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Effect of short and long exposure duration and dual-tasking on a global–local task

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Abstract

Past research has demonstrated a global advantage in responses to visually presented hierarchical stimuli such that, on incongruent trials, the global form interferes with responses to the local level [Kimchi, R. (1992). Primacy of wholistic processing and global/local paradigm: A critical review. *Psychological Bulletin, 112*, 24–38]. In Experiment 1, 32 adults performed alternating blocks of global or local identification of hierarchical letter stimuli in which the global and local letters were congruent, incongruent, or neutral, and were presented at either a short (17 ms) or long (100 ms) exposure duration. A global advantage was demonstrated at both durations. In the local-directed task, interference on incongruent, relative to neutral, trials was observed at both exposure durations, but facilitation on congruent trials, relative to neutral trials, was present only when stimuli were presented at the long exposure duration. In Experiment 2, global or local identification was performed by another group of 24 adults at either a long or short exposure duration, and also under conditions of full attention (FA) or dual-task (DT) conditions with a digit-monitoring task. Under FA, we again found significant interference at both exposure durations, but facilitation only at the long exposure duration. Under DT conditions, the pattern of facilitation and interference at the short duration remained unchanged. At the long duration, however, dual-tasking eliminated interference in the RT but not error data, while facilitation was present in both sets of data. Results are in line with a perceptual account of the global advantage, and suggest that facilitation requires consciously-mediated processes, whereas interference does not.

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1. Introduction

Visual perception and identification of objects is an important and intricate process in humans. One aspect of object identification that has received much attention in the literature is whether visual processing proceeds from the global aspects of an object to the local aspects, or from local to global features. That is, is the whole object perceived before its parts, or are the parts perceived first, and then combined to see the whole? One paradigm designed to examine this question is the Global–local paradigm. Introduced by Kinchla (1974, 1977), and used by Navon (1977), this task involves the presentation of a hierarchical compound stimulus, usually a letter, which has a larger (global) form composed of smaller (local) elements. In the traditional design, participants are directed to respond to either the large global letter or to the small local letters in the stimulus, usually by making a key press on a computer keyboard. A congruent trial is one in which the global and local letters match, such as a large H composed of smaller H's. An incongruent trial is one in which the global and local letters do not match, but both have keys assigned to them. For example, participants would be instructed to respond to the global form of an H composed of irrelevant local S's, with H and S as available response keys. Finally, a neutral trial is one in which the irrelevant level of the global–local stimulus has no corresponding response key. For example, participants would be instructed to respond to the local level of a large O composed of small S's, with S and H as response keys.

Under a wide variety of conditions, a global advantage has been demonstrated on this task (see Kimchi, 1992, for a review; Modigliani, Bernstein, & Govorkov, 2001; Navon, 1977). That is, (a) participants tend to be faster and more accurate at identifying the global level of the stimulus, and (b) the decrease in performance from congruent to incongruent trials is greater on the local-directed task than on the global-directed task, indicating that the global level interferes when participants are asked to respond to the local level, whereas the local level interferes very little with global processing. These results have been interpreted as evidence that, if both global and local levels are equally visible, global processing precedes local processing (Kimchi, 1992; Navon, 1977).

While the global advantage has been demonstrated under a wide variety of conditions, the source of this advantage is not fully understood (Navon, 2003). One explanation posits that the global advantage is due to differences in *perceptual* processing of the global and local levels of the global–local stimulus. That is, the global level is perceived more readily than the local level, thus making responses to the global form faster and more accurate than local level responses (Bruyer, Scailquin, & Samson, 2003; Koivisto & Revonsuo, 2004; Paquet & Merikle, 1988). Another account presents the idea that the difference exists at a later, *post-perceptual* level of processing. That is, the global and local elements of the hierarchical stimulus are perceived simultaneously, but processing of the global form proceeds faster than that of the local level at some later stage of visual object identification. For example, the global advantage may exist at the decision making level of processing, such that decisions about the identity of the global form are more quickly made than those about the local elements (see Kimchi, 1992, for a review; Miller, 1981a, 1981b; Paquet & Merikle, 1988).

While it is difficult to directly link levels of consciousness to specific stages in object identification and processing, the classic work by Posner and Boies (1971) suggests that post-perceptual processes, such as decision-making, require longer processing times than does the perceptual encoding of a stimulus. Thus post-perceptual processes can be described as more consciously controlled processes, which require attention when a response to the stimulus is needed (Lamme, 2003). Visual perception, in contrast, can occur at much shorter durations, and is relatively automatic. In the current study, we use this premise to contrast the alternative accounts of the global advantage. We examine performance when global–local stimuli are presented at either a long or short exposure duration. If the global advantage is dependent on post-perceptual processes, such as decision-making, presenting stimuli at a very short duration should diminish the advantage, since more consciously controlled processes, which require longer durations, would not be available. However, if the global advantage arises from perceptual-level differences between global and local stimuli, presenting stimuli at a shorter exposure duration should not alter the global advantage, as more automatic early perceptual processes can still occur.

The experiments presented here manipulate the availability of post-perceptual processes first by limiting the exposure duration of global–local stimuli, and later by manipulating both stimulus exposure duration and availability of attention. In line with Lamme's (2003) recent views, manipulations of exposure duration likely affect whether one is consciously aware that a stimulus has been presented, and therefore whether post-perceptual processes are available. This is distinct from manipulations of attention, whose effects are believed to operate directly on the (post-perceptual) report stage. However, both manipulations affect the availability of post-perceptual processes. We examine the effects of these manipulations on both facilitation and interference. Facilitation in this study refers to improved performance, characterized by fewer errors and faster reaction times, on congruent trials of the global–local task relative to neutral trials. In contrast, interference refers to poorer performance, characterized by more errors and slower reaction times, on incongruent trials relative to neutral trials.

Previous work either fails to discuss (Navon, 1977; Paquet & Merikle, 1984), or fails to include the neutral trial type necessary to separate facilitation from interference (Evert & Kmen, 2003; Filoteo, Friedrich, Rabbel, & Stricker, 2002). However, an understanding of the contributions of facilitation and interference to the global advantage, when the availability of post-perceptual processes is manipulated, may allow us to differentiate between the perceptual and post-perceptual accounts of the global advantage. In addition, our study allows us to describe the global advantage on the local-directed task in terms of either facilitation or interference. It could be that the global advantage occurs due to interference of the global form when responding to the local elements, but it is also possible that facilitation generated by congruency of the global and local letters leads to the differences in performance between congruent and incongruent trials in some situations, accounting for the observed global advantage.

2. Experiment 1

The purpose of Experiment 1 was to examine the effect of exposure duration on the global advantage reported in previous studies that used the global–local paradigm. In this experiment, we presented compound, hierarchical global–local stimuli randomly to participants at either a long (100 ms) or a short (17 ms) exposure duration. A 17 ms exposure duration was selected as the short presentation duration, as several studies suggest that presenting visual information at this duration has a measurable effect on cognition, though participants are unaware of its presentation. For example, Draine and Greenwald (1998) demonstrated reliable semantic priming when the prime was presented for 17 ms. Similarly, Jönsson and Sonnby-Borgström (2003) presented pictures of faces for 17 ms and found a physiological response to the emotion of the face, despite participant reports that they had not seen the face.

Although these studies use paradigms that differ from the one used in the current research, they demonstrate that stimuli perceived without awareness can have a detectable effect on performance. It should also be noted that the stimuli used in these two studies differ greatly from one another, one being words and the other pictures of faces. Despite this difference, participants still demonstrated a lack of conscious awareness for these stimuli at the 17 ms exposure duration. This suggests that a visual stimulus exposure duration of 17 ms often results in an inability to use more consciously controlled processes to guide performance. Also, the exposure duration of 17 ms was selected because it is the shortest reliable presentation duration of visual stimuli possible on a typical computer, given the refresh rate of the computer screen. Future studies could use shorter exposure durations using more sophisticated computer equipment. Nonetheless, this study provides a first step in examining the effect of a very short exposure duration on the performance of a global–local task.

A duration of 100 ms was selected as the long exposure duration. This duration has been used in a variety of studies involving the global–local paradigm, and has been shown to result in a global advantage on the traditional global–local task (Blanca, Zalabardo, García-Criado, & Siles, 1994; Fernandes, Francis, Ryan, & Bialystok, in preparation; Paquet & Merikle, 1984; Roux & Ceccaldi, 2001).

The present study offers a unique extension to previous works using the global–local paradigm. To our knowledge, this is the first study to examine the global advantage at an exposure duration as short as 17 ms. What is more, other studies that have looked at the effect of manipulating exposure duration of global–local stimuli have used different paradigms (Blanca et al., 1994) or lacked an appropriate neutral condition (Evert & Kmen, 2003; Paquet & Merikle, 1984), and so could not differentiate between the effects of facilitation and interference.

We predict that the global advantage will be maintained at both exposure durations. Our prediction is based on prior studies that suggest a preconscious locus of the global advantage (Koivisto & Revonsuo, 2004). In line with this, a neuropsychological study by Filoteo et al. (2002) involving an Alzheimer's patient who had lost the ability to consciously identify the global level of global–local stimuli, found that the global level of the stimulus still interfered with his processing of the local level features, despite his inability to overtly report the global form. This study, however, had no neutral condition and therefore could not examine the relative contributions of facilitation and interference to the global advantage. The present study included a neutral condition, allowing us to examine this issue.

3. Methods

3.1. Participants

Participants consisted of 31 undergraduate students and 1 graduate student at the University of Waterloo (16 female), with ages ranging from 18 to 24 years ($M = 19.41$;

SD = 1.62). All had normal or corrected to normal vision, were right-handed, and were naïve with respect to the hypotheses of the study. Participants were recruited from an introductory psychology course, and received course credit for their participation, or received token remuneration ($5.00) for their participation. The study took approximately 30 min to complete.

Two neuropsychological tests were administered to all participants. The National Adult Reading Test—Revised (NART-R; Blair & Spreen, 1989; Nelson, 1982) was administered to allow an estimate of Full Scale IQ (FSIQ), and was needed to ensure that the sample used in this study had levels of intelligence comparable to the general population. The mean FSIQ for participants in this study was 102.52 (SD = 7.51). The Trails task was also administered (Partington & Leiter, 1949). This is a task requiring attention, sequencing, flexibility in mental processing, motor function and visual search abilities (Spreen & Strauss, 1998), which are also important in the global–local task. This test was administered to ensure that participants in our sample did not differ greatly from the general population in these skills. The mean time taken to complete Trails A was 18.33 s (SD = 6.04 s), and Trails B was 40.52 s (SD = 14.90 s), which is in line with norms for our given age range (Spreen & Strauss, 1998).

3.2. Materials

All stimuli were presented in a fully illuminated room on a 17 in. (43.18 cm) computer screen. The local letters of the global–local stimuli (see Fig. 1 for examples) were presented in a 24-point Times New Roman font, yielding a stimulus 5 mm wide by 7 mm high which subtended a visual angle of approximately .59°. The large global form, composed of these local letters, was approximately 7.11 cm in height and 8.13 cm in width and subtended a visual angle of approximately 5.97°. There were 2 congruent stimuli, and 2 incongruent stimuli used in both the global- and local-directed tasks. We also created a set of 2 neutral stimuli for use during the global task, in which the local level was composed of Os (which was not a response option) and the global level formed either an H or S. A separate set of 2 neutral stimuli were created for use during the local-directed task, in which the global level formed an O (which was not a response option) and the local level was composed of either H's or S's. Note that the number of local elements making up the global H was held constant (19 elements) across the congruent, incongruent or neutral stimulus types, and the number of local elements making up the global S, was also held constant (25 elements) across stimuli. While the total number of elements making up the global forms H and S differed, both contained seven local elements across the horizontal and vertical axes. For both of the local task neutral stimuli, the large O was made up of the same number of local elements (16 Hs or 16 Ss). This allowed the spacing between the local elements in the neutral stimuli to be the same as the spacing between elements in the congruent and incongruent stimuli.

These global–local stimuli were presented in black on a white background, and were presented randomly in one of 4 presentation locations: above (screen coordinates: ($X = 512$, $Y = 192$)), below ($X = 512$, $Y = 576$), to the left ($X = 256$, $Y = 384$) or to the right ($X = 768$, $Y = 384$) of the center of the computer screen. The location of the stimulus was randomized, in order to keep participants from adopting a strategy in which they systematically ignored the global level of the stimulus, during the local task response condition, by focusing on a small portion of the screen.

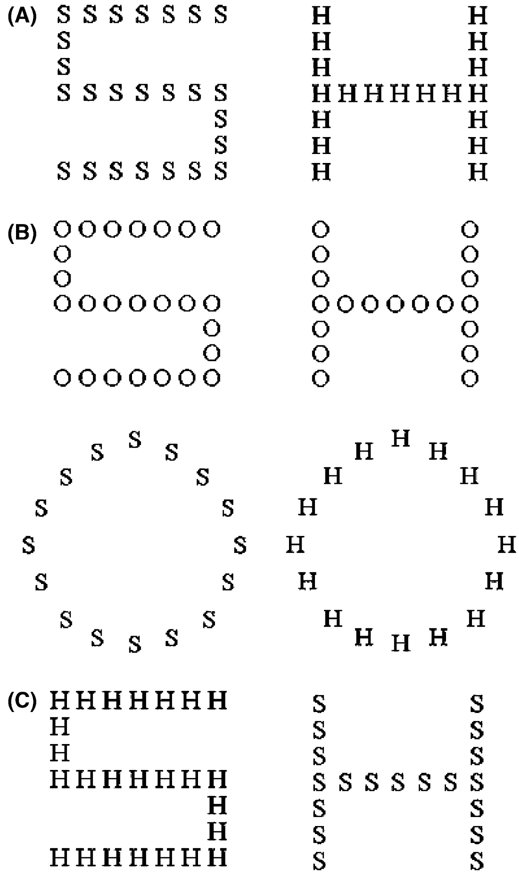

Fig. 1. Examples of (A) congruent, (B) neutral (on global- and local-directed tasks), and (C) incongruent global–local stimuli.

3.3. Procedure

Participants completed a set of practice trials that served as an acuity check to ensure that each participant could identify items presented in the local and global sizes. In 12 trials, participants were presented with local or global-sized letters. Prior to each trial, participants were presented with a fixation cross and instructed to press the space bar when they were ready to begin. On each trial, one of the letters (H or S), at one of the sizes (large or small), was presented for 100 ms in the center of the computer screen followed by a mask for 100 ms and then a blank white screen for 1000 ms. Participants responded by making a key press corresponding to ‘H’ or ‘S’, and were provided with accuracy and reaction time feedback. If participants failed to respond by the end of the 1000 ms white screen, they received feedback indicating that no response had been detected and this was counted as an error. Participants were required to reach an accuracy of 80% before they could move on to the next set of practice trials.

Participants then completed 12 practice trials with the compound global–local stimuli. They were first instructed to respond to the BIG (global) letter. Two congruent, two incongruent, and two neutral global–local stimuli were presented randomly at one of the 4 presentation locations. The stimuli stayed on the screen until participant responded, and participants were then given feedback about their accuracy and reaction times. Following this, participants were instructed to respond to the SMALL (local) letters in the stimulus. Two congruent, two incongruent and two neutral trials were presented randomly at one of the 4 presentation locations. Again, the stimuli stayed on the screen until the participant responded and participants were again given feedback about their accuracy and reaction times. Accuracy of at least 80% overall was required on these 12 global–local practice trials before participants could continue to the next set of trials. This block was completed to familiarize participants with the stimulus types.

Finally, participants were presented with 8 experimental blocks of 24 trials per block. Each block began with the instruction to respond to either the large global letter, or to the small local letters of the global–local stimulus, in alternating fashion, beginning with global task instructions. Participants were reminded at the beginning of each block to identify the target letter by making a key press corresponding to 'H' or 'S'. Participants pressed the space bar to begin the trial, which consisted of a white screen presented for 2000 ms, followed by a fixation cross for 200 ms, followed by a randomly presented congruent, incongruent or neutral global–local stimulus trial type, at one of the two exposure durations (17 ms or 100 ms). Following this, a full screen mask of random lines was presented, and it remained on the screen until the participant responded, up to a maximum duration of 5000 ms. If participants failed to respond while the mask was on the screen, their performance on that trial was coded as an error with no reaction time recorded. Each trial type was presented twice at each of the four presentation locations, once at each of the two exposure durations (17 or 100 ms). Thus, in each block, participants performed 12 trials at the 17 ms exposure duration and 12 at the 100 ms duration, with 4 congruent, 4 incongruent, and 4 neutral trials at each exposure duration. Exposure duration was pseudorandomized within the blocks of trials. In between trials, a white screen was presented for 500 ms before the onset of the next fixation cross, and trial.

The keys participants used to respond were counterbalanced across participants so that half of the participants responded 'H' by pressing the 'v' key on the computer keyboard (labelled H) and responded 'S' by pressing the 'n' key on the keyboard (labelled S), while this mapping was reversed for the other half. For each key order, half of the correct responses were allocated to each key.

4. Results and discussion

We conducted a 2 (Exposure Duration: 17 ms or 100 ms) $\times$ 2 (Task: global- or local-directed) $\times$ 3 (Trial Type: congruent, neutral or incongruent) repeated-measures ANOVA. In the first analysis we used error data, and in the second median RT data, as the dependent variable. Here, as well as in the second experiment, Greenhouse-Geisser corrections were applied, which alters the degrees of freedom, and provides a more conservative estimate of p values.

4.1. Error data

Table 1 shows the mean error data. We found a significant main effect of Trial Type, $F(2,62) = 43.19$, $p < .001$, and a significant main effect of Exposure Duration, $F(1,31) = 6.31$, $p < .05$.

Table 1
Mean number of errors on the global- and local-directed tasks for each trial type at each exposure duration, in Experiment 1

Trial type	Global				Local			
	17 ms		100 ms		17 ms		100 ms	
	M	SD	*M*	SD	*M*	SD	*M*	SD
Congruent	1.38	1.39	1.13	1.24	1.00	1.11	.38	.75
Neutral	2.13	1.86	.94	1.19	1.31	1.26	1.13	1.10
Incongruent	1.94	1.72	1.50	1.30	2.75	2.11	3.25	2.55

This analysis also yielded a significant Task × Trial Type interaction, $F(2,62) = 14.16$, $p < .001$, an Exposure Duration × Task interaction, $F(1,31) = 5.05$, $p < .05$, an Exposure Duration × Trial Type interaction, $F(2,62) = 4.07$, $p < .05$, and a significant three-way (Exposure Duration × Task × Trial Type) interaction, $F(2,62) = 3.75$, $p < .05$.

This interaction was characterized by a higher number of errors at the 17 ms duration than at the 100 ms duration, particularly on the global task. Furthermore, the number of errors varied across trial types. On the global task at the 100 ms exposure duration, errors were highest on incongruent trials, and lowest on neutral trials. At the 17 ms duration, errors were lowest on congruent trials, while the other two trial types showed similar mean errors.

To better understand the global advantage, we conducted post-hoc tests on the difference in errors between congruent and neutral trial types as a measure of facilitation, and on the difference in errors between neutral and incongruent trials as a measure of interference, *on the local-directed task* only.

At the *100 ms exposure duration*, there were significantly more errors on neutral trials than on congruent trials, $t(31) = 3.74$, $p < .001$, indicating significant facilitation effects. There were also significantly more errors on incongruent trials than on neutral trials, $t(31) = 5.71$, $p < .001$, indicating significant interference effects.

At the *17 ms exposure duration*, there was no difference in the number of errors between congruent and neutral trial types, $t(31) = 1.31$, $p > .05$, indicating a lack of facilitation. Similar to the 100 ms duration, however, there were more errors on incongruent trials than on neutral trials, $t(31) = 4.62$, $p < .001$, indicating significant interference effects (see Table 1 for means).

Thus we see that there was a large amount of interference at both exposure durations. Facilitation, however, was present only at the longer exposure duration. These findings are in line with an early perceptual account of the global advantage, given that the advantage was maintained at the short 17 ms exposure duration, in which only more automatic early perceptual processes can occur. The contribution of facilitation and interference to the advantage, however, differed depending on exposure duration. That is, the contributions of facilitation and interference to the global advantage were not uniform across exposure durations, with a combination of facilitation and interference accounting for the increase in errors from congruent to incongruent trials on the local task at the long exposure duration, while interference accounted fully for this increase at the short exposure duration. This suggests that facilitation on the local task cannot operate at very short durations, and may therefore be an effect that requires consciously controlled post-perceptual processing.

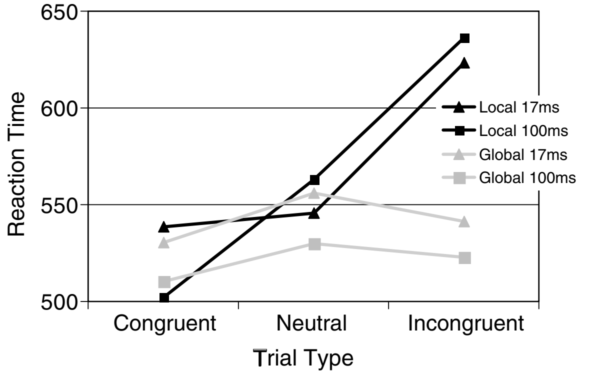

Fig. 2. Median RT data on the global- and local-directed tasks for each trial type at each exposure duration, in Experiment 1.

4.2. Reaction time data

Fig. 2 shows the mean RT data. We found a significant main effect of Task $F(1,31) = 14.13$, $p < .01$, a main effect of Trial Type, $F\ (2,62) = 83.92$, $p < .001$, a significant Task × Trial Type interaction, $F(2,62) = 61.94$, $p < .001$, and a significant two-way Exposure Duration × Trial Type interaction, $F(2,62) = 4.12$, $p < .05$. A significant three-way Exposure Duration × Task × Trial Type interaction, $F(2,62) = 4.18$, $p < .05$ was also observed.

This interaction was characterized by slightly slower RTs on the global task across all trial types at the 17 ms exposure duration, as compared to the 100 ms duration. To better understand the global advantage, we conducted post-hoc tests on the difference in RTs on congruent and neutral trial types as a measure of facilitation, and on the difference in RTs on neutral and incongruent trials as a measure of interference, *on the local-directed task* only.

At the *100 ms exposure duration*, there were significantly faster RTs on congruent trials than on neutral trials, $t(31) = -6.26$, $p < .001$, indicating facilitation, and faster RTs on neutral trials than on incongruent trials, $t(31) = 6.52$, $p < .001$, indicating interference. At the *17 ms exposure duration,* however, there was no difference in RTs between congruent and neutral trials, $t(31) = -.66$, $p = .52$, indicating a lack of facilitation, while there was a slowing in RTs from neutral to incongruent trials, $t(31) = 6.42$, $p < .001$, indicating interference.

These results in the local-directed task are similar to the error data, with a large amount of interference at both exposure durations, but with facilitation being present only when stimuli are presented at the longer exposure duration. The presence of interference on incongruent trials of the local task, but not on the global task, demonstrates a global advantage at both exposure durations, which supports the early perceptual account of the global advantage. In addition, the lack of facilitation at the 17 ms exposure duration again suggests that facilitation requires more consciously controlled processing, which is not available at shorter durations. The presence of interference at both durations, however, suggests that for interference to be observed, only more automatic processing of perceptual stimuli is necessary (see Fig. 2).

4.3. Correlational analysis

In addition to the ANOVA statistics, a correlational analysis of number of errors and median RT was conducted to see if there were any significant speed–accuracy tradeoffs in the data. None of these correlations were significant except that between number of errors and reaction time on the local task on incongruent trials at the 100 ms duration ($r = -.37$, $p < .05$).

5. Experiment 2

Experiment 1 suggested that the global advantage is maintained when stimuli are presented at both long and short exposure durations, but that facilitation contributes to this advantage only at the long duration, while interference contributes at both durations. In Experiment 2, we examined the effects of another manipulation of the availability of post-perceptual processes. As in Experiment 1, we presented global–local stimuli at either long or short exposure durations, but in addition to this, identification of the global or local letter was done under either full attention, or concurrently with another task (a dual-task condition). By dividing a person's attention across two different tasks, it was expected that fewer attentional resources could be devoted to the primary, global- or local-directed task. If reducing available processing time (as in Experiment 1) and reducing availability of attentional resources (in Experiment 2) similarly affect consciously controlled processes (such as post-perceptual ones), then we should observe a similar pattern of results during long exposure durations, under dual-task conditions, as those found when stimuli were presented at a short exposure duration under full attention. That is, dual-tasking during the long exposure duration should decrease the availability of post-perceptual processes and result in the elimination of facilitation and preservation of interference.

Previous work has used divided attention (dual-task) as a manipulation of conscious processing. For example, a study by Debner and Jacoby (1994) found similar levels of performance on a task involving the completion of word stems (e.g. ela____) when words were presented at either a short exposure duration or presented at a longer exposure duration under conditions of divided attention (dual-tasking). Similarly, we expected that performance levels under dual-task conditions at the 100 ms exposure duration of global–local stimuli would be similar to those found under full attention conditions at the 17 ms exposure duration, since the short exposure duration and the division of attention during dual-tasking would both reduce the availability of consciously controlled post-perceptual processes. Also, we expected no change in the pattern of results demonstrated at the 17 ms duration under dual-task (DT) conditions since this duration was assumed to be preconscious, and therefore less reliant on the availability of attention. Such results would lend support to our claim that the 17 ms exposure duration used in Experiment 1 allowed only early perceptual, pre-attentive processing to occur.

The second goal of Experiment 2 was to determine if the global advantage found under conditions of full attention in Experiment 1 would be maintained under DT conditions, in which available attention is reduced. This study differs, in several ways, from previous studies that describe a 'divided attention' condition using the global–local paradigm (see Kimchi, 1992, for review; Koivisto & Revonsuo, 2004; Roux & Ceccaldi, 2001). First, it examines the effects of reduction of attention when stimuli are presented at both long and short exposure durations. Second, it considers the relative contributions of facilitation and interference to the global advantage under DT conditions at both of these exposure durations. Finally, this study differs from others in that it uses a distracting task (hence the term dual-task) manipulation to reduce attention. Much research with the global–local paradigm has divided attention by asking participants to identify whether a given target letter is at the global or the local level of the stimulus, rather than directing their attention to a given level and asking them to identify the letter. The rational in these studies is that attention must be divided across the two levels (global and local) of the stimulus in order to respond. Such studies have found that the global advantage is eliminated under these divided attention conditions (see Kimchi, 1992, for review; Koivisto & Revonsuo, 2004). However, this method of dividing attentions requires the instructions of the global–local task to be changed. Participants are asked to identify the level of the global–local stimulus composed of a given letter, rather than identifying the letter(s) that makes up a level.

In the current study we did not change the instructions in the global–local task when manipulating available attention, but rather added an auditorily presented digit-monitoring task for participants to complete in combination with the global–local task. This type of task has been used to divide attention in many other studies (e.g. Mangels, Craik, Levine, Schwartz, & Stuss, 2002; Troyer & Craik, 2000), in the memory domain. Such a manipulation of attention allowed the response demands of the global–local task to be identical under full and dual-task conditions, with participants attempting to direct their attention to a given level of the stimulus and respond to the letter at that level.

6. Methods

6.1. Participants

The participants in this study consisted of a new group of 23 undergraduate and 1 graduate student at the University of Waterloo (12 female), ages 18–24 years ($M = 20.67$; SD = 1.61). All reported being right-handed, having normal or corrected to normal vision, no hearing difficulties, and were naïve with respect to the hypotheses of the study. Participants were recruited from various university courses, and received either course credit or token remuneration ($8.00) for their participation. The study took approximately 45 min to complete.

The NART-R and Trail-making tasks were administered to all participants. The mean FSIQ for participants was 107.39 (SD = 6.48). On the Trails task, the mean time taken to complete Trails A was 15.91 s (SD = 3.73), and the mean time for Trails B was 32.74 s (SD = 14.22). We note some appreciable differences between this sample and that from Experiment 1. The mean FSIQ was significantly lower in the first Experiment (102.5; $F(1, 54) = 6.46$ $p < .05$), and performance on Trails B somewhat slower (40.5 s). Nevertheless, both estimates of FSIQ and Trails B fall within 1.25 standard deviation units from the mean of their normative age group (Graf & Uttl, 1995; Spreen & Strauss, 1998). Thus we do not believe that these differences contribute meaningfully to our pattern of results, or conclusions.

6.2. Materials

For the global–local task, the materials were identical to those used in Experiment 1. The distracting task used in this experiment involved digit-monitoring of auditorily presented digits. For this task, an audiotape with numbers spoken in a female voice at a rate of approximately one number every two seconds was played. Participants were asked to say "yes" as soon as they heard three odd digits in a row. Before the experimental trials, a set of 20 practice numbers was played, with three 3 odd digit series contained within those 20 numbers. In the full attention digit-monitoring task, there were 240 numbers spoken, for a total of 8 min, with 43 occurrences of the 3 odd digit series. On the divided attention task, digits were played until the participant finished the global–local task, and the maximum total of correct identifications in the digit-monitoring task was noted for each individual, and was used in the calculation of accuracy rate.

6.3. Procedure

As in Experiment 1, participants began by completing the NART-R and Trails neuropsychological tests. They then completed the practice trials for the global–local task, described in the Methods section of Experiment 1. Participants then listened to the set of practice digits and were asked to say "yes" when they heard three odd digits in a row. Finally, each participant completed three conditions: (1) the global–local task as outlined in Experiment 1 (full attention condition), (2) the global–local task in combination with the distracting digit monitoring task (dual-task condition), and (3) the digit monitoring task alone. The order of these three conditions was counterbalanced across participants.

7. Results and discussion

We conducted a 2 (Exposure Duration: 17 ms or 100 ms) $\times$ 2 (Task: global- or local-directed) $\times$ 2 (Attention: full or dual-task) $\times$ 3 (Trial Type: congruent, neutral or incongruent) repeated-measures ANOVA. In the first analysis we used error data, and in the second median RT data, as the dependent variable.

7.1. Error data

Table 2 shows the mean error data.

We found a significant main effect of Attention, $F(1,23) = 52.16$, $p < .001$, a main effect of Task, $F(1,23) = 4.48$, $p < .05$, a main effect of Trial type, $F(2,46) = 84.69$, $p < .001$, and a

Table 2
Mean number of errors on global- and local-directed tasks under full attention and dual-task conditions for each trial type, at each exposure duration, in Experiment 2

	Trial type	Global				Local			
		17 ms		100 ms		17 ms		100 ms	
		M	SD	*M*	SD	*M*	SD	*M*	SD
Full attention	Congruent	.96	1.27	.79	.83	.50	.88	.17	.48
	Neutral	1.29	1.12	.46	.59	.58	.77	.58	.58
	Incongruent	1.00	.83	1.08	1.14	2.17	2.10	2.04	1.99
Dual task	Congruent	2.25	1.62	1.29	1.40	2.29	1.88	.71	.62
	Neutral	2.33	1.81	1.08	1.06	1.96	1.78	1.25	.90
	Incongruent	2.33	1.55	2.25	1.42	5.04	2.26	3.92	2.32

main effect of Exposure Duration, $F(1,23) = 18.42$, $p < .001$. There was also a two-way Attention × Exposure Duration interaction, $F(1,23) = 10.44$, $p < .01$. This interaction was characterized by more errors in the dual-task condition than under full attention, but with the difference in errors being greater at the 17 ms exposure duration than at the 100 ms duration. Under full attention, errors were approximately the same at both durations. There was a two-way Attention × Task interaction, $F(1,23) = 8.46$, $p < .01$, such that errors increased from full attention to dual-task conditions on both global and local-directed tasks, but the increase was greater on the local-directed task. A significant two-way Attention × Trial Type interaction, $F(2,46) = 10.02$, $p < .001$, was also observed, such that errors were similar on congruent and neutral trials but higher on incongruent trials in both the full attention and dual-task conditions. The difference in errors between the neutral and incongruent trials was greater in the dual-task condition than the full attention condition. The Task × Trial Type interaction was also significant, $F(2,46) = 20.38$, $p < .001$, as was the three-way Exposure Duration × Task × Trial Type interaction, $F(2,46) = 5.53$, $p < .01$.

To better understand the global advantage, we conducted post-hoc tests on the difference in errors between congruent and neutral trial types as a measure of facilitation, and on the difference in errors between neutral and incongruent trials as a measure of interference, *on the local-directed task* only.

In the *full attention condition* at the 100 ms exposure duration, there were significantly more errors on neutral trials than on congruent trials, $t(23) = 2.85$, $p < .01$, indicating significant facilitation. As well, there were significantly more errors on incongruent trials than on neutral trials, $t(23) = 3.88$, $p < .001$, indicating significant interference. At the 17 ms exposure duration, however, there was no difference in errors between congruent and neutral trials, $t(23) = .70$, $p = .49$, indicating a lack of facilitation. There was, nonetheless, significantly more errors on incongruent trials than on neutral trials, $t(23) = 4.52$, $p < .00$, indicating significant interference (see Table 2 for means). These results, under full attention, thus replicate the pattern of facilitation and interference found in Experiment 1, with interference being present at both exposure durations, but with facilitation being observed only at the long exposure duration. These findings again suggest that facilitation cannot operate when stimuli are presented at short durations, and may therefore be an effect that requires more consciously controlled processing of the stimuli.

In the *dual-task condition* at the 100 ms exposure duration, significant facilitation was still observed: there were significantly more errors on neutral trials than on congruent trials, $t(23) = 2.41$, $p < .03$. There were also more errors on incongruent trials than on neutral trials, $t(23) = 5.35$, $p < .001$, indicating significant interference. At the 17 ms exposure duration, there was no difference in number of errors between congruent and neutral trials, $t(23) = .78$, $p = .45$, indicating a lack of facilitation, though there was an increase in errors in the incongruent compared to neutral trials, $t(23) = 7.40$, $p = .00$, indicating significant interference (see Table 2).

These results demonstrate that the same pattern of errors was observed in both the full attention and dual-task conditions. This is contrary to our prediction that the pattern of results would differ across attention conditions, such that facilitation would be observed at the long duration under full attention, but not under dual-task conditions. Instead, facilitation was observed in both attention conditions at the 100 ms exposure duration. This unexpected result suggests that the DT manipulation affects post-perceptual processes differently than does reductions in available processing time. Explanations for this difference are considered in the general discussion.

At the 17 ms exposure duration, both attention conditions (full and dual-task) led to significant interference effects coupled with a lack of facilitation. The fact that the pattern of results in the full attention condition was maintained under dual-task at this duration, lends support to the claim that the type of processing underlying performance at the 17 ms exposure duration is not attentionaly mediated.

7.2. Reaction time data

Fig. 3 shows the mean RT data. We found a significant main effect of Attention, $F(1,23) = 23.27$, $p < .001$, a main effect of Task, $F(1,23) = 49.09$, $p < .001$, a main effect of Trial Type, $F(2,46) = 38.55$, $p < .001$, and a main effect of Exposure Duration, $F(1,23) = 8.74$, $p < .01$. There was also a significant two-way Attention × Trial Type interaction, $F(2,46) = 5.45$, $p < .01$, and a significant Attention × Exposure Duration interaction, $F(1,23) = 5.86$, $p < .05$. A significant two-way Task × Trial Type interaction, $F(2,46) = 39.46$, $p < .001$, a two-way Exposure Duration × Trial Type, $F(2,46) = 5.38$, $p < .01$, and a three-way Exposure Duration × Task × Trial Type interaction, $F(2, 46) = 7.38$, $p < .001$, were also observed. The four-way Attention × Task × Trial Type × Exposure Duration interaction was nearly significant, $F(2,46) = 2.85$, $p = .07$.

On the global-directed task under full attention, RTs were fairly similar across trial types at both exposure durations, though RTs were slightly slower at the 17 ms than 100 ms exposure duration on congruent and neutral trials. Under dual-task conditions, responses on the global task were slower than under full attention, with more variability across trial type (see Fig. 3).

On the *local-directed task,* post-hoc *t*-tests were conducted on the difference in RTs between congruent and neutral trial types as a measure of facilitation, and on the difference in RTs between neutral and incongruent trials as a measure of interference, in order to examine the global advantage. In the *full attention condition* at the 100 ms exposure duration, RTs were significantly faster on congruent trials than on neutral trials, $t(23) = -6.47$, $p < .001$, indicating facilitation; RTs were also slower on incongruent trials than on neutral trials, $t(23) = 7.60$, $p < .00$, indicating significant interference. At the 17 ms exposure duration, however, there was no difference in RTs between congruent and neutral trials, $t(23) = -1.43$, $p = .17$, indicating a lack of facilitation, though there was a slowing of RTs in the incongruent compared to neutral trials, $t(23) = 7.43$, $p < .001$, indicating significant interference (see Fig. 3).

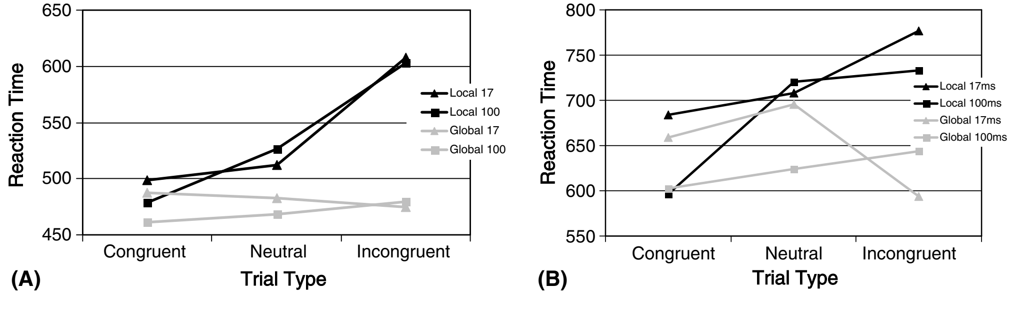

Fig. 3. Median RT data under conditions of (A) full attention and (B) dual-task on the global- and local-directed tasks for each trial type, at each exposure duration, in Experiment 2.

These results again replicate the global advantage at both durations under full attention, and they replicate the pattern of facilitation and interference on the local task observed in Experiment 1. Facilitation was present when stimuli were presented at the long exposure duration, but not at the short duration, while interference was found at both durations. These results lend further support to the claim that facilitation requires more consciously controlled processing, which is not available at shorter durations, whereas interference does not.

Under *dual-task conditions* at the 100 ms exposure duration, RTs were significantly faster on congruent trials than on neutral trials, $t(23) = -5.57$, $p < .001$, indicating significant facilitation. Surprisingly, we found no difference in RTs between neutral and incongruent trials, $t(23) = .50$, $p = .63$, indicating a lack of interference. At the 17 ms exposure duration, facilitation was not observed; there was no significant difference in RTs between congruent and neutral trials, $t(23) = -.95$, $p = .35$. There was, nonetheless, an increase in RTs in the incongruent compared to neutral trials, $t(23) = 3.58$, $p < .01$, indicating significant interference.

In summary, at the 100 ms exposure duration we found significant facilitation and interference under full attention; dual-tasking served to eliminate interference, but not facilitation. At the shorter exposure duration of 17 ms under full attention, we observed a lack of facilitation, together with an interference effect; here dual-tasking did not alter the pattern of results.

7.3. Digit monitoring task data

Performance of each participant on the digit monitoring task under both full and dual-task conditions was recorded. Percent accuracy on the task was obtained for each participant by calculating hit rate minus false alarm rate. Specifically, for hit rate, the number of 3 odd digits series correctly identified was divided by the total number of 3 odd digit series present in the list of numbers. For the false alarm rate, the number of times a set of 3 numbers was falsely reported was divided by the total number of false identifications possible in the list of numbers. The result of this calculation was then multiplied by 100, to obtain a percent accuracy.

In the dual-task condition, the number of 3 odd digit series and the number of possible false identifications differed for each participant, depending on how long they took to complete the global–local task. All but one participant completed the global–local task in less than 8 min. For the participant who exceeded 8 min, the audiotape with the practice digits was replayed to continue the division of attention until the global–local task was completed.

The mean percent digit monitoring accuracy for participants in the full attention condition was 98.54% (SD = 1.54, range = 94.16–100), while the mean accuracy in the dual-task condition was 70.70% (SD = 15.09, range = 41.94–95.65).

7.4. Correlational analysis

A correlational analysis of number of errors and median RT was conducted to see if there were any significant speed–accuracy tradeoffs in the data. There were no significant negative correlations between error rate and reaction time in the data. However, there was a significant positive correlation between error rate and RT on the local task at the 17 ms exposure duration on congruent trials ($r = .57$, $p < .01$) and on incongruent trials ($r = .65$, $p < .01$) under full attention.

8. General discussion

The primary purpose of this research was to examine whether the global advantage demonstrated in past research (see Kimchi, 1992, for review) is maintained regardless of the availability of post-perceptual processes, and to measure the relative contributions of facilitation and interference to the global advantage. We manipulated the availability of post-perceptual processing in Experiment 1 by limiting the exposure duration of global–local stimuli. In Experiment 2 we examined how manipulations of both stimulus exposure duration and level of attention affected facilitation and interference.

In the first experiment, both error and RT data for the local-directed task showed a large amount of interference on incongruent trials, relative to neutral, at both exposure durations. In contrast, facilitation on congruent trials, relative to neutral trials, was present only when stimuli were presented at the long exposure duration. In Experiment 2, global or local identification was again performed with either a long or short exposure duration of stimuli, but also under full attention (FA) and DT conditions, using a digit-monitoring task. On the local task under FA, we again found significant interference at both exposure durations, with facilitation present only at the long exposure duration. Under DT conditions, the pattern of facilitation and interference at the short duration remained unchanged. At the long duration, however, dual-tasking eliminated interference in the RT data, but not in the error data, while there was no effect of DT on facilitation.

8.1. Effects of exposure duration

Our results have implications for the debate in the global–local literature regarding the source of the global advantage (Bruyer et al., 2003; Koivisto & Revonsuo, 2004; Kimchi, 1992; Paquet & Merikle, 1988). We observed a global advantage, regardless of exposure duration, on incongruent trials, in the local-, but not global-directed, tasks. As such, our results support the hypothesis that the global advantage does not require post-perceptual processes, such as decision-making, which require longer processing times than perceptual encoding of a stimulus (Posner & Boies, 1971), and that the advantage exists at an early perceptual stage of processing. This conclusion is in line with a perceptual account of the global advantage.

While the global advantage was maintained at both exposure durations, the contribution of facilitation and interference to this effect differed across durations. At the longer 100 ms exposure duration, the difference in performance between congruent and incongruent trials on the local-directed task was accounted for by both facilitation and interference. At the shorter 17 ms duration, however, interference accounted fully for the difference, as there was a lack of facilitation (see Fig. 2). This pattern of results was also found in the error and RT data of Experiment 2, under FA conditions (see Fig. 3). This demonstrates that facilitation and interference are dissociable on the local-directed task. Facilitation requires a longer processing time of the visual stimulus to operate, as it was observed only in the longer, 100 ms exposure duration condition. Very short presentation durations, such as 17 ms in our experiment, are unlikely to be long enough to allow conscious awareness of the stimuli (Lamme, 2003); thus, facilitation likely requires more consciously controlled processes. Interference, in contrast, likely operates at an earlier stage of processing, as its effect was maintained even when stimuli were presented at the shorter, 17 ms exposure duration.

8.2. Effects of divided attention

In Experiment 2, we manipulated the availability of post-perceptual processes in another way, by introducing a DT manipulation. If reducing available processing time (as in Experiment 1) and reducing availability of attentional resources (as in Experiment 2) similarly affect post-perceptual processes, then we should have observed a similar pattern of results during long exposure durations under dual-task conditions, as those found when stimuli were presented at a short exposure duration under full attention. That is, dual-tasking during the long exposure duration was expected to eliminate facilitation but not interference. Our results did not support this prediction, however, as facilitation was maintained under DT conditions. Also, the interference observed under FA, at both exposure durations, was diminished in the RT data under DT conditions at the 100 ms exposure duration.

It was also hypothesized that the DT manipulation would have no effect on the pattern of results at the 17 ms exposure duration, since performance in this condition was thought to involve only perceptual processes, and not attentionaly mediated post-perceptual processes. This hypothesis was supported, and strengthens our claim that the global advantage, observed at the 17 ms duration, arises from early perceptual or preconscious processes.

8.3. Implications and future directions

Our results suggest that manipulations of attention and exposure duration do not lead to similar patterns of performance in a visual perception task such as a global–local paradigm. It may be that manipulations of exposure duration affect only whether one is *consciously aware* that a stimulus has been presented. This is distinct from manipulations of attention, which affect one's ability to report on consciously perceived stimuli (Lamme, 2003).

It has been suggested that the global advantage arises from a purely sensory mechanism, whereby low spatial frequencies are processed faster than high spatial frequencies, which favours global processing of Navon-type figures such as the ones used in the current study (Badcock, Whitworth, Badcock, & Lovegrove, 1990; Hughes, Fendrich, & Reuter-Lorenz, 1990). Other work, however, suggests that spatial frequency plays a more minor role in determining the presence and magnitude of a global advantage (Lamb & Yund, 1996a, 1996b; Lamb, Yund, & Pond, 1999), and as Navon (2003) suggests, it is doubtful that sensory factors can account for all of the variance in a global–local paradigm. In our study, one might suggest that the short exposure duration disrupted the processing of high spatial frequencies, thus favouring the processing of low spatial frequencies; this would increase the global advantage at the short exposure duration. What we see, however, is a diminution in the global advantage at the 17 ms compared to 100 ms exposure duration. What is more, we can account for this diminution in the global advantage: the contribution of facilitation to the global advantage is eliminated at short durations, though the size of the interference effect is unaffected.

This series of studies provides an important first step in examining the effects of exposure duration and availability of attention using a distracting task on the contributions of facilitation and interference in a global–local paradigm. Overall, our results show a global advantage at both long and short exposure durations, and under both FA and DT conditions. However, the contributions of facilitation and interference to this advantage differed across the manipulations.

First, facilitation was found only at the longer 100 ms exposure duration, while interference was observed at both durations. These results indicate that facilitation is a process that requires longer stimulus processing time, and more consciously controlled processing, while interference can operate even at much shorter, preconscious, durations. While the specific mental processes used on congruent and incongruent trials, relative to neutral trials, could not be addressed in this research, one possibility is that facilitation results from congruency in the *meaning* of the letters in congruent stimuli, while interference results from incongruence in the *physical form* of the two letters in incongruent stimuli. This suggestion is based on the finding that facilitation was present only at the longer exposure duration in which deeper processing, such as accessing meaning, would have time to occur. Interference, in contrast, was found even at the shorter exposure duration, in which only superficial perceptual processing of physical form would be available.

If facilitation cannot operate without processing the meaning of the letters, it would be considered a learning-based process, since it requires knowledge of the identity of the letter. Interference, however, would be an innate perceptual process, requiring only perception of a physical form. To test this suggestion, the current studies could be repeated using generated symbols, which have no inherent meaning, as the elements of the global–local stimulus, rather than using letters. If facilitation was eliminated at both exposure durations, it would suggest that processing of the meaning of the stimulus is the source of facilitation, since the stimuli that lacked meaning eliminated facilitation. Alternately, one could use the stimuli from the present experiments in populations that were unfamiliar with the Latin alphabet, since, for these populations, the letters in the global–local stimuli would be without meaning.

Future research would also be helpful to determine the range of exposure durations under which facilitation is, and is not, observable. A lack of facilitation was observed in Navon's original 1977 study at a 40 ms exposure duration of global–local stimuli, though he did not discuss this finding. It is thus possible that a 40 ms exposure duration still allows only early perceptual processing. This is in line with research by Merikle, Joordens, and Stolz (1995), which found that conscious influences on performance were largely reduced in a stem completion task when words were presented for durations ranging from 29 ms to 71 ms, depending on the participant.

Finally, the results under DT conditions were unexpected. It is possible that the pattern of effects occurred due to the fact that the division of attention was incomplete, allowing some post-perceptual processing, available only at the 100 ms long exposure duration, to guide performance in the DT condition. Alternatively, these findings may be explained by the suggestion of Bruyer et al. (2003) that exposure duration affects perceptual properties of the global–local stimulus, while attention manipulations affect post-perceptual processes. This hypothesis is in line with Lamme's (2003) distinction between (conscious) awareness and attention, described earlier. Thus in our study, the exposure duration manipulation affected perception, or an associated early process in object identification, whereas reductions in attention, resulting from the DT manipulation, affected post-perceptual processes, but only if these processes were available to guide performance. Specifically, in Experiment 2, the DT manipulation had no effect at the 17 ms exposure duration because there was no access to post-perceptual processes. The results at the 17 ms duration were essentially the same as those under full attention. At the 100 ms duration, however, post-perceptual processes were available, and the DT manipulation may have affected these later processes to obtain the results found in Experiment 2. It is not clear, however, why dual-tasking affected post-perceptual processing in such a way that facilitation was unaffected while interference was reduced in the RT data.

Also, it must be noted that, although the pattern of results was the same at the 17 ms exposure duration under both full and dual-task conditions, RTs were slower under DT conditions. As such, DT did affect some process at the shorter exposure duration, leading to a general slowing across all trials. However, this process is independent of the processes mediating facilitation and interference.

Overall, this research is the first to look at the effects of long and short exposure durations, and dual-tasking using a distracting task, on facilitation and interference in a global–local paradigm. The maintenance of the global advantage across all manipulations argues for an early perceptual account of this advantage. However, the consistent lack of facilitation at the short exposure duration suggests that more consciously controlled processes are required for facilitation to operate, while interference can operate without awareness.

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