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Perceptual load is not always a crucial determinant of early versus late selection☆

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ABSTRACT

The perceptual load hypothesis posits that early and late selection occurs under conditions of high and low perceptual load, respectively. Recent work, however, suggests that the absence of a congruency effect in high-load trials – the behavioral signature of early selection in studies of perceptual load – may not provide an exhaustive index of failing to identify task-irrelevant distractors. Prior research also suggests that the congruency sequence effect (CSE) – a modulation of the congruency effect after incongruent relative to congruent trials – provides complementary information about whether participants identify distractors. We therefore conducted a novel test of the perceptual load hypothesis that employed both the congruency effect and the CSE as measures of distractor identification. Experiment 1 revealed that distractors were identified not only in low-load trials but also in high-load trials wherein there was no overall congruency effect. Experiment 2 further revealed which task parameters allowed us to observe such "hidden" distractor identification. These findings suggest that perceptual load is not always a crucial determinant of early versus late selection.

The locus of selection remains a controversial topic in the attention literature. In particular, two competing models propose that attention selects relevant stimuli at different stages of processing. The early selection view posits that attention selects such stimuli relatively early in perception (Broadbent, 1958; Treisman & Riley, 1969). Thus, attention filters *irrelevant* stimuli before participants identify them. The late selection view posits that attention selects relevant stimuli after all stimuli have been identified (Deutch & Deutch, 1963; Norman, 1968). While some findings are consistent with early selection (Moray, 1959; Neisser & Becklen, 1975; Treisman & Riley, 1969), others are consistent with late selection (Eriksen & Eriksen, 1974; Logan, 1988; Miller, 1987). Thus, researchers have sought to identify the factors that determine whether selection occurs early or late.

1. A proposed resolution to the early-versus-late selection controversy

Lavie and colleagues (Lavie, 1995; Lavie & Tsal, 1994) have proposed that perceptual load is a crucial determinant of whether selection in the visual modality occurs early or late. Perceptual load refers to the demands that identifying task-relevant visual stimuli impose on perceptual attention. When identifying such stimuli is relatively easy (i.e., when perceptual load is low), the perceptual load hypothesis posits there are sufficient perceptual resources remaining to identify *task-irrelevant* visual stimuli afterward. These resources are then subsequently (and automatically) allocated to irrelevant stimuli, resulting in late selection. When identifying task-relevant stimuli is relatively difficult (i.e., when perceptual load is high), the perceptual load hypothesis posits there are insufficient perceptual resources to identify *task-irrelevant* visual stimuli after identifying task-relevant visual stimuli, resulting in early selection.

Evidence to support the perceptual load hypothesis often comes from studies of flanker tasks showing that irrelevant distractors do not interfere with performance under conditions of high (but not low) perceptual load. For example, in one study, participants searched for a target letter (X or N) within a circular search array of six letters while ignoring an irrelevant flanker letter (X or N) that appeared randomly to the left or right of the array (Lavie & Cox, 1997). In congruent trials (50%), the distractor (e.g., X) was mapped to the same response as the target (e.g., X) while in incongruent trials (50%) the distractor was mapped to the opposite response (e.g., N). The authors manipulated perceptual load by varying whether the non-target letters in the search array were visually dissimilar to the target letters (i.e., all Os; low perceptual load) or visually similar to the target letters (i.e., KMZHW; high perceptual load). Consistent with the perceptual load hypothesis, the authors reported a congruency effect (i.e., longer response times in

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incongruent relative to congruent trials) in low-load trials but not in high-load trials. As noted in a recent review, the finding that increasing perceptual load reduces or eliminates the congruency effect has been replicated numerous times over the past 22 years (Murphy, Groeger, & Greene, 2016). Moreover, although other explanations for the lack of an overall congruency effect in high-load trials have emerged, such as the attentional slippage and dilution hypotheses (Gaspelin, Ruthruff, & Jung, 2014; Tsal & Benoni, 2010), these explanations also assume that the lack of a congruency effect in high-load trials is an exhaustive index of early selection (i.e., of failing to identify distractors).

2. Is the overall congruency effect an exhaustive measure of whether participants identify a distractor?

Contrary to the assumptions of the perceptual load hypothesis, Cosman and colleagues (Cosman, Mordkoff, & Vecera, 2016) recently suggested that the congruency effect is not an exhaustive measure of whether distractors are identified. They suggested that the congruency effect depends not only on identifying the distractor but also on post-identification processes that map the distractor onto an arbitrary response. In this view, a failure of stimulus-response (S-R) translation for the distractor, rather than a failure to identify the distractor, eliminates the congruency effect in high-load trials.

To test their hypothesis, Cosman et al. (2016) investigated whether increasing perceptual load eliminates the congruency effect not only in a standard flanker task but also in a correlated flanker task. As described earlier, in the standard flanker task the congruency effect indexes the influence of applying an instructed stimulus-to-response mapping to a distractor that is a potential target at a task-irrelevant location. In Cosman et al.'s version of the correlated flanker task, however, the congruency effect indexes the influence of repeatedly associating a distractor that is *not* a potential target with a specific target (e.g., associating an “A” target with a “G” flanker 83% of the time and with an “S” flanker 17% of the time, when “G” and “S” are not potential targets). In this way, the distractor becomes associated with a specific response, even though the instructed stimulus-to-response mapping is never directly applied to the distractor (Miller, 1987). After this association is created, the distractor can activate a response in subsequent trials wherein it appears equally often with every possible target. Thus, as long as the distractor is identified, it can engender a correlated congruency (i.e., flanker) effect. In line with the S-R translation hypothesis, Cosman et al. reported that increasing perceptual load eliminates the standard congruency effect but does not influence the correlated congruency (i.e., flanker) effect. They therefore argued that participants identify the distractor in high-load trials of the standard flanker task but fail to translate the distractor into a response.

It is important to mention, however, two limitations of Cosman et al.'s (2016) study that the authors also noted. First, increasing perceptual load may consume attentional resources more in the standard flanker task than in the correlated flanker task. For example, participants may allocate more attention to the search array when they know the distractor can interfere with performance via the instructed S-R mapping in the standard flanker task than when they know the distractor cannot interfere with performance via this mapping in the correlated flanker task. If, for any reason, spare attentional capacity remains to identify the distractor in high-load trials of the correlated flanker task, then the perceptual load hypothesis can explain the presence of a correlated flanker effect in these trials. Second, because each of the flankers in Cosman et al.'s correlated flanker task is associated with a particular target and, hence, a particular response (see Miller, 1987 for different versions of this task), the flankers in this task are not entirely task-irrelevant. The attentional system may therefore prioritize correlated flankers along with targets to facilitate quick, accurate responses. In this view, the correlated congruency effect that Cosman et al. observed under conditions of high perceptual load is consistent with the perceptual load hypothesis, which assumes that participants identify task-relevant stimuli regardless of whether perceptual load is high or low.[1] While arguing against this interpretation of their findings, Cosman et al. presented data indicating that participants who were aware of the target-flanker pairings following the experiment did not exhibit a larger correlated congruency effect than participants who were not aware of such pairings. However, the “unaware” participants could have been aware of these pairings during the experiment and forgotten about them later. They could also have identified the pairings outside of awareness. For these reasons, it is unclear whether Cosman et al.'s findings contradict or support the perceptual load hypothesis.

3. The present study

Given the limitations of Cosman et al.'s (2016) study, we revisited the issue of whether perceptual load influences whether selection occurs early or late in the standard flanker task. Moreover, we employed a complementary measure of distractor processing – the congruency sequence effect (CSE) – to provide a novel test of the perceptual load hypothesis. The CSE is a phenomenon wherein the congruency effect differs after incongruent relative to congruent trials (Gratton, Coles, & Donchin, 1992). A CSE can occur only when participants identify a distractor, because doing so is required to distinguish between incongruent and congruent trials. Prior work further indicates that the overall congruency effect and the CSE provide non-overlapping information about whether participants identify task-irrelevant distractors. For example, while the overall congruency effect and the CSE often co-occur, one can observe both (1) an overall congruency effect without a CSE and (2) a CSE without an overall congruency effect (Weissman, Egner, Hawks, & Link, 2015). We therefore reasoned that assessing both the overall congruency effect and the CSE would provide a more sensitive test of whether early selection occurs in high-load trials than assessing only the overall congruency effect.[2]

The CSE in a standard two-alternative-forced-choice (2-AFC) flanker task indexes cognitive control, feature integration, and priming processes (Hommel, Proctor, & Vu, 2004; Mayr, Awh, & Laurey, 2003; Weissman, Hawks, & Egner, 2016). In much of our prior work, we focused on isolating the influence of cognitive control processes on the CSE from the influences of feature integration and priming processes, which requires the use of 4-AFC tasks to avoid stimulus and response repetitions in consecutive trials (Schmidt & Weissman, 2014; Weissman et al., 2015; Weissman, Jiang, & Egner, 2014). As discussed earlier, however, our present goal was to determine whether participants identify distractors in high-load trials of a standard 2-AFC flanker task that is employed in studies of perceptual load (Cosman et al., 2016; Lavie, 1995). We therefore employed such a task in the present study even though it confounds cognitive control, feature integration, and priming processes. We reasoned that this confound would not be problematic for testing our hypotheses for two reasons. First, both cognitive control and feature integration processes can engender a CSE only when participants identify a distractor. Second, negative priming, which also influences CSE magnitude in 2-AFC flanker tasks (Notebaert, Gevers, Verbruggen, & Liefooghe, 2006), is absent in high-load trials (Lavie & Fox, 2000).[3]

While no prior study of perceptual load has employed the CSE as a probe of distractor identification under conditions of high perceptual

[1] Proponents of the perceptual load hypothesis typically define task-relevant stimuli as targets that are specified by the task instructions. However, distractors often aid performance when they predict the correct response (Logan & Zbrodoff, 1979; Mordkoff, 2012; Schmidt & De Houwer, 2011). Thus, when distractors are informative, they may be processed as task-relevant stimuli.

[2] Some prior work has already investigated whether sequential-trial effects can inform the early versus late selection debate (Driver & Tipper, 1989), but this work did not employ the CSE as a measure of distractor identification.

[3] See the General Discussion for a more detailed explanation of why various types of stimulus and response repetitions – including those that lead to negative priming – are unlikely to explain the present findings.