & Duncan, 1995). Thus, in high-load presentation, distractor interference is eliminated. In low-load presentations, the absence of neural competition between target and neutral letters results in the absence of top-down biases toward the target. Consequently, there is privation of distractor inhibition. Thus, according to the bias competition account, the ability to ignore distracting information stems from, in part, neuronal competition in the visual cortex, and is not the consequence of an exhausted attentional capacity per se.

The role of post-attentive processes Recent work by Kyllingsbæk et al. (2011) highlighted the critical role of VSTM in producing perceptual "load effects." Kyllingsbæk and colleagues built upon the Theory of Visual Attention (TVA), originally proposed by Bundesen (1990), to propose that perceptual "load effects" are best explained by a model that also refers to the storage-capacity constraints of VSTM. According to Kyllingsbæk and colleagues, attention is allocated simultaneously for both task-relevant stimuli and task-irrelevant distractors. Thus, in *both* high- and low-load conditions, distractors are expected to receive attentional resources (although the relative attentional weight given to distractors is expected to be higher in low-load conditions). The second highlight, according to Kyllingsbæk et al., is that VSTM capacity is an additional critical bottleneck. Thus, even an attended distractor may lose the competition with the neutral stimuli in high-load presentations for representation in the memory buffer and thus be excluded from the ability to affect reactions. In a similar vein, Roper and Vecera (2013, 2014) also argued that VSTM is an important bottleneck underlying perceptual "load effects," which emerge in short presentations. In one study, Roper and Vecera (2013) extended the exposure duration of stimuli, a manipulation considered to free up the availability of mnemonic resources. They observed a reliable "flanker effect" under high-load presentations in response-terminated displays. Roper and Vecera then argued that under a low-load condition, an ample VSTM capacity exists; therefore, the target and distractor both enter the memory buffer as a default and without attention prioritization. As opposed to low-load conditions, in typical high-load conditions, only stimuli that win the race will enter VSTM in short presentations. Thus, distractors may lose the race or be *diluted* in the VSTM buffer by the additional neutral letters. In a follow-up study (Roper & Vecera, 2014), the authors provide a direct test of VSTM load on distractor processing. In the study, observers performed a low perceptual load flanker task during the delay period of a VSTM change detection task. The results demonstrated a reduction of the "flanker effect" in the perceptual load task as a function of increasing concurrent VSTM load. These findings suggest that perceptual representations of distractor stimuli compete with the maintenance of visual representations held in memory, and thus support the notion that the "load effect" may in fact be driven by post-attentive resource limitations.

Defining a target in the common high-load condition requires the function of searching. Thus, further support to the notion that the elimination of distractor interference in high-load presentations may be driven by post-attentive resource limitations comes from several models of visual working memory (WM). Those models proposed that visual WM is critical for a number of important operations during visual search (e.g., Duncan & Humphreys, 1989; Bundesen, 1990). Consistent with this view, evidence from several neurophysiological studies have indicated that during visual search neurons that are selective for the search target often remain active during a delay period before the onset of the next search display. Interestingly, the same brain areas show template-related activity during the delay period, followed by an enhanced response to a matching target during visual WM tasks (e.g., Miller & Desimone, 1993, 1994). Moreover, cells in the inferior temporal (IT) cortex also show enhanced firing rates during search, just before a saccadic eye movement toward that target (Chelazzi, Miller, Duncan, & Desimone, 1993). These findings led to the conclusion that visual search is just a variant of a WM task. This conclusion is strongly supported by Luria and Vogel (2011) who directly tested the notion that perceptual load manipulations by display set size are actually WM manipulations. They followed the set-size manipulation conducted in Lavie and Cox (1997) while using an electrophysiological measure of WM capacity – the contralateral delay activity (CDA) amplitude – which is a marker for WM capacity (e.g., Vogel & Machizawa, 2004). Luria and Vogel found that the CDA amplitude was significantly larger in high-load conditions compared to low-load conditions, indicating a greater involvement of WM in the former. As far as the CDA amplitude does indeed reflect WM, this finding provides direct evidence to the argument that perceptual load manipulations are post-attentive manipulations. Further evidence in favor of the notion that WM, rather than attentional resources, produces the “load effect” is driven from a recent study by Zhang and Luck (2015). This study proposed that “load effects” are not a result of loading perception per se, but instead reflects an increased need for resolution in WM in the high-load perceptual task relative to the low-load perceptual task.

Another recent work in favor of the view that perceptual load manipulations are, in fact, post-attentive manipulations, is the study by Cosman, Mordkoff, and Vecera (2016). Cosman and colleagues have argued that the different “flanker effects” in low- and high-load manipulation may be due to post-attentive processing of the stimulus-response translation. To test whether the absence of “flanker effect” under high-load presentations may be due to failures in a response translation stage, Cosman and colleagues have used the correlated-flankers task (Miller, 1987), which is supposed to be a more sensitive measure for distractors identification. In the correlated flanker task, unlike the standard flanker task, flanker letters are never potential targets and therefore are not part of the response set. Instead, the flankers have a direct learned, statistical relationship to the target; certain flankers have either a high or low probability of co-occurring with certain visual targets. This learned relationship allows the correlated flankers to influence responses directly, so long as they are perceptually processed (Mordkoff & Halterman, 2008). The authors found that in the standard flanker task, distractor interference was eliminated in high-load presentation, while in the correlated-flankers task, identical high-load displays produced interference as low-load displays. Cosman and colleagues thereby argued that the distractors in the high-load presentations in the standard flanker task are attended but do not readily activate the corresponding response. Thus, similar to other studies which are described above, this study undermines the basic tenet that traditional “load effect” depends on changes in *attentional resources*.

A process that does not require attention versus attended distractor that does not compete with other stimuli

All the findings and accounts discussed above strongly suggest that via perceptual load manipulation, post or pre-attentive processes, rather than attentional resources, may be manipulated. Moreover, most of these accounts leave open the possibility that attention is not manipulated along with the pre- or post-attentive processes. For example, although Roper and Vecera (2013, 2014) and Kyllingsbæk et al. (2011) did not preclude the role of attention in their models, their accounts do not exclude the possibility that even distractors that are *similarly attended* in high- and low-load conditions may produce the traditional “load effect,” i.e., produce interference only in the low-load condition.

Thus, by undermining the basic tenet that “load effect” depends on changes in *attentional resources,* these findings also question the validity of the studies which lean on this tenet to test automaticity (i.e., assume that a distractor in high-load conditions did not receive attention). That is, while receiving similar interference effects in high- and low-load conditions, we may consider other alternatives to the conclusion that specific stimuli are processed without attention.

For example, consider the VSTM view, we may propose that while conducting configurations with unique distractors (e.g., faces, emotion stimuli, relevant objects, finger movements), perceptual load manipulations are less effective than typical configurations in manipulated competition in VSTM or perceptual dilution. Perhaps neutral letters in high-load displays cannot dilute unique distractors as typical manipulations that utilize letter distractors can because the unique distractors do not share the same physical features as the neutral letters. Alternatively, we may propose that letters and words do not compete with the unique distractors for representations in short-term memory because of the domain specificity of working memories.

In this regard, one might be cautious and ask: does the interference produced by a unique distractor in both high- and low-load conditions reflect automatic processing of the distractor, or is it the outcome of a *similarly attended* distractor that does not compete with other stimuli in pre- or post- attentive stages?

Alternative interpretations to automaticity that derive from questioning the spillover assumption

Even when accepting the assumption that "load effect" depends on changes in *attentional resources*, one should still question another fundamental assumption that lies at the basis of the studies that use "perceptual load" to manipulate attention – the *spillover assumption*. This assumption postulates that the allocation of attention is a two-step process in which resources are first allocated to task-relevant stimuli, and then, the distractors receive leftover resources.

This section introduces relevant literature that challenges the spillover assumption. Following these examples, alternative interpretations to automaticity that derive from these studies are discussed.

Not all models, accounts, and studies are in agreement with the spillover assumption (e.g., Giesbrecht, Sy, Bundesen, & Kyllingsbæk, 2014; Kyllingsbæk et al., 2011; Neokleous, Shimi, & Avraamides, 2016; Tsal & Benoni, 2010b). Moreover, there is no consensus on this assumption, even in accounts that support the idea that *attention* determines the traditional perceptual "load effect" (e.g., Biggs & Gibson, 2010; Cosman & Vecera, 2010a; Eltiti, Wallace, & Fox, 2005). Some studies suggest one step of attentional allocation to the target and distractors, as described above (e.g., Bundesen, Habekost, & Kyllingsbæk, 2005, 2011; Kyllingsbæk et al., 2011); other studies emphasize the importance of the characteristics of the distractor and its ability to initially capture attention (e.g., Biggs & Gibson, 2010; Biggs, Kreager, Gibson, Villano, & Crowell, 2012; Cosman & Vecera, 2010a; Eltiti et al., 2005). For example, Eltiti et al. (2005) argued that distractor interference depends on the relative salience of the target and the distractor rather than the target load. They jointly manipulated perceptual load and the onset (salient) or offset (not salient) of target and distractors. They found distractor interference for the offset target and the onset distractor even under high-load conditions. Eltiti et al. (2005) thus concluded that salient distractors can capture attention rather than receive leftover attentional resources from the load of the target.

Interestingly, in a recent study conducted by Biggs et al. (2012), attentional capture by distractors was measured by using a paradigm in which task-irrelevant distractors appeared while observers performed a visual search task under different levels of perceptual load (Forster & Lavie, 2008a, b). In a series of experiments in which the meaning of the distractors and their affective significance for the observers were manipulated, the authors found that it was not the perceptual load of the task that affected the extent of distractor interference but rather their characteristics; specifically, they found that while increased knowledge of distractors may reduce interference, affect can restore their ability to interfere.

Finally, a recent study by Neokleous et al. (2016) proposed a computational model that has been implemented to account for experimental findings of perceptual load theory. Interestingly, the model considered mostly the saliency of visual stimuli (using the algorithm proposed by Koch & Ullman, 1985, and implemented by Walther & Koch, 2006), and the effects from top-down factors (using the model proposed by Hamker, 2004). The authors' conjecture was that all items in the display are processed *simultaneously* in a single step, and that the probability of distractor interference is determined by the features of the stimuli and potential top-down biases. That is, the model was designed based on disagreement with the spillover assumption of perceptual load theory. Simulation results of this model reproduced the behavioral findings from load manipulation via set-size, suggesting that the spillover assumption is not essential in producing this basic pattern.

All these findings strongly suggest that the amount of attention that specific distractors receive cannot be altered solely by the manipulation of the load of the *relevant information*; instead, the characteristic of the *distractor itself* and its saliency should be considered, especially when distractors are emotional stimuli.

A process that does not require attention versus a salient distractor that attracts attention

An alternative interpretation to the notion of automaticity may stem from the problem of building upon the spillover assumption; most of the studies that manipulate load to test automaticity use more salient distractors than in the typical manipulation (e.g., emotional stimuli, faces, relevant stimuli to experts, movements), without considering the possibility that these distractors have the ability to initially capture attention. Hence, with similar distractor interference in high- and low-load conditions in these studies, an alternative to the interpretation that the distractors have been processed without attention is that the distractors attract attention in both high- and low-load conditions and thereby produced interference in both conditions.

An illustration from the recent study by Catmur (2016) can make this point clearer. The results of Experiment 4 in Catmur's study revealed that the imitative effect was similar in low- and high-load conditions; consequently, this finding was interpreted in terms of attention-free distractor processing. However, it is reasonable that the salient moving fingers, which served as distractors in this experiment, simply captured attention in the high-load condition. After all, in contrast to several findings that support the idea that perceptual load manipulation may modulate attentional capture by motion and other types of dynamic discontinuity (i.e., abrupt onsets) (e.g., Cosman & Vecera, 2009, 2010a; Rees, Frith, & Lavie, 1997), there is a growing body of literature that proposes that perceptual load cannot modulate salient distractors (e.g., Biggs & Gibson, 2010; Cosman & Vecera, 2010b; Eltiti et al., 2005), and a large variety of studies that generally propose that dynamic discontinuity (i.e., motion) elicits involuntary shifts of attention (e.g., Al-Aidroos, Guo, & Pratt, 2010; Müller & Rabbitt, 1989; Von Mühlenen & Lleras, 2007). In similar vein, in the study of Ro et al. (2009), peripheral musical instruments may capture more attention from musician than from non-musician participants, and in a variety of studies (e.g., Bishop et al., 2007; Fox et al., 2012; Norberg et al., 2010; Okon-Singer et al., 2007), emotional stimuli and faces may attract more attention than letter stimuli.

All these studies propose that we cannot state a priori that a certain manipulation of perceptual load *of the target* will modulate the attentional resources received by the distractor. In this regard, one might be cautious and ask: does the interference produced by a unique distractor in high-load condition reflect an attention-free automatic processing of the distractor, or is it the outcome of a salient distractor being processed due to the attentional capture?

Alternative interpretations to automaticity within the framework of load theory

This section discusses two lines of studies that also utilize perceptual load manipulations: studies that test individual differences in attentional capacity, and studies that test attentional modality. The conclusions from these studies are susceptible to the same aforementioned caveats. Moreover, the results obtained from these studies can be interpreted in terms of automaticity rather than modality or enhanced capacity *within* the framework of load theory, and vice versa. That is, bearing the tenets of load theory in mind, results from studies that manipulate load to test automaticity may be interpreted in terms of modality or enhanced capacity.

Automaticity versus modality

Several studies have manipulated load to test whether a certain category (usually faces) is processed by a *specific attentional resources* (e.g., Lavie, Ro, & Russell, 2003; Neumann, Mohamed, & Schweinberger, 2011; Neumann & Schweinberger, 2008; Thoma & Lavie, 2013). In these studies, much like the studies that manipulate load to test automaticity, the basic axiom is that under high-load presentations, no spare attentional capacity is left over from target processing. However, if a distractor elicits similar interference effects in high- and low-load presentations, the conclusion is that the distractor *receives attentional resources* from a separate attentional capacity rather than that it has been processed without attention. For example, in the study of Neumann and Schweinberger (2008), participants were presented with a perceptual load letter search task superimposed on background distractor faces. They identified target letters under varying conditions of perceptual load. Letter identification was followed by probe presentations without the letter task. The images in the probe presentations were either repetitions of faces from the earlier trials, new faces, or infrequent butterflies. Results revealed repetition priming effects for repeated faces (i.e., better performance for faces that were presented as distractors in earlier trials). More important, these repetition effects, that indicate distractors interference, were unaffected by perceptual load at the first presentations. These results were found to support the notion of face-specific attentional resources.

The rationale of these studies raises an additional question: modality or automaticity? In agreement with the tenets of perceptual load theory, interference under a high-load condition may be interpreted in two different ways: a process that consumes attentional resources that are separate from the attentional resources that the target consumes (i.e., attentional modality); or a process that does not consume attention (i.e., automatic process). The problem is that these two inferences are not interchangeable, in fact, they are essentially contradictory.

Each of those lines of studies infers under the same manipulations, framework, and results the contradictory conclusion concerning attentional resources. Thus, in studies that test modality, as well as in studies which test automaticity, one that supports load theory still ought to be cautious and ask: does the interference produced by a unique distractor in high-load condition reflect an attentional-free automatic processing of the distractor, or is it the outcome of a distractor being processed due to the attentional resources it receives from a separate specific capacity?

Automaticity versus enhanced attentional capacity

Several studies have manipulated load to test attentional capacity differences across development (Couperus, 2011; Huang-Pollock, Carr, & Nigg, 2002; Maylor & Lavie, 1998), autism spectrum disorder (e.g., Remington, Swettenham, & Lavie, 2012), deaf individuals (e.g., Hauthal, Neumann, & Schweinberger, 2012), and other differences between different groups (see Murphy et al., 2016 for a review). The rationale goes as follows: if a group has less attentional capacity than the regular population, then these individuals are expected to be undistracted even under small set size displays or in medium-load, compared to a control group. If, on the other hand, a group of individuals is suspected to have an increased attentional capacity compared to the control group, then distractor interference is expected to be preserved in this group, even under high-load presentations. That is, due to their enhanced attentional capacity, leftover resources are expected to remain from the task even in a high-load presentation. For example, in the study of Hauthal et al. (2012), manipulating load via set size affected distractor interference in hearing participants, but had no effect on deaf participants. Hauthal and colleagues then concluded that auditory deprivation may result in enhanced visual attentional capacities. Similarly, several studies have found that manipulation of load did not modulate distractor interference in action video game players, while it did in non-gamers (e.g., Green & Bavelier, 2003). These studies propose that gamers have an increased attentional capacity compared to non-gamers (See also Dye, Green, & Bavalier, 2009).

Since this line of research relies on the basic assumptions of load theory, it is susceptible to the aforementioned caveats as well. Additionally, in some studies, one that supports load theory may still argue that the distractor interference that is obtained under high-load presentation in a certain group is the outcome of an attention-free process, rather than enhanced attentional resources that characterize this group. Indeed, the study of Ro and colleagues, which is described above, proposed that musical instruments can be processed without attention in a group of musicians (compared to non-musicians). Alternatively, under the same framework of perceptual load theory, one may use the same manipulation to test whether musicians have enhanced attentional capacity compared to non-musicians. Since these two questions are not interchangeable, studies that compare groups to test attentional capacity differences should thus be used with caution.

Suggestions for future directions

The change in perspective that perceptual load theory solidified in the literature cannot be underestimated: replacing the archaic theoretic question of the locus of selective attention (see Lavie & Tsal, 1994) with the new pragmatic question of efficiency of perceptual selectivity. In application, the theory can provide good predictions concerning the outcomes of selectivity, even without specifying the fundamental theoretical roles that determine these predicted outcomes. However, since the core theoretical tenets of load theory concerning attentional resources have not been tested directly and were criticized in many studies, the use of load manipulation to manipulate attention (i.e., leaning on tenets that have not been tested), must be questioned as well. Here I outline two main suggestions that may reduce the limitations described in this paper.

An appropriate control condition In each study in this line of research it is necessary to conduct an additional experiment in which a letter distractor and a unique distractor will be presented simultaneously within the same paradigm. Such manipulation could demonstrate a larger letter compatibility effect in the low-load condition than in the high-load condition (i.e., showing no evidence of attentional capture by the letter distractor in the high-load condition), while the unique distractor produces similar interference in the low- and high-load conditions. For example, it was necessary in Catmur's study to conduct an additional experiment in which imitation compatibility and letter compatibility *upon* the moving fingers were orthogonally manipulated, within the same paradigm. That is, to demonstrate that although the letter compatibility effect was higher in the low-load condition than in the high-load condition, the imitative effect was similar in the low- and high-load conditions. Such results would have been necessary to answer some of the problems, although they would not have been sufficient to resolve all the arguments discussed above.

Using direct ways to manipulate attention Perhaps the best suggestion is to consider ways to directly manipulate attention to test whether specific processing is automatic or resource-demanding. For example, by using the Posner cuing paradigm (Posner, 1980), where a cue is used to attract participants' attention to a location in space (valid cue), and banish participants' attention to other locations (invalid cue).

The use of the cuing manipulation to test whether specific processing requires attention or not should also be used with caution; items that appear at the invalid locations are less attended (compared to items at valid locations) but not necessarily unattended. The use of additional piloting to validate the cuing manipulation, before using it in order to manipulate attention (e.g., Gronau & Izoutcheev, 2017), may reduce this problem and provide a good tool to utilize.

Summary

The present paper provides a closer look at studies that test automatic processes of unique stimuli by the common methodology of manipulating perceptual load. The paper provides four major arguments that strongly suggest that the notion of automaticity cannot be verified by altering the perceptual load of a relevant task via set size manipulations.

The same significant distractor interference in high- and low-load conditions indeed may suggest that distractor processing is attention-free (i.e., automatic). However, the different arguments suggest several alternatives to this interpretation. The first argument discusses the problem of circularity in manipulating and testing attentional resources using the same load manipulation. Due to this circularity, such results can be interpreted as a failure to replicate the "load effect" rather than evidence for automatic processing of the distractor. The second argument postulates that load manipulation via set size may in fact be a VSTM manipulation or perceptual dilution manipulation, rather than manipulation of attention. Thus, the second argument proposes that a unique distractor interference in both high- and low-load conditions may be the outcome of a similarly attended distractor that did not compete with other stimuli in pre- or post- attentive stages. The third argument, which emphasizes the problems in building upon the spillover assumption, proposes that such findings may simply reveal that the unique salient distractors in these studies capture attention rather than being processed without attention. Finally, the fourth argument discusses alternative interpretations to automaticity within the framework of load theory. For example, interference effect under high-load condition may be interpreted in different ways according to load theory. It can be interpreted as a process that does not consume attention at all (i.e., automatic process), or as a process that consumes special attentional resources (i.e., attentional modality).

Although load manipulations appear to offer a convenient tool to manipulate the amount of attention that distractors receive, the arguments discussed in this paper suggest caution when drawing conclusions based on these manipulations and call to manipulate the amount of attention that current stimuli receive in different, direct, ways.

References

Al-Aidroos, N., Guo, R.M., & Pratt, J. (2010). You can't stop new motion: Attentional capture despite a control set for colour. *Visual Cognition*, *18,* 859–880.

Benoni, H. & Tsal, Y. (2010). Where have we gone wrong? Perceptual load does not affect selective attention. *Vision Research, 50,* 1292-1298.

Benoni, H., & Tsal, Y. (2012). Controlling for dilution while manipulating load: Perceptual and sensory limitations are just two aspects of task difficulty. *Psychonomic Bulletin & Review, 19,* 631-638.

Benoni, H. & Tsal, Y. (2013). Conceptual and methodological concerns in the theory of perceptual load. *Frontiers in Psychology, 4* (522)*,* 1-7.

Benoni, H., Zivony, A. & Tsal, Y. (2014). Attentional sets influence perceptual load effects, but not dilution effects. *Quarterly Journal of Experimental Psychology,* 67, 785-792.

Biggs, A. T., & Gibson, B. S. (2010). Competition between color salience and perceptual load during visual selection can be biased by top-down set. *Attention, Perception, & Psychophysics, 72,* 53–64.

Biggs A. T., Kreager R. D., Gibson B. S., Villano M., Crowell C. R. (2012). Semantic and affective salience: The role of meaning and preference in attentional capture and disengagement. *Journal of Experimental Psychology: Human Perception and Performance, 38,* 531–541.

Bishop S. J., Jenkins R., & Lawrence A. D. (2007). Neural processing of fearful faces: Effects of anxiety are gated by perceptual capacity limitations. *Cerebral Cortex*, *17,* 1595–1603.

Bundesen, C. (1990). A theory of visual attention. *Psychological Review*, *97*(4), 523-47.

Bundesen, C., Habekost, T., & Kyllingsbæk, S. (2005). A neural theory of visual attention: Bridging cognition and neurophysiology. *Psychological review*, *112(2*), 291-325.

Bundesen, C., Habekost, T., & Kyllingsbæk, S. (2011). A neural theory of visual attention and short-term memory. *Neuropsychologia*, 49, 1446–1457.

Catmur, C. (2016). Automatic Imitation? Imitative compatibility affects responses at high perceptual load. *Journal of Experimental Psychology: Human Perception and Performance, 42,* 530-539.

Chelazzi L, Miller E.K., Duncan J., & Desimone, R. (1993). A neural basis for visual search in inferior temporal (IT) cortex. *Nature, 363*, 345–347.

Couperus, J.W. (2011). Effects of perceptual load on selective attention across Development. *Developmental Psychology. 47*, 1431-1439.

Cohen, A., Ivry, R., Rafal, R. D., & Kohn, C. (1995). Activating response codes by stimuli in the neglected visual field. *Neuropsychology, 9,* 165–173.

Cosman, J. D., & Vecera, S. P. (2009). Perceptual load modulates attentional capture by abrupt onsets. *Psychonomic Bulletin & Review, 16*(2), 404-410.

Cosman, J. D., & Vecera, S. P. (2010a). Attentional capture by motion onsets is modulated by perceptual load. *Attention, Perception, & Psychophysics*, *72*, 2096-2105.

Cosman, J. D., & Vecera, S. P. (2010b). Attentional capture under high perceptual load. *Psychonomic Bulletin & Review, 17,* 815–820.

Cosman, J. D., Mordkoff, J. T., & Vecera, S. P. (2016). Stimulus recognition occurs under high perceptual load: Evidence from correlated flankers. *Journal of Experimental Psychology: Human Perception and Performance*, *42*, 2077-2083.

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual review of neuroscience, 18(1), 193-222.*

Duncan, J., & Humphreys, G. W. (1989). Visual search and stimulus similarity. *Psychological Review, 96,* 433–458.

Dye, M. W., Green, C. S., & Bavelier, D. (2009). The development of attention skills in action video game players. *Neuropsychologia, 47*(8–9), 1780-1789.

Eltiti, S., Wallace, D., & Fox E. (2005). Selective target processing: Perceptual load or distractor salience? *Perception & psychophysics, 67*, 876-885.

Fitousi, D., and Wenger, M. J. (2011). Processing capacity under perceptual and cognitive load: A closer look at load theory. *Journal of Experimental Psychology: Human Perception and Performance, 37,* 781-798.

Forster S., Lavie N. (2008a). Failures to ignore entirely irrelevant distractors: The role of load. *Journal of Experimental Psychology: Applied, 14,* 73–83.

Forster S., Lavie N. (2008b). Attentional capture by entirely irrelevant distractors. *Visual Cognition, 16,* 200–214.

Fox, E., Yates, A., and Ashwin, C. (2012). Trait anxiety and perceptual load as determinants of emotion processing in a fear conditioning paradigm. *Emotion 12*, 236–249.

Giesbrecht, B., Sy, J., Bundesen, C., & Kyllingsbæk, S. (2014). A new perspective on the perceptual selectivity of attention under load. *Annals of the New York Academy of Sciences*, *1316*(1), 71-86.

Green, C. S., & Bavelier, D. (2003). Action video games modify visual selective attention. *Nature, 423,* 534–537.

Gronau, N., Cohen, A., & Ben-shakhar, G. (2009). Distractor interference in focused attention tasks is not mediated by attention capture. *The Quarterly Journal of Experimental Psychology, 62,* 37–41.

Gronau, N., & Izoutcheev, A. (2017). The necessity of visual attention to scene categorization: Dissociating "task-relevant" and "task-irrelevant" scene distractors. *Journal of Experimental Psychology: Human Perception and Performance*, *43*(5), 954-970.

Hamker, F. H. (2004). A dynamic model of how feature cues guide spatial attention. *Vision research*, *44*(5)*,* 501-521.

Hauthal, N., Neumann, M.F., & Schweinberger, S.R. (2012). Attentional spread in deaf and hearing participants: Face and object distractor processing under perceptual load. *Attention, Perception & Psychophysics, 74(*6), 1312-1320.

Heyes, C. (2001). Causes and consequences of imitation. *Trends in Cognitive Sciences, 5,* 253–261.

Huang-Pollock, C., Carr, T.H. & Nigg J.T. (2002) Development of selective attention: Perceptual load influences early versus late attentional selection in children and adults. *Developmental Psychology, 38*(3), 363-375.

Khetrapal, N. (2010). Load theory of selective attention and the role of perceptual load: Is it time for revision? *European Journal of Cognitive Psychology, 22(1),* 149-156.

Koch, C., & Ullman, S. (1985). Shifts in selective visual attention: Towards the underlying neural circuitry. *Human neurobiology, 4,* 219-227.

Kyllingsbæk, S., Sy, J. L., & Giesbrecht, B. (2011). Understanding the allocation of attention when faced with varying perceptual load in partial report: A computational approach. *Neuropsychologia*, *49*(6), 1487-1497.

Lamy, D., Leber, A. B., and Egeth, H. E. (2013). "Selective attention", in *Handbook of Psychology, Experimental Psychology, 2nd Edn*, Vol. 4 eds R. W. Proctor and I. B. Weiner (Hoboken, NJ: John Wiley and Sons Inc), 267–294.

Lavie, N. (1995). Perceptual load as a necessary condition for selective attention. *Journal of Experimental Psychology: Human Perception and Performance, 21*, 451-468.

Lavie, N., & Cox, S. (1997). On the efficiency of visual selective attention: Efficient visual search leads to inefficient distractor rejection. *Psychological Science, 8,* 395–398.

Lavie, N., & Tsal, Y. (1994). Perceptual load as a major determinant of the locus of selection in visual attention. *Perception & Psychophysics*, *56*, 183-197.

Lavie, N., Ro, T., & Russell, C. (2003). The role of perceptual load in processing distractor faces. *Psychological science*, *14*, 510–515.

Lleras, A., Chu, H., & Buetti, S. (2017). Can we "apply" the findings of Forster and Lavie (2008)? On the generalizability of attentional capture effects under varying levels of perceptual load. *Journal of Experimental Psychology: Applied*, *23*(2), 158-179.

Luria, R., & Vogel, E.K. (2011). Visual Search demands dictate reliance on working memory storage. *The Journal of Neuroscience, 20,* 6199–6207.

Marciano, H. & Yeshurun, Y. (2011). The effects of perceptual load in central and peripheral regions of the visual field. *Visual Cognition, 19*(3), 367–391.

Maylor, E. & Lavie N. (1998). The influence of perceptual load on age differences in selective attention. *Psychology and Aging, 13*, 563-573.

Mevorach, C., Tsal, Y., & Humphreys, G. W. (2014). Low level perceptual, not attentional, processes modulate distractor interference in high perceptual load displays: Evidence from neglect/extinction. *Frontiers in psychology*, *4 966*, 1–8.

Miller, J. (1987). Priming is not necessary for selective-attention failures: Semantic effects of unattended, unprimed letters. *Perception & Psychophysics, 41,* 419–434.

Miller, E.K., Desimone, R. (1993). Scopolamine affects short-term memory but not inferior temporal neurons. *NeuroReport, 4,* 81– 84.

Miller, E.K., Desimone, R. (1994). Parallel neuronal mechanisms for short term memory. *Science, 263*, 520 –522.

Mordkoff, J. T., & Halterman, R. (2008). Feature integration without visual attention: Evidence from the correlated flankers task. *Psychonomic Bulletin & Review, 15,* 385–389.

Müller, H. J., & Rabbitt, P. M. (1989). Reflexive and voluntary orienting of visual attention: Time course of activation and resistance to interruption. *Journal of Experimental psychology: Human perception and performance*, *15*(2), 315.

Murphy, G., Groeger, J. A., & Greene, C. M. (2016). Twenty years of load theory—Where are we now, and where should we go next? *Psychonomic Bulletin & Review,* 1-25.

Neokleous, K., Shimi, A., & Avraamides, M. N., (2016). Modeling the effects of perceptual load: Saliency, competitive interactions, and top-down biases. *Frontiers in Psychology, 7 (1)*, 1-15.

Neumann, M.F., Mohamed, T.N., & Schweinberger, S.R. (2011). Face and object encoding under perceptual load: ERP evidence. *NeuroImage, 54,* 3021-3027.

Neumann, M. F., & Schweinberger, S. R. (2008). N250r and N400 ERP correlates of immediate famous face repetition are independent of perceptual load. *Brain research, 1239,* 181-190.

Norberg, N., Peira, & Wiens, S. (2010). Never mind the spider: Late positive potentials to phobic threat at fixation are unaffected by perceptual load, *Psychophysiology, 47*, 1151–1158.

Okon-Singer, H., Tzelgov, J., & Henik, A. (2007). Distinguishing between automaticity and attention in the processing of emotionally significant stimuli. *Emotion, 7*, 147–157.

Posner, M. I. (1980). Orienting of attention. *Quarterly journal of experimental psychology*, *32*, 3-25.

Rees, G., Frith, C. D., & Lavie, N. (1997). Modulating irrelevant motion perception by varying attentional load in an unrelated task. *Science*, *278*, 1616-1619.

Remington, A.M., Swettenham, J.G., & Lavie, N. (2012). Lightening the load: Perceptual load impairs visual detection in typical adults but not in autism. *Journal of Abnormal Psychology, 121* (2), 544-51.

Ro, T., Friggel, A., & Lavie, N. (2009). Musical expertise modulates the effects of visual perceptual load. *Attention, Perception, & Psychophysics*, *71*(4), 671-674.

Roper, Z. J. J., & Vecera, S. P. (2013). Response terminated displays unload selective attention. *Frontiers in psychology*, *4 967*, 1-10.

Roper, Z. J. J. & Vecera, S. P. (2014). Visual short-term memory load strengthens selective attention. *Psychonomic Bulletin & Review, 21,* 549-556.

Scalf, P. E., Torralbo, A., Tapia, E., & Beck, D. M. (2013). Competition explains limited attention and perceptual resources: Implications for perceptual load and dilution theories. *Frontiers in psychology*, *4 243,* 1-9.

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory. *Psychological Review, 84,* 127–190.

Theeuwes J., Kramer A. F., & Belopolsky A. V. (2004). Attentional set interacts with perceptual load in visual search. *Psychonomic Bulletin & Review, 11*, 697-702.

Thoma, V. & Lavie, N. (2013). Perceptual load effects on processing distractor faces indicate face-specific capacity limits. *Visual Cognition, 21* (8), 1053-1076.

Torralbo, A., & Beck, D. M. (2008).Perceptual-load-induced selection as a result of local competitive interactions in visual cortex. *Psychological Science, 19*, 1045–1050.

Townsend, J. T., & Ashby, F. G. (1978). Methods of modeling capacity in simple processing systems. In J. Castellan & F. Restle (Eds.), Cognitive theory (Vol. 3, pp. 200–239). Hillsdale, NJ: Erlbaum.

Tsal, Y., & Benoni, H (2010a). Diluting the burden of load: Perceptual load effects are simply dilution effects. *Journal of Experimental Psychology: Human Perception and Performance, 36,* 1645-1656.

Tsal, Y., & Benoni, H (2010b). Much dilution little load in Lavie and Torralbo's (2010) response: A reply. *Journal of Experimental Psychology: Human Perception & Performance*, *36*, 1665-1668.

Vogel, E.K., & Machizawa, M.G. (2004). Neural activity predicts individual differences in visual working memory capacity. *Nature, 428*, 748 –751.

Von Mühlenen, A., & Lleras, A. (2007). No-onset looming motion guides spatial attention. *Journal of Experimental Psychology: Human Perception and Performance, 33(6),* 1297-1310.

Walther, D., & Koch, C. (2006). Modelling attention to salient proto-objects. *Neural networks, 19*(9)*,* 1395-1407.

Wenger, M. J., & Gibson, B. S. (2004). Using hazard functions to assess changes in processing capacity in an attentional cuing paradigm. *Journal of Experimental Psychology: Human Perception and Performance, 30*, 708–719.

Wilson, D. E, Muroi, M., & MacLeod, C. M. (2011). Dilution, not load, affects distractor processing. *Journal of Experimental Psychology: Human Perception & Performance, 37*, 319-335.

Yeshurun, Y., & Marciano, H. (2013). Degraded stimulus visibility and the effects of perceptual load on distractor interference. *Frontiers in Psychology*, *4* (289), 1-4.

Zhang, W., & Luck, S. J. (2015). Opposite effects of capacity load and resolution load on distractor processing. *Journal of Experimental Psychology-Human Perception and Performance, 41*, 22–27.