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Attentional Window and Global/Local Processing

Steven Peter Schultz
University of South Florida, steven.schultz24@gmail.com

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by

Steven Peter Schultz

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Department of Psychology
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Major Professor: Thomas Sanocki, Ph.D.
Chad Dubé, Ph.D.
Toru Shimizu, Ph.D.

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DEDICATION

I dedicate this work to my family for all of their unconditional love, support, and guidance.

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ABSTRACT

How does the focus of attention influence the encoding of information? Research has shown that size and allocation of the attentional window has an influence on what information is attended to or missed. The size-scale of features also effects processing of visual information. Previous research involving hierarchical stimuli suggests precedence for global features. In the present experiment, I investigated the influence of attentional window size on accuracy of encoding hierarchical stimuli at the global and local level. Here I introduce a new method for manipulating the size of the attentional window and for collecting unconstrained responses. At the start of each trial, observers tracked a dashed-line rectangular box, which either broadened or narrowed in size after onset. This sequence was immediately followed by a brief presentation of two hierarchical letters presented simultaneously on the left and right sides of the screen. The box preceding the hierarchical letters either broadened to a size large enough to include both letters at the global level, or narrowed to a size small enough to include a maximum of two letters at the local level at either side of the screen. Observers reported all letters they were able to identify. Results from two experiments indicate an overall precedence of global letters. However, a narrow attentional window reduced global precedence, as would be expected with more focused attention. The narrow windows also produced more same-side identifications of both global and local letters. The second experiment also showed that reducing the processing time decreased the global advantage.

INTRODUCTION

When waiting at a red light a driver may fix their eyes on one of the traffic signals directly in front of them, increasing the amount of attention directed to that specific location. This increase in attention directed towards a small area of the visual field increases the processing speed and acuity for information in that area, though it limits the amount of attention available to allocate to information outside of the focused area. When waiting at the traffic light, if attention is focused only on the traffic signal, the information outside of that window of focused attention is less likely to capture the driver's attention. What information from the environment is being missed when attention is directed to such a small area, compared to when attention is spread across a larger area?

The current research is related to attention and the influence it has on processing of information at global and local hierarchical levels. Specifically, the goal of this research is to investigate how attentional window size (i.e. the distribution of attention across the visual field) influences hierarchical letter processing.

ATTENTION AND THE STAGES OF VISION

Attention is a strong driving factor of perception. Attention determines what information from the environment gets processed at a higher level, beyond the low level of processing that occurs for a larger amount of information available across the visual field. This process of selecting portions of available stimuli can be referred to as selective attention (Lamy, Leber, & Egeth, 2012).

The information selected for higher level processing is believed to depend on the interaction of the perceiver's previous experiences, current goals, as well as the bottom-up stimulus information. Though the extent to which these factors contribute to selective attention is still debated.

Vision research has shown that visual processing occurs in stages, rather than in a single process (e.g. Broadbent, 1958; Neisser, 1967; Treisman & Gelade, 1980). The early stage of visual processing involves parallel processing of information across the visual field. This stage is referred to as a preattentive stage. The later stage of processing, the attentive stage, involves employing attention to process a subset of the information available in the visual field in a more serial fashion.

Treisman (1986) proposed a visual perception model that incorporates feature maps to explain that the early stages of visual processing include encoding of a number of different features of a scene. The features of scenes that can be encoded during the early stages include color, orientation, size, and stereo distance. These features and the spatial relations of the information are used in our understanding of scenes. This information that is available during the early stages of vision is encoded based on the allocation of an attention spotlight. The properties and relations of the objects perceived within the attention spotlight are compared to previous experiences with similar objects to determine the identity of the objects. The attention spotlight is used to gather information across multiple locations of a scene. This information is then used to determine the relationship between objects across multiple locations, leading to a more comprehensive understanding of the scene. This process guides how we store a representation of the environment we have encountered. The attention spotlight may also be referred to as the attentional window.

Similarly, Lamy et al. (2012) argue that both stimulus-driven and goal-oriented processes contribute to perception of the environment. It is also argued that attention research findings support the idea that much of perception is driven by an initial early stage of visual processing. This early stage of vision uses information gathered from stimuli in combination with prior knowledge to filter information for encoding and improve processing efficacy.

Research related to attentional sets also suggests that the processing of perceptual information involves an interaction of bottom-up and top-down processing. Visual information is processed based on observer expectations and goals, while irrelevant information can be ignored, at least to a certain degree (e.g. Folk, Remington, & Johnston, 1992; Most, Scholl, Clifford, & Simons, 2005; Sanocki & Sulman, 2013). Sanocki and Sulman (2013) show that attentional sets can be efficiently implemented for perceiving complex scenes with multiple events occurring. Observers are able to reach an optimal attentional set for perceiving multiple events, depending on how the events are spatially organized. Observers are able to detect multiple types of target stimuli, with multiple distractors present, relatively efficiently when the targets appear in expected areas. Though when these multiple events are spatially intermixed, observers cannot optimally detect the target stimuli mixed with distractors. This suggests that observer's attentional sets and the spatial location of objects are important to how objects are perceived.

Spatial cues decrease the response time for a stimulus presented in close proximity to a cue (Posner et al., 1980). The zoom lens model proposed by Eriksen and St. James (1986) suggests that the size of attentional focus can vary when cues provide spatial information about a subsequent stimulus. Top-down control over the spread of attention interacts with bottom-up stimulus information, which influences what information is available for encoding.

ATTENTIONAL WINDOW

Research related to the size of the attentional window provides some knowledge about the interaction of top-down and bottom-up processing. The attentional window is the area where attention is allocated across the visual field. The distribution of attention has been compared to a spotlight (e.g. Eriksen & Yeh, 1985; LaBerge, 1983; Posner, Snyder, & Davidson, 1980). The zoom lens model expands on the idea that attention is spatially directed by explaining that decreasing the size of the attentional field increases the efficiency of processing (Eriksen & St. James, 1986).

The visual system is designed to help us identify and locate information in our environment. This information can be used to help us create and complete goals related to the environment. But not all of the information available in the environment is relevant to the goals we have set. Therefore, we must be able to direct our attention towards the information that is relevant to our goals. This helps us collect and process a relevant subset of information from the larger amount available in the environment (Belopolsky, Zwaan, Theeuwes, & Kramer, 2007).

Theeuwes (1994) supports the idea that the size of an observer's attentional window influences the degree to which salient stimuli capture attention during a visual search task. It was observed that when attention is spread across a large area, a color singleton (i.e. a salient feature that is unique compared to surrounding features) could interfere with searching for a shape singleton by capturing the observer's attention. Though, when attention is focused on a smaller area, with the singleton outside of the attentional window, this effect is not found. This suggests that the observer can adjust the attentional window based on the expectations of the task (Theeuwes, 2004).

Belopolsky et al. (2007) demonstrate that the size of the attentional window can be adjusted voluntarily, based on a global or local task set. They presented task-irrelevant stimuli during a search task, which was preceded by an attentional window size manipulation, to demonstrate that the size of the attentional window influences the attentional capture by task-irrelevant stimuli. The attentional window was manipulated by instructing observers to either diffuse their attention across the visual field to detect the global shape of stimuli, or focus their attention on a local feature shape in the center of the stimuli, before starting a search task. The results show that when observers use a broad attentional window, compared to a narrow window, task-irrelevant stimuli are more likely to capture attention based on the salient and bottom-up features of the stimuli (Belopolsky et al., 2007).

Belopolsky & Theeuwes (2010) manipulated the attentional window size in combination with a rapid serial visual presentation (RSVP) singleton search task to show that a larger attentional window size allows irrelevant stimuli, located around a central RSVP letter stream, to involuntary capture attention, resulting in an increase in reaction time for detecting target stimuli. Though when attention is focused on the smaller central letter stream the effect of attention capture by irrelevant, yet salient, distractors is eliminated and the reaction time for target stimuli is quicker. This supports the idea that the observer can control the attentional window size, which allows the observer to inhibit task-irrelevant stimuli. Belopolsky and Theeuwes (2010) suggest that a parallel search process is used when the attentional window is wide. This allows salient features to capture attention, irrespective of the top-down goals of the observer. A small attentional window is a less efficient search strategy, as it is suggested to use a serial search process.

Leonard, Lopez-Calderon, Kreither, and Luck (2013) suggest that when attention is directed toward a goal-relevant object, the size of the attentional window is adjusted to a size appropriate for processing the object. They also show that the process and timing of the process for adjusting the attentional window is similar to the timing for shifting attention to objects in the peripheral of the visual field.

A perceiver's attentional window can influence what information is attended to and what type of information is prioritized for comprehension (Notebaert, Crombez, Van Damme, Durnez, & Theeuwes, 2013). The size of the attentional window can alter which features of an image are considered objects and which features are considered contextual informational. A broad attentional window will incorporate a large area of the visual field and potentially large amounts of information to process. On the other hand, a narrow attentional window involves localized attention. This narrow attentional window will process a portion of the visual field that is smaller but higher in resolution. The size of a perceiver's attentional window can be a factor in determining whether information is captured or missed (Notebaert et al., 2013).

Notebaert and colleagues (2013) showed that adopting a broader attentional window also allows perceivers to prioritize meaningful stimuli. They showed that participants instructed to spread their attention across their visual field, compared to participants instructed to focus their attention to the center of a computer screen, were better able to prioritize and attend to a stimulus that was learned to be predictive of an electrocutaneous stimulus. When information is outside of the attentional window, it is unable to capture attention and be prioritized for further processing (Notebaert et al., 2013).

Van Beilen, Renken, Groenewold, and Cornelissen (2011) measured eye movements during a search task and found evidence suggesting the attentional window can be voluntarily controlled. They also suggest the attentional window is set based on the perceiver's expectations of the environment. Van Beilen and colleagues (2011) manipulated the reliability of visual cues during a search task to adjust the size of the attentional window. They show that participants are able to use their knowledge and experience with the cues to voluntarily adjust the size of their attentional window. As the validity of a cue increases, observers can narrow their attentional window to the cued location, and performance on the search task increases. When less valid cues are used, observers must disperse their attention across a larger area, and performance on the search task decreases. Adopting a narrow window size allows observers to attend to task-relevant stimuli quicker than those with a broader attentional window. When observers adopt a larger attentional window, distracting stimuli captures attention and there is an increase in the amount of time it takes to complete the search task. This suggests that top-down processing plays a role in controlling the attentional window. Though the capture of attention within the attentional window is suggested to involve a bottom-up process. This is consistent with previous attentional window research (e.g. Belopolsky et al., 2007; Belopolsky & Theeuwes, 2010). This supports the idea that the process of perception involves an interaction of top-down and bottom-up processing.

Theeuwes (2010) argues that the initial stage of visual processing can be driven by the saliency of the bottom-up features in the visual field, if the size of the attentional window is large. This initial object selection process is believed to occur within the first 150 ms of visual processing. After this initial processing stage with spread attention, during the attentive stage of processing, top-down processing is shown to modulate object selection based on the goals, previous knowledge, and expectations of the observer. Top-down knowledge of non-spatial object features is not able to influence early visual selection, but top-down knowledge of spatial information can influence the selection of visual information. Theeuwes (2010) states that selecting information for further processing in a top-down manner is accomplished by adjusting the size of the attentional window to include an area of interest.

The attentional window influences what subset of information gets processed from the environment and helps prioritize the information to be processed. A broad attentional window tends be best for processing larger pieces of information; on the other hand, a narrow attentional window tends to be best for processing smaller more detailed pieces of information.

GLOBAL AND LOCAL PROCESSING

One way to differentiate features of the environment is to classify the information as global and local features. Features can be processed at a global level (i.e. the whole), as well as at a local level (i.e. the parts). Local features can be described as features that make up the global whole. The relative size of features is often used to classify features as global (large) or local (small). The size-scale of features has an influence on the order of processing of visual information. There is evidence for large size-scale information facilitating identification early in processing, while small size-scale information facilitates identification late in processing (Sanocki, 2001).

Förster (2012) developed the global and local processing model ($GLOMO^{sys}$) to explain the global processing system (“glo-sys”) and local processing system (“lo-sys”). When the glo-sys is activated, observers perceive features in a holistic manner. Activation of the glo-sys is also suggested to be associated with an activation of broad categories in memory and building upon prior knowledge. When the lo-sys is activated, observers perceive the details of features. Activation of the lo-sys is associated with activation of narrow categories in memory and excluding a portion of the incoming features from being processed. $GLOMO^{sys}$ suggests that global processing is utilized for understanding novel events, whereas local processing is utilized for collecting details in familiar situations (Förster, 2012).

It appears that information at the global and local levels are processed differently and this processing does not always seem to occur simultaneously. As will be seen below, there tends to be a preference for processing elements at the global level, as this information interferes with the processing of local elements.

Hierarchical Stimuli

Navon (1977) introduced hierarchical letter stimuli (e.g. a large S made out of small Hs) to investigate differences in processing of global and local features. This research revealed an overall global precedence effect (GPE). Participants were faster at identifying the global letters compared to the local letters of the hierarchical letter stimuli. This provided some evidence that there may be a preference for perceiving global features in the early stages of visual processing, while there is a delay in processing local features.

Hierarchical stimuli have been implemented in numerous ways since being demonstrated as useful stimuli for investigating global and local processing differences. Researchers have implemented many different hierarchical stimuli to analyze different aspects of global/local processing. It's been shown that the GPE can be altered depending on the tasks used with these hierarchical stimuli. The number of elements used to create hierarchical stimuli also plays a role in the precedence of processing between the global and local levels. The proximity and size of these elements can alter how the features are processed (Kimchi & Palmer, 1982; Kinchla & Wolfe, 1979). A large number of local features arranged closely together increases the GPE, while more sparsely arranged local features decreases the GPE. This suggests the processing advantage is determined by which level(s) are presented at an optimal size for viewing, and stimuli with both global and local features optimally sized leads to more of a "middle-out" processing style (as opposed to top-down or bottom-up) (Kinchla & Wolfe, 1979).

When there is incongruence between the elements presented at the global and local levels, and participants must determine if the simultaneously presented hierarchical patterns are the same or different from one another, processing of global features interferes with processing of local features (Kimchi, 1988).

The GPE can be reduced when participants are given forced choice targets to respond to with a key press (Grice, Canham, & Boroughs, 1983). Grice and colleagues demonstrate that participants have similar reaction times for detecting global and local letters during a global/local task, though participants only had to detect the presence of one of two possible target letters during this task. It is also possible to eliminate the advantage for processing global features, but only after extended training of identifying only local features during a global/local task (Dulaney & Marks, 2007).

The meaningfulness of the elements used to create the different levels of hierarchical shape stimuli also play a role in the processing of global/local features. Non-object shapes do not cause interference between levels as seen with meaningful object stimuli (Poirel, Pineau, & Mellet, 2008). Poirel et al. (2008) also noted that there is a faster global processing advantage for processing stimuli that have “goodness of form” when compared to unidentifiable and meaningless stimuli.

Dale and Arnell (2013) reviewed global/local stimuli commonly used to measure global/local bias and determined that the variety of different hierarchical stimuli and tasks used may be measuring different underlying processes. These hierarchical letters may have fairly low reliability for measuring global/local bias within an individual’s responses when instructed to attend to one level. However, a general advantage for processing global features has generally been demonstrated across differing global/local tasks and with different hierarchical stimuli.

Some studies have shown that an increase in acuity at the local level decreases the GPE (Lamb & Robertson, 1988; Pomerantz, 1983). This increase in acuity can be a result of differences of discriminability between global and local levels. Lamb and Robertson (1988) do address the possibility of the attentional spotlight influencing the efficiency of processing global and local features. They note that increases in processing efficiency may be a result of a decrease in area of the attentional spotlight. This effect was compared between centrally presented stimuli and peripherally presented stimuli, though they do not manipulate the attentional spotlight prior to stimuli presentation. It is assumed the spotlight is adjusted after the presentation of the stimuli. These effects are also only investigated with the presentation of single hierarchical stimuli. Centrally presented stimuli allow for more efficient processing of local features compared to peripherally presented stimuli (Lamb & Robertson, 1988).

While the global/local processing literature suggest mixed results when presenting participants with various hierarchical stimuli, there tends to be a general advantage for global features over local features, supporting the GPE. Previous research in the field has involved instructing participants to report targets at only one level (global or local) of the stimuli per trial.

The current research investigates the potential of reducing the global advantage for letter identification accuracy, while keeping both global and local features task-relevant for all trials. This provides insight about how the hierarchical levels are prioritized. An attentional window manipulation preceded the presentation of hierarchical letter pairs. This allows for investigating the influence the allocation of attention has on global/local processing, which previous research has not fully explored.

Based on findings discussed earlier about the importance of attention, and more specifically the attentional window, during perceptual tasks, it is of interest to further investigate the influence the attentional window has on global and local processing. This research is a step towards understanding how attentional window size influences how we understand complex environments. Though in order to understand the role the attentional window plays in processing different levels of complex environments (such as natural scenes and events) it is important to first improve our understanding of the role the attentional window plays in processing simpler global/local information and build on past research in this area. Hierarchical stimuli pairs provide a way of studying this relationship in a more controlled manor, with fewer variables than involved in stimuli like complex scenes.

OVERVIEW AND HYPOTHESES

This research is an attempt to determine the relationship between the attentional window and global/local processing by combining attentional window manipulations with hierarchical letter pair stimuli. This research introduces a new method for manipulating the attentional window, along with an open-ended report method for identifying global and local letters within hierarchical stimuli.

The current research was designed to investigate if adopting broad or narrow attentional windows, prior to the presentation of hierarchical stimuli, differentially effects processing of global and local letters. This research was also aimed at determining if a narrow attentional window location (presented on the left or right side of the screen) differentially influences the processing of global and local letters presented on either side of the screen. Building upon past research related to the attentional window and hierarchical stimuli, as outlined above, this study tested the following hypotheses:

Hypothesis 1: Participants will report global letters of hierarchical stimuli with higher accuracy after broad attentional window manipulations, compared to after narrow attentional window manipulations.

Hypothesis 2: Participants will report local letters with higher accuracy after narrow attentional window manipulations, compared to after broad attentional window manipulations.

Hypothesis 3: After narrow attentional window manipulations, participants will have higher accuracy for local and global letters presented on the same side of the screen as the ending location of the narrow attentional window, compared to letters presented on the side opposite the narrow window.

Hypothesis 4: The advantage for global letters will be reduced as stimuli processing time is reduced, compared to when participants have more time to readjust the size of the attentional window and process all letters presented.

Experiment 1

The purpose of Experiment 1 was to examine the effect the size and location of the attentional window has on global and local letter processing. Participants were presented with attentional window manipulations, and hierarchical letter stimuli and had to perform a letter identification task.

Method

Design and procedure

I employed a within-subjects design in this study. A new method for manipulating the size of the attentional window is introduced, as shown in Figure 1. Participants completed 54 trials consisting of an attentional window manipulation, followed by a pair of hierarchical letters and then a mask.

Participants

Participants were 50 undergraduate students (35 female) who reported normal or corrected-to-normal vision and provided informed consent. Participants were recruited from the University of South Florida psychology department subject pool, and were compensated with course credit. The data for 3 participants were excluded due to low performance on the attentional window manipulation task.

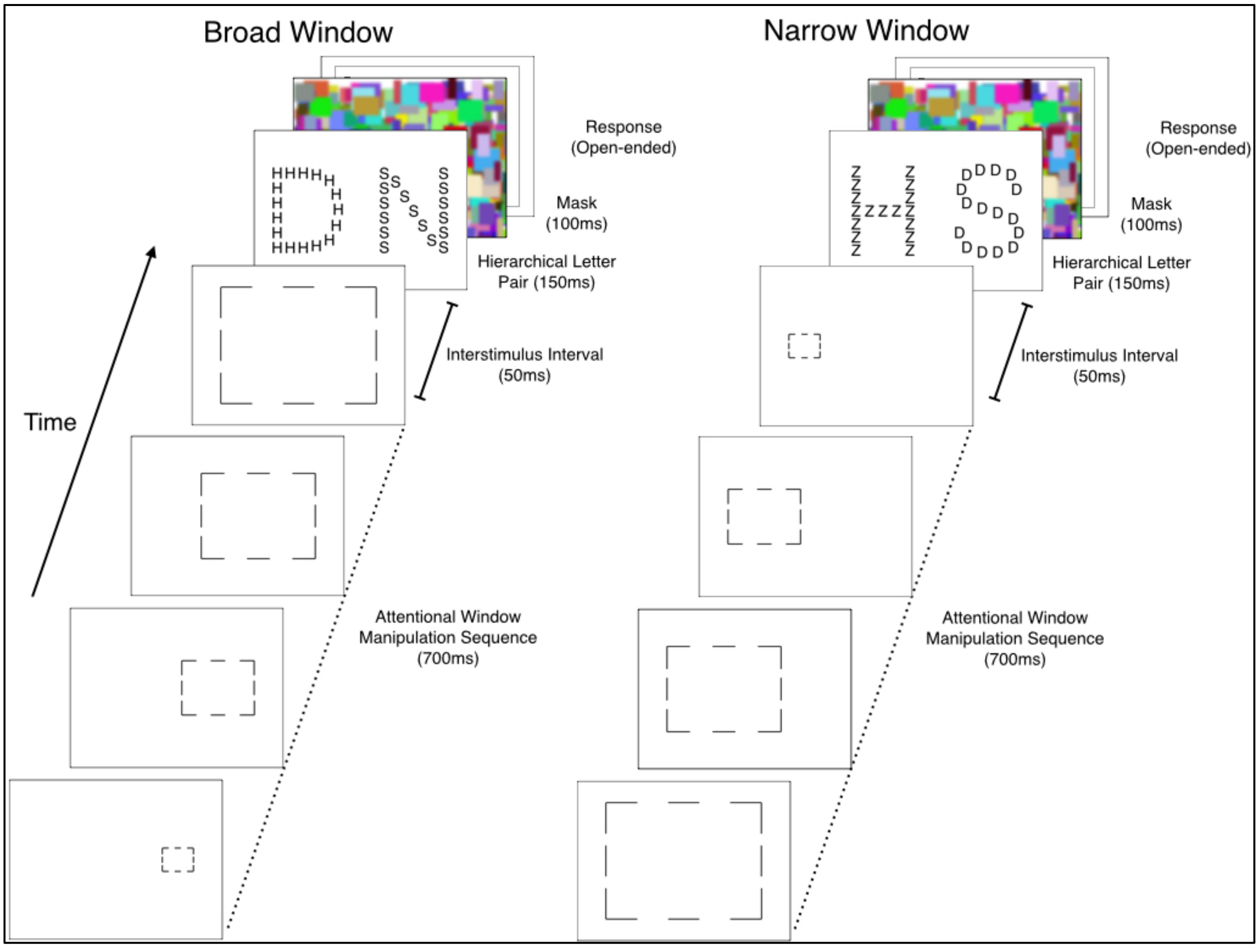

Figure 1. Trial procedure for Experiment 1. The attentional window manipulation sequence was made up of seven dashed-line rectangular boxes presented consecutively for 100ms each. Participants attended to the dashed-line rectangular box, which either narrowed or broadened after onset. This manipulation was followed by a 50ms ISI and a pair of hierarchical letters, presented for 150ms.

Apparatus

Stimuli were presented on a 20-inch iMac computer with a LCD screen. Participants were seated approximately 50cm from the computer screen, in a partially darkened laboratory room.

Attentional window manipulation

Participants were presented with a narrow (24 trials) and broad (24 trials) attentional window manipulation prior to the presentation of a hierarchical letter pair. Trials were presented in a randomized order. There were also 6 trials consisting of attentional window manipulation checks. Attentional window manipulations consisted of a dashed-line rectangular box, which either narrowed or broadened in size after onset. The box either broadened to a size large enough to include both letters at the global level (750x560 pixels), or narrowed to a size small enough to include a maximum of two letters at the local level (150x110 pixels) at either side of the screen. Participants were instructed to focus their attention on the dash-lined box the entire time it was moving on the screen. During the majority (48) of trials the box broadened or narrowed normally. During the other (6) trials the dash-lined box became misaligned, no longer forming the shape of a rectangle. Participants were instructed to identify and report any misaligned box, by typing the word 'box' on the response screen, to insure they attended to the boxes the entire time they were presented. The attentional window manipulation sequence lasted 700ms, with 7 dash-lined boxes appearing consecutively for 100ms each. Each attentional window manipulation was followed by the brief presentation of hierarchical letter pairs, with a 50ms interstimulus interval (ISI) before the hierarchical letter pairs.

Hierarchical letter pairs

Two hierarchical letters were presented simultaneously for 150ms on the left and right side of the screen (7.4 deg) on each trial. Hierarchical letter stimuli were made up of combinations of the following letters: D, F, H, N, S, T, X, AND Z. Letters at the local level were made of size 75pt Helvetica font. Global letters were modeled after size 550pt Helvetica font. Global letters were made up of 12-17 local letters. This varied depending on the goodness of shape of the global letter and the features of each letter. Different letters were used at the local and global levels of each hierarchical letter, creating incongruence between the levels. Four different letters were presented simultaneously on each trial, with incongruence between hierarchical letter pairs as well (As seen in Figure 2). No vowels were included to avoid the possibility of word formations and/or pronounceable letter combinations. The arrangement of the hierarchical letter pairs was counterbalanced. Participants were instructed to report all letters they were able to identify by typing their response in a free response box at the end of each trial.

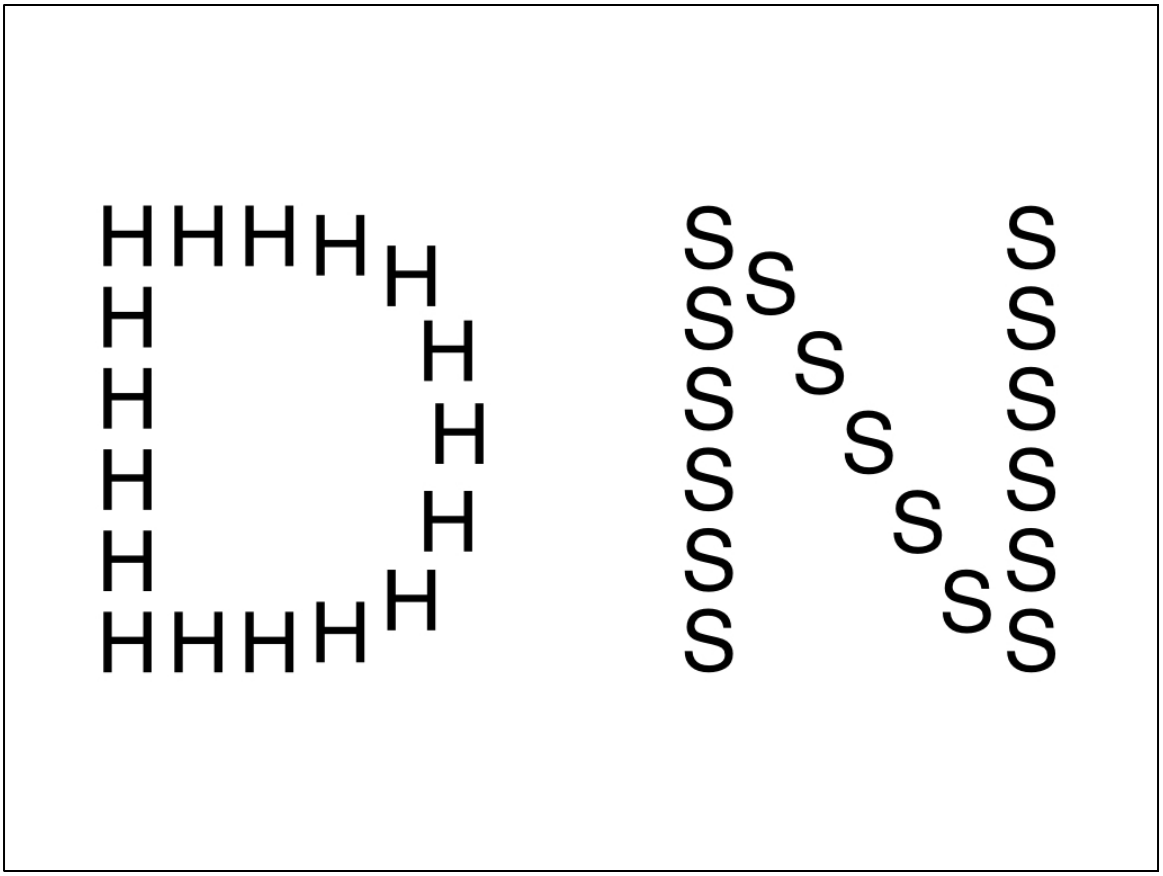

Figure 2. Hierarchical letter pair stimuli. Each letter pair had incongruence at the global and local levels and incongruence between the pairs.

Data

Each participant completed 54 trials (24 narrow window, 24 broad window, and 6 catch trial). There were 4 letters total (2 global and 2 local) presented per trial, and 2 letters (1 global and 1 local) presented on each side of the screen (left and right). There were 12 narrow window trials ending on the left of the screen and 12 ending on the right. All the broad window trials ended with the window in the center of the screen, with 12 broad window trials starting on the left and 12 starting on the right. The dependent variable is the correct number of letters reported, out of 12 (average correct per condition).

Experiment 1 Results

Two repeated measures analyses of variance (ANOVA) were conducted to analyze the effect of the attentional window on global and local letter processing in Experiment 1.
The first *window size effectiveness* assesses whether the attentional window size differentially effects the processing of global and local letters. The second *widow side effectiveness* assesses whether the narrow attentional window side differentially effects the processing of hierarchical letters presented on the left versus right.

Window size effectiveness

Global and local letter processing accuracy was analyzed in a 2 (window size: broad or narrow) X 2 (letter size: global or local) X 2 (window side: left or right) X 2 (letter position: left or right) repeated measures ANOVA. There was a significant main effect of letter size; accuracy for global letters was greater than for local letters [$F(1,49)= 137.87$, $p < 0.0001$ (global: $M=$ 80.8%, $SE=$ 1.50; local: $M=$ 40.4%, $SE=$ 2.86)]. This suggests there was an advantage for processing global letters, which supports the GPE.

There was also a significant main effect of letter position; accuracy for letters present at screen left was greater than for letters presented at screen right [$F(1,49)= 18.40$, $p < 0.0001$ (screen left: $M=$ 63.9%, $SE=$ 1.70; screen right: $M=$ 57.4%, $SE=$ 1.66)]. This advantage for letters presented on the left could have appeared due to the natural tendency of reading from left to right, and prioritizing letters or words presented on screen left.

There was a significant two-way window size X letter size interaction [$F(1,49)= 13.09$, $p = 0.001$], as seen in Figure 3, though the effect was small. This result suggests the size of the attentional window differentially effects the processing of hierarchical letters, with global letters being reported with higher accuracy overall. A post-hoc paired-samples *t*-test shows this interaction was driven by an advantage for having a broad attentional window when processing global letters (83.5%) compared to a narrow window when processing global letters (78.1%) ($p < 0.0001$). Though, there was no advantage found for having a narrow attentional window (compared to a broad window) when processing local letters.

Window side effectiveness

In order to test the effect of the narrow attentional window ending locations (left or right) on global and local letter processing, narrow attentional window trials were analyzed separately from the broad window trials in a 2 (letter size: global or local) X 2 (narrow window end side: left or right) X 2 (letter position: left or right) repeated measures ANOVA. There was a significant main effect of narrow window side; accuracy was greater when the ending location of the narrow window was on the left versus the right [$F(1,49)= 5.40$, $p = 0.024$ (window end left: $M= 61.4\%$, $SE= 1.58$; window end right: $M= 57.7\%$, $SE= 1.83$)]. This result could also be due to prioritization of letters presented on the left, with the window ending location contributing to this advantage.

There was a significant main effect of letter size; accuracy for global letters was greater than local [$F(1,49)= 119.31$, $p < 0.0001$ (global: $M= 78.1\%$, $SE= 1.58$; local: $M= 41.0\%$, $SE= 2.75$)]. The narrow attentional window manipulation did not produce an advantage for local letters.

There was also a significant main effect of letter position; accuracy was greater for letters positioned on the left versus the right [$F(1,49)= 10.11$, $p = 0.003$ (screen left: $M= 62.2\%$, $SE= 1.67$; screen right: $M= 56.9\%$, $SE= 1.75$)].

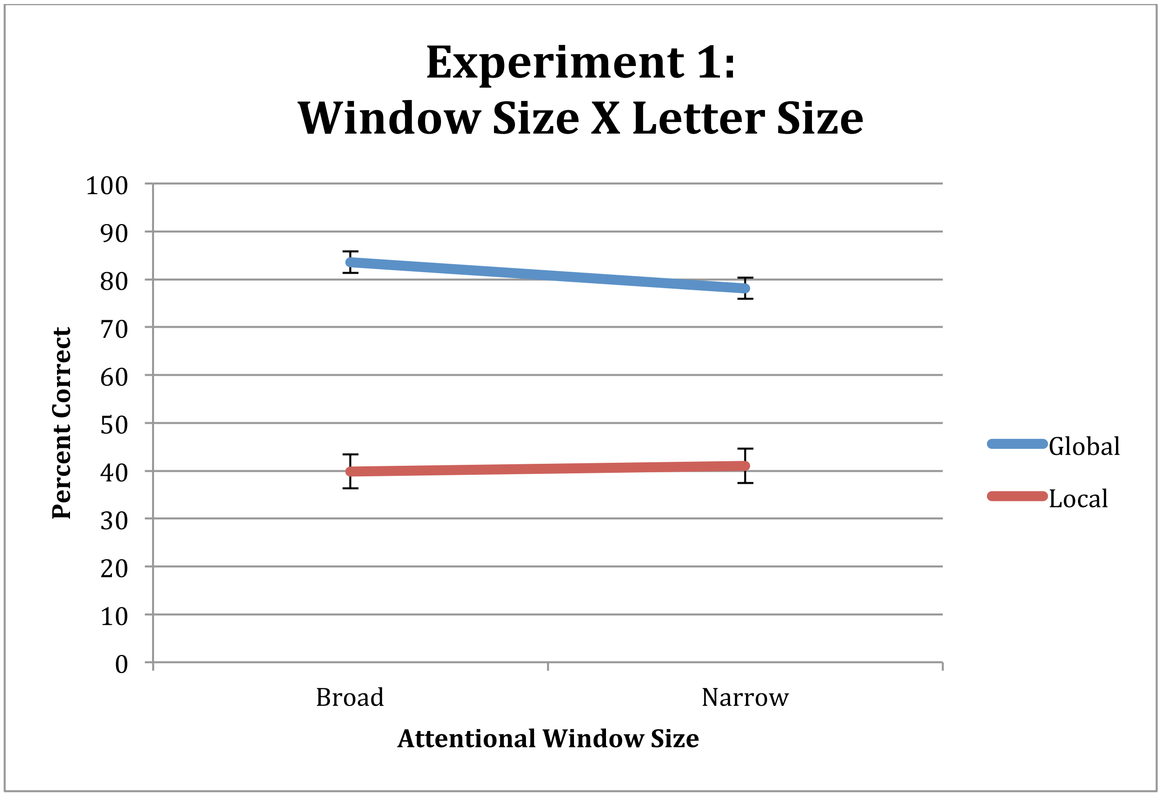

Figure 3. Experiment 1 window size by letter size.

There was a significant two-way narrow window side X letter position cross-over interaction [$F(1,49) = 82.43$, $p < 0.0001$], as seen in Figure 4. This interaction is characterized by an advantage for processing the letters presented on the side that matches the ending side of the narrow window (69.3%) (e.g. window side – left; letter position – left) compared to letters presented on the side opposite of the narrow window (49.8%) (e.g. window side – left; letter position – right) ($p < 0.0001$). This suggests the attentional window manipulation was effective for improving letter processing at either side of the screen.

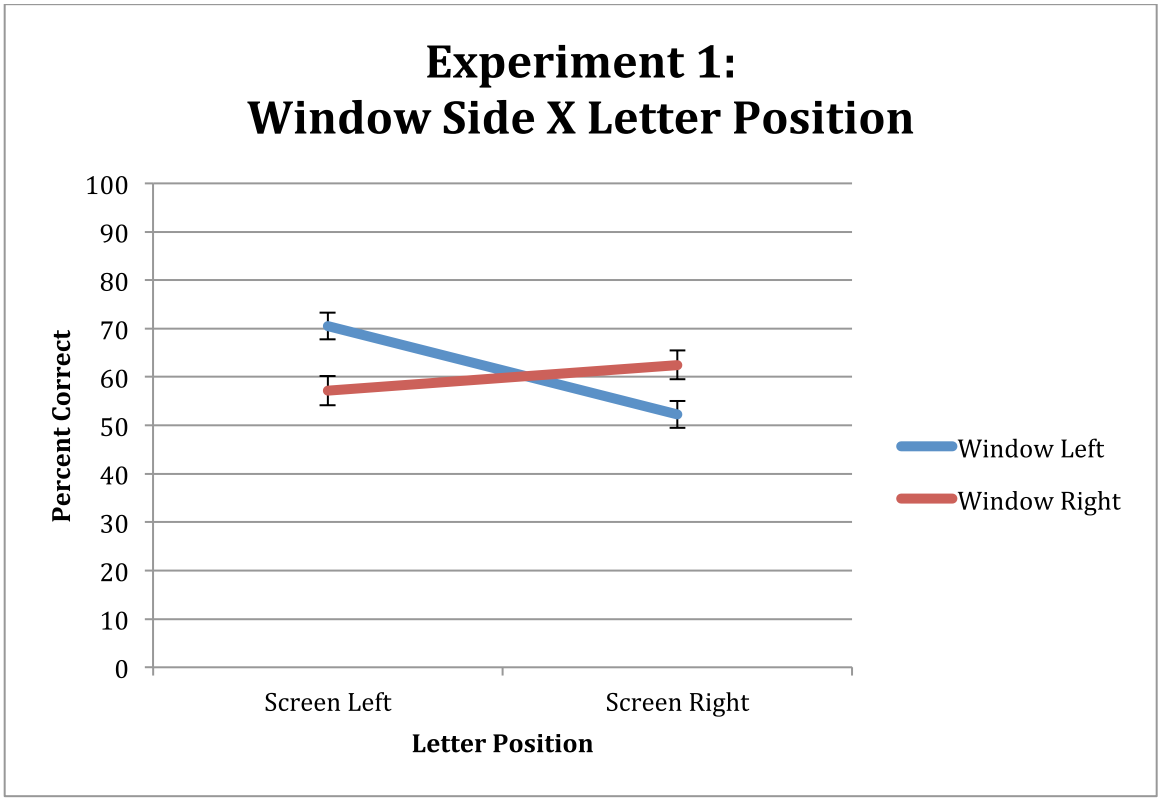

Figure 4. Experiment 1 window side by letter position.

There was also a significant three-way letter size X narrow window side X letter position interaction [$F(1,49)= 12.02$, $p = 0.001$] for the narrow window trials, as seen in Figure 5 and Figure 6. This could be caused by a ceiling effect for processing global letters and/or floor effect for processing local letters.

Broad attentional window trials all ended with a broad window in the center of the screen, large enough to contain both global letters. The windows on these trials began on either the left or right. A 2 (letter size: global or local) X 2 (window start side: left or right) X 2 (letter position: left or right) repeated measures ANOVA was conducted to analyzed the possible effect of the side the broad window started on. There was no main effect of window start side, which was expected [$F(1,49)= 0.40$, $p = 0.530$].

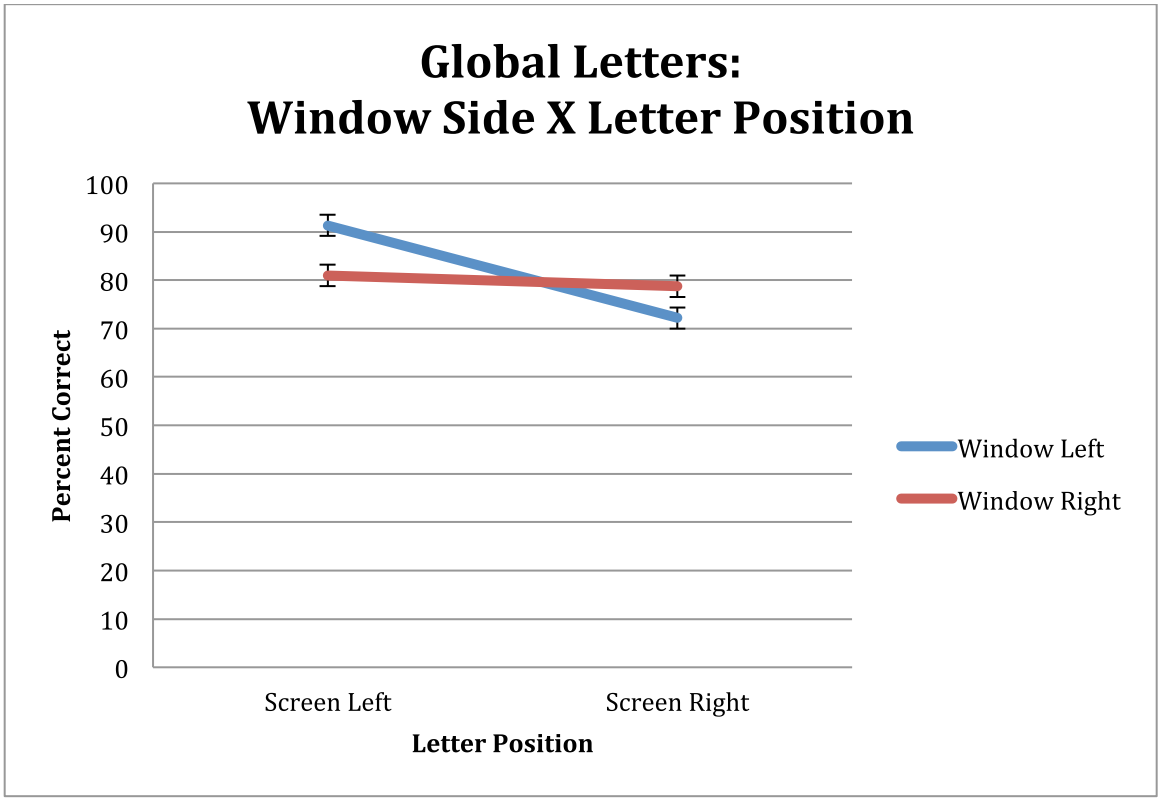

Figure 5. Experiment 1 window side by letter position for global letters.

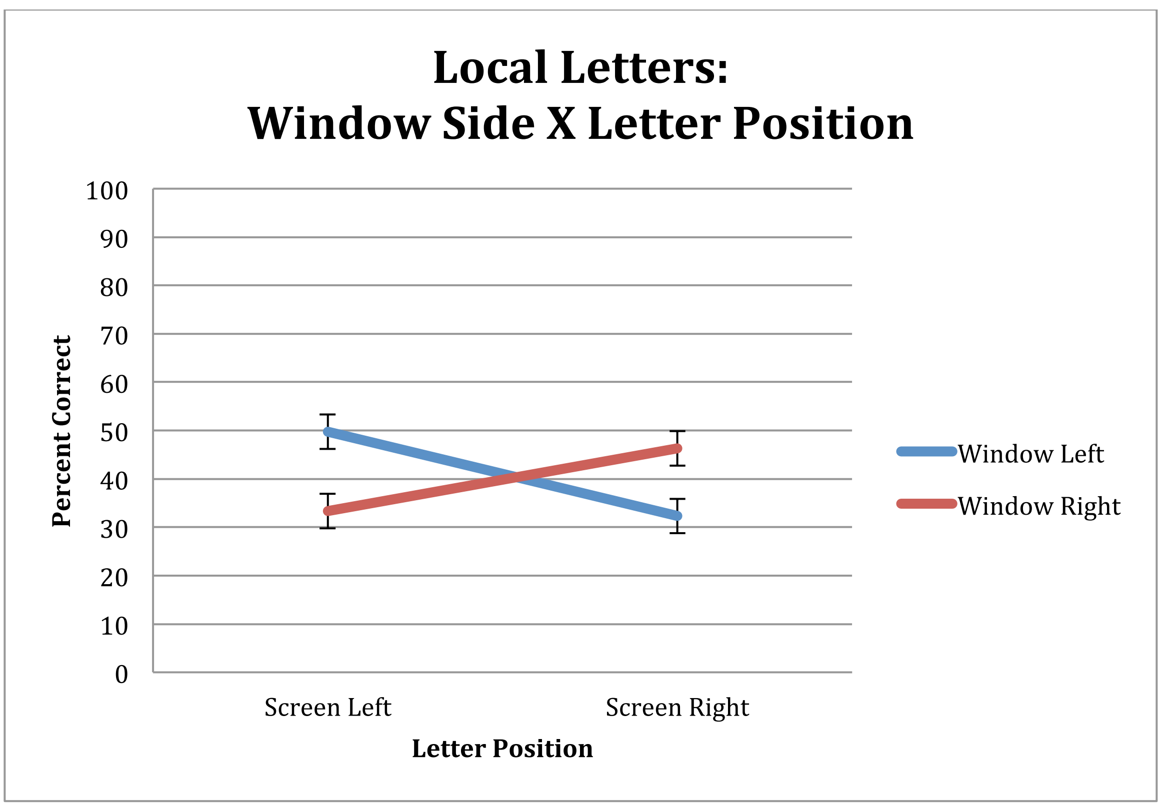

Figure 6. Experiment 1 window side by letter position for local letters

Experiment 1 subsidiary results

The following interactions were also significant: window size X window side interaction [$F(1,49) = 7.13$, $p = 0.01$]; letter size X letter position interaction [$F(1,49) = 18.85$, $p < 0.0001$]; window size X window side X letter position interaction [$F(1,49) = 42.08$, $p < 0.0001$]. These interactions were not directly related to the proposed hypotheses and were not analyzed further for the current research study.

Experiment 1 Discussion

Window size effectiveness

Hypothesis 1 states that participants will report global letters of hierarchical stimuli with higher accuracy after broad attentional window manipulations, compared to after narrow attentional window manipulations. The results of Experiment 1 support this prediction. There was a significant interaction of window size by letter size (Figure 3), which was driven by higher global letter identification accuracy on broad attentional window trials than on narrow window trials. This was a small effect, but the attentional window manipulations successfully created differences in global letter processing with hierarchical letters.

Hypothesis 2 states that participants will report local letters with higher accuracy after narrow attentional window manipulations, compared to after broad attentional window manipulations. The results of Experiment 1 did not support this prediction. There was no significant difference between narrow attentional window trials and broad window trials for accuracy of local letter identification (Figure 3). Participants were still able to identify the local letters equally as well after attention was spread across a larger area as when attention was narrowed to a smaller area. Though the accuracy for identifying local letters was significantly lower than for global letters.

These results together suggest the narrow attentional window manipulation effectively narrowed the spread of attention enough to negatively affect the processing of global letters, but did not narrow the spread of attention enough to create an advantage for processing local letters (or eliminate the advantage for processing global letters). This supports the global precedence effect.

Window side effectiveness

Hypothesis 3 states that after narrow attentional window manipulations, participants will have higher accuracy for local and global letters presented on the same side of the screen as the ending location of the narrow attentional window, compared to letters presented on the side opposite the narrow window. Experiment 1 supports this prediction, as there was a significant interaction of window side by letter position (Figure 4). Narrow attentional windows ending on the left of the screen created an advantage for identifying both global (Figure 5) and local (Figure 6) letters positioned on the left side of the screen. The same was true for narrow windows ending on the right and letters positioned on the right. Participants had lower identification accuracy for letters positioned on the side opposite the ending narrow window side.

This suggests the narrow attentional window manipulation effectively directed attention to either side of the screen, causing participants to miss the letters positioned on the opposite side more frequently.

Global advantage and processing time

Experiment 2 was implemented to replicate the findings related to *window size effectiveness* and *window side effectiveness*, as well as to test the possibility of decreasing the advantage for global letters by decreasing the time for processing the hierarchical stimuli, which is outlined below.

Experiment 2

The purpose of Experiment 2 was to investigate the possibility of further reducing the global advantage for hierarchical stimuli. To investigate this, the overall processing time was reduced. The ISI between the attentional window manipulation and the hierarchical letter pairs was reduced from 50ms to 0ms, so the hierarchical letters were present immediately as the attentional window manipulation was completed. This change was made to reduce the possibility of the attentional window size to be readjusted before processing the letter stimuli.

Method

Design and procedure

With the exception of the processing time reductions (ISI preceding the hierarchical letter stimuli and the presentation time of the letter pairs) the procedure for Experiment 2 was identical to Experiment 1 (Figure 7).

Participants

A separate group of participants were recruited for this experiment. Participants were 56 undergraduate students (38 female) who reported normal or corrected-to-normal vision and provided informed consent. Participants were recruited from the University of South Florida psychology department subject pool, and were compensated with course credit. The data for 10 participants were excluded due to low performance on the attentional window manipulation task.

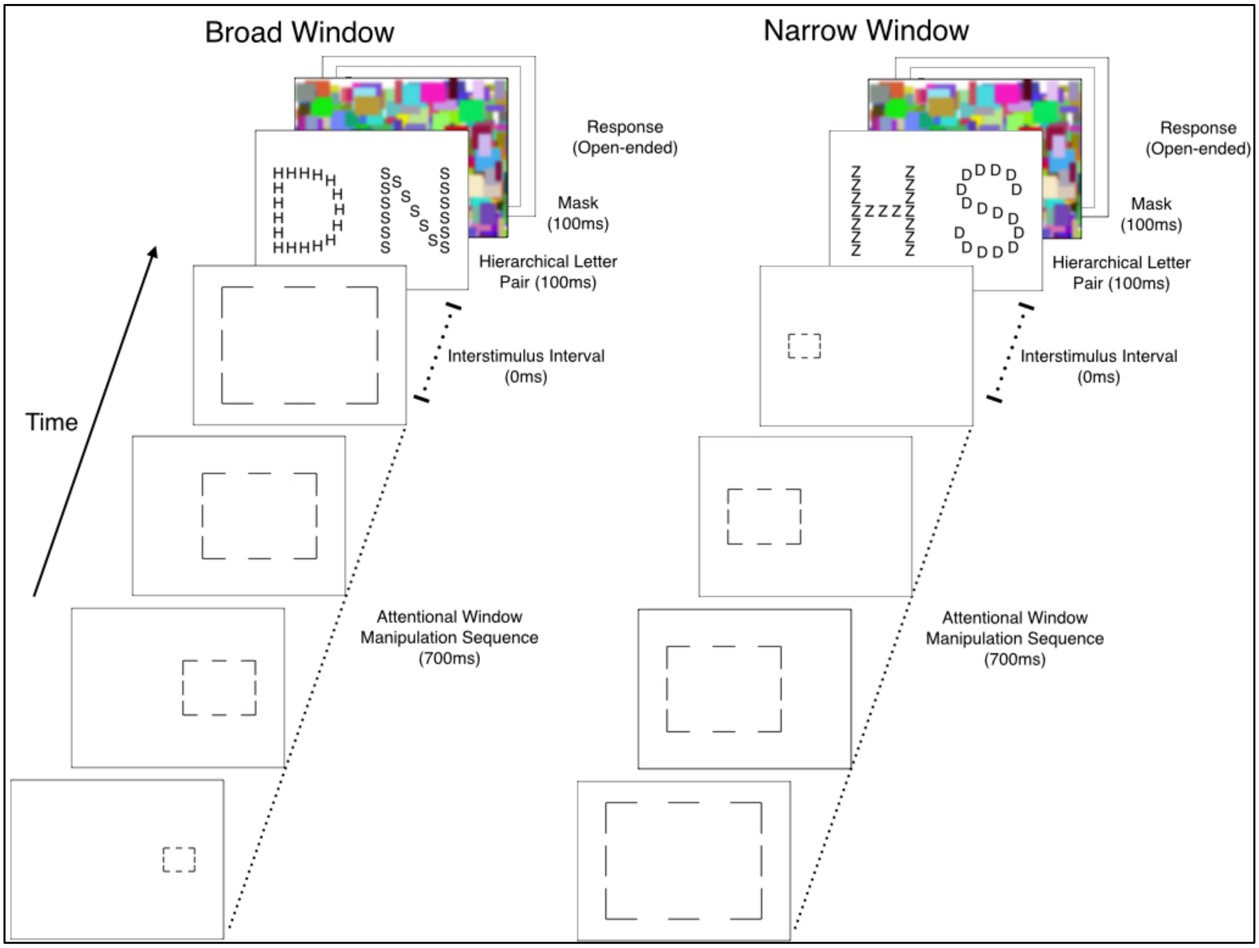

Figure 7. Trial procedure for Experiment 2. The attentional window manipulation sequence was made up of seven dashed-line rectangular boxes presented consecutively for 100ms each. Participants attended to the dashed-line rectangular box, which either narrowed or broadened after onset. This manipulation was immediately followed (0ms ISI) by a pair of hierarchical letters, presented for 100ms.

Experiment 2 Results

As in Experiment 1, two repeated measures analyses of variance (ANOVA) were conducted to analyze the *window size effectiveness* and the *window side effectiveness* in Experiment 2, which was characterized by a shorter letter processing time.

Window size effectiveness

There was a significant main effect of window size; greater accuracy with broad windows [$F(1,55)= 19.20$, $p < 0.0001$ (broad: $M= 57.1\%$, $SE= 1.27$; narrow: $M= 53.75\%$, $SE= 1.33$)].

There was significantly higher accuracy of letters reported on broad attentional window trials compared to narrow window trials, which was not found to be significant in Experiment 1.

There was a significant main effect of window side; greater accuracy with windows on the left [$F(1,55) = 9.16$, $p = 0.004$ (window left: $M = 56.7\%$, $SE = 1.36$; window right: $M = 54.2\%$, $SE = 1.26$)]. This result was not significant in the analysis including both narrow and broad window trials conducted for Experiment 1. Further analysis, presented below, shows a significant main effect of window side for narrow attentional windows but no significant main effect of window side for broad windows, suggesting this result was driven by an advantage for narrow windows ending on the left of the screen.

As seen in Experiment 1, there was a significant main effect of letter size; greater accuracy for global letters [$F(1,55) = 18.82$, $p < 0.0001$ (global: $M = 65.6\%$, $SE = 2.75$; local: $M = 45.3\%$, $SE = 2.53$)]. This result again supports the GPE.

Also as seen in Experiment 1, there was also a significant main effect of letter position; greater accuracy for letters positioned on the left [$F(1,55) = 21.28$, $p < 0.0001$ (screen left: $M = 59.4\%$, $SE = 1.49$; screen right: $M = 51.4\%$, $SE = 1.55$)].

There was a significant two-way window size X letter size interaction [$F(1,55) = 10.75$, $p = 0.002$], as seen in Figure 8, though the effect was small. A post-hoc paired-samples *t*-test shows this interaction was again driven by an advantage for having a broad attentional window when processing global letters (68.9%) compared to a narrow window when processing global letters (62.2%) ($p < 0.0001$). There was still no advantage found for having a narrow attentional window when processing local letters.

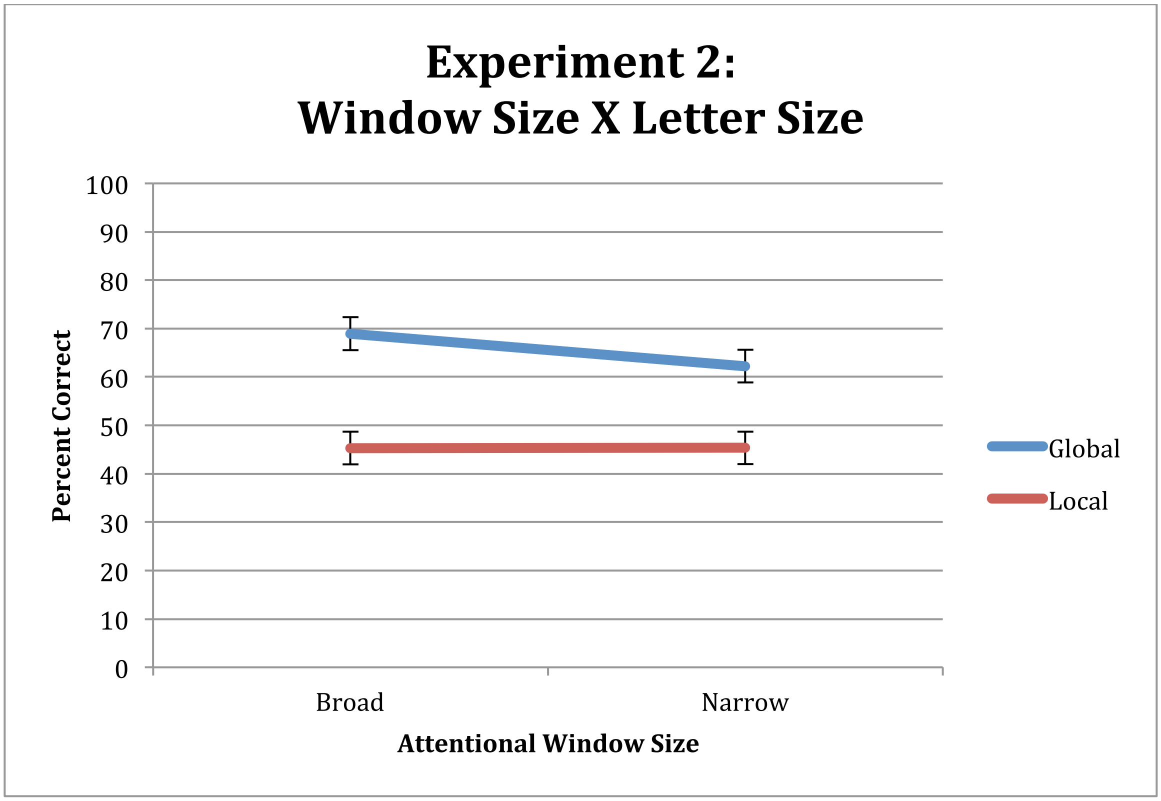

Figure 8. Experiment 2 window size by letter size.

Window side effectiveness

For the narrow attentional window trials in experiment 2, there was a significant main effect of letter size; greater accuracy for global letters [$F(1,55)= 14.03$, $p < 0.0001$ (global: $M= 62.2\%$, $SE= 2.75$; local: $M= 45.3\%$, $SE= 2.42$)].

There was a significant main effect of narrow window side; greater accuracy with windows ending on the left [$F(1,55)= 16.92$, $p < 0.0001$ (window left: $M= 55.9\%$, $SE= 1.50$; window right: $M= 51.6\%$, $SE= 1.42$)].

There was also a significant main effect of letter position; greater accuracy for letters positioned on the left [$F(1,55)= 4.54$, $p = 0.038$ (screen left: $M= 55.7\%$, $SE= 1.58$; screen right: $M= 51.9\%$, $SE= 1.67$)]. These significant main effects of letter size, narrow window side, and letter position were all replications of findings in Experiment 1.

There was a significant two-way narrow window side X letter position cross-over interaction [$F(1,55) = 142.29$, $p < 0.0001$], as seen in Figure 9. This interaction is characterized by an advantage for processing the letters presented on the side that matches the ending side of the narrow window (76.4%) compared to letters presented on the side opposite of the narrow window (48.0%) ($p < 0.0001$).

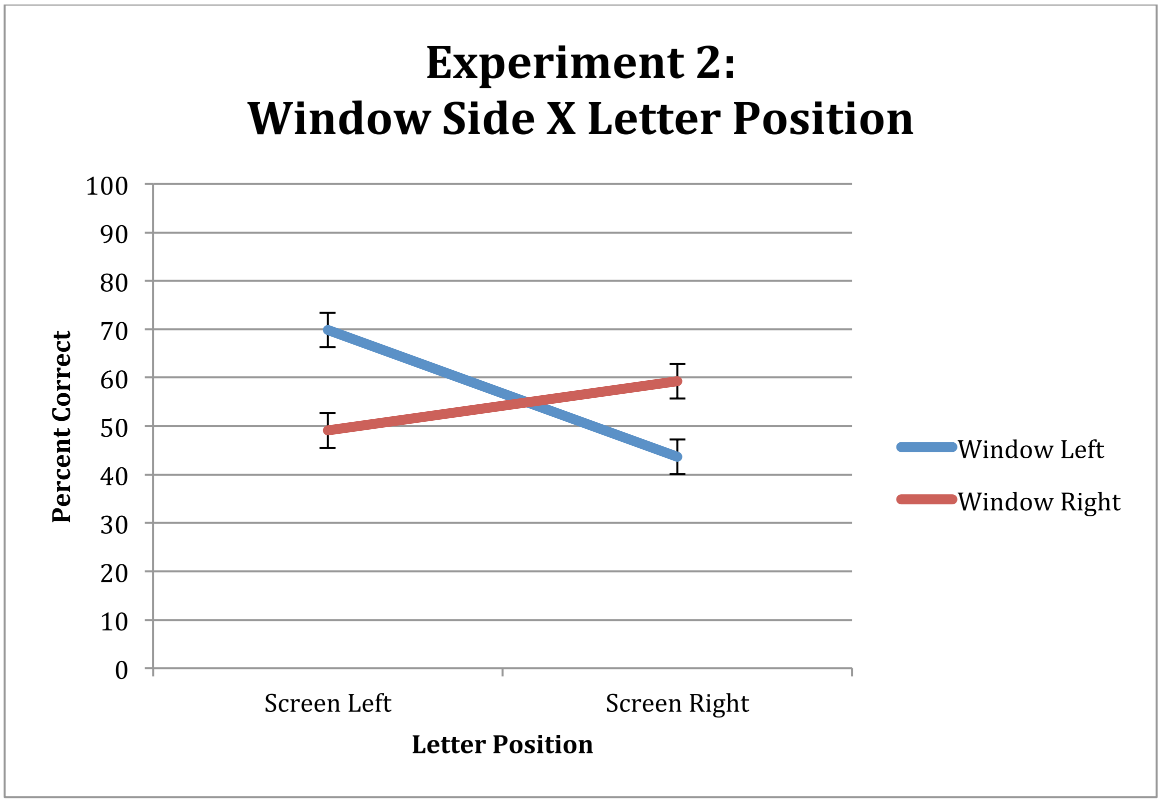

Figure 9. Experiment 2 letter position by attentional window side.

Unlike in Experiment 1, the three-way letter size X narrow window side X letter position interaction for the narrow window trials was not significant [$F(1,55) = 3.86$, $p = 0.055$]. These data are shown in Figure 10 and Figure 11. This could be caused by the shorter processing time eliminating a potential ceiling effect for processing global letters and/or floor effect for processing local letters. Again there was no main effect of window start side for the broad window trials, which was expected [$F(1,55) = 0.46$, $p = 0.499$].

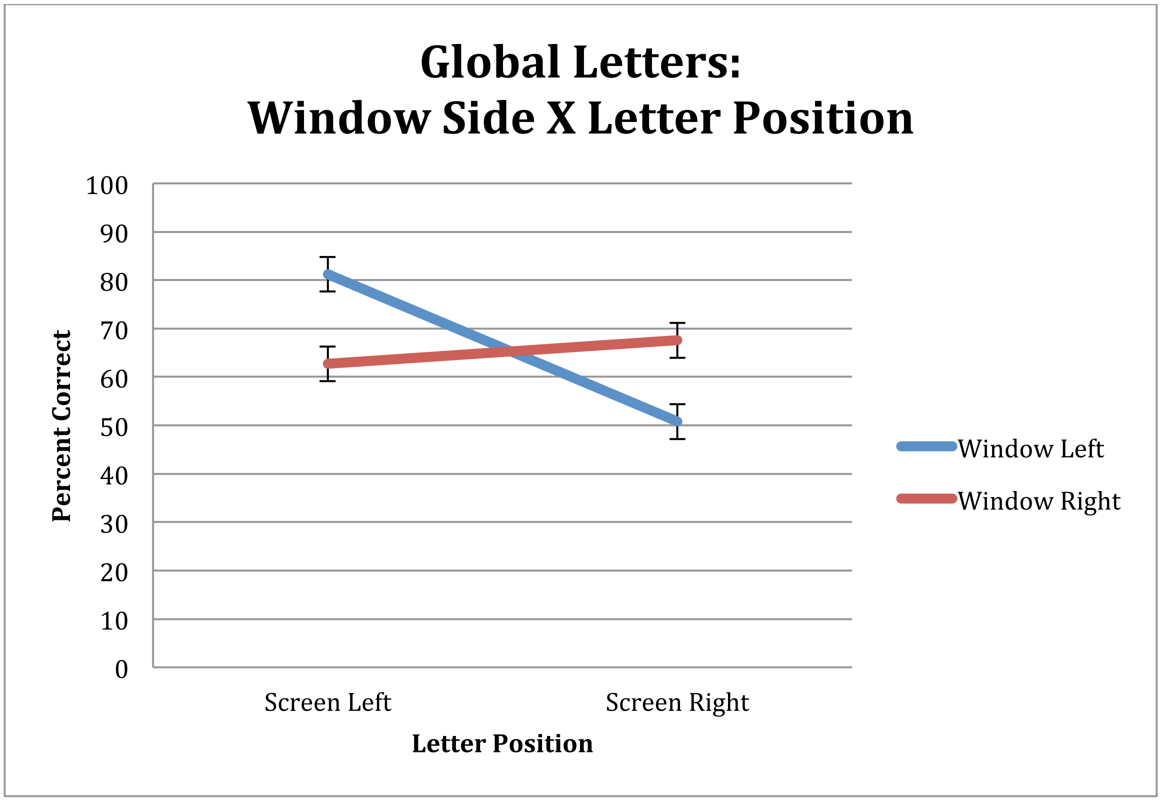

Figure 10. Experiment 2 window side by letter position for global letters.

Experiment 2 subsidiary results

The following interactions were also significant: window size X window side interaction [$F(1,55) = 7.27$, $p = 0.009$]; letter size X window side interaction [$F(1,55) = 4.64$, $p = 0.036$]; window size X letter position interaction [$F(1,55) = 11.93$, $p = 0.001$]; letter size X letter position interaction [$F(1,55) = 17.69$, $p < 0.0001$]; window size X letter size X letter position interaction [$F(1,55) = 4.50$, $p = 0.038$]; window size X window side X letter position interaction [$F(1,55) = 86.67$, $p < 0.0001$]; window size X letter size X window side X letter position interaction [$F(1,55) = 9.00$, $p = 0.004$]. These interactions were not directly related to the proposed hypotheses and were not analyzed further for the current research study.

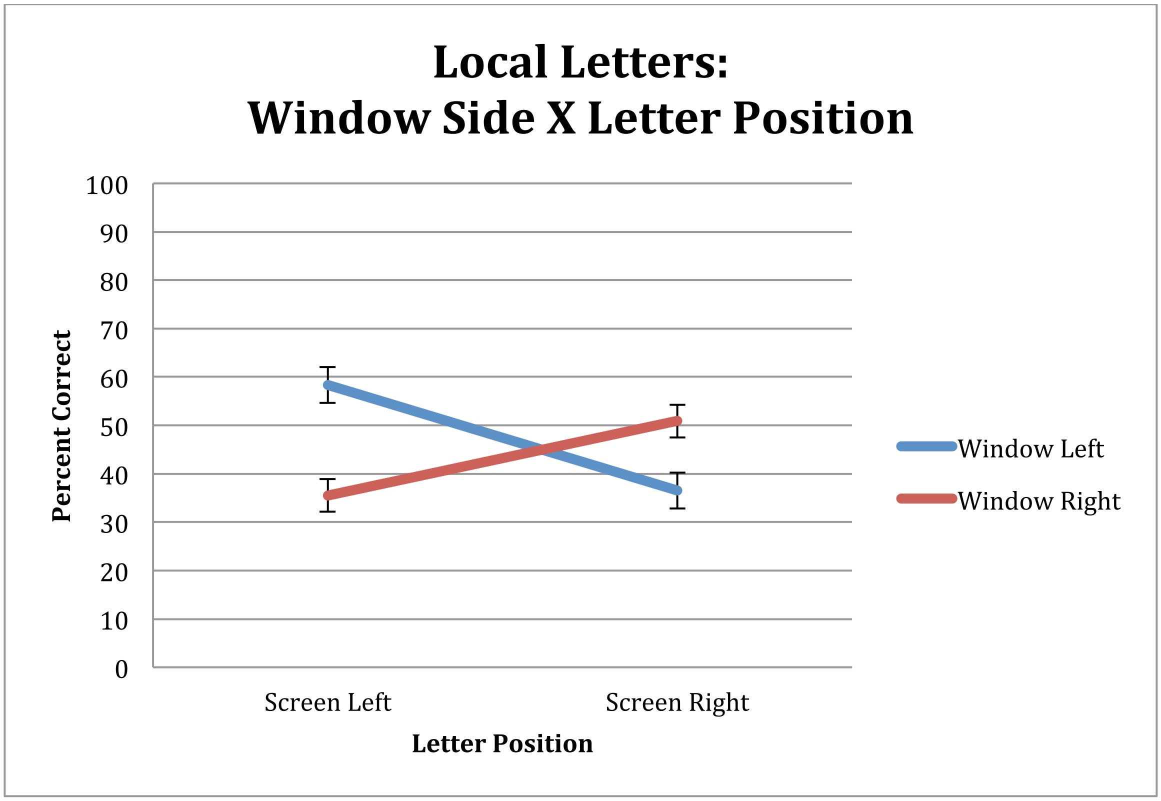

Figure 11. Experiment 2 window side by letter position for local letters.

Experiment 2 Discussion

Window size effectiveness

The results of Experiment 2 did replicate the results of Experiment 1 in relation to the window size effectiveness, providing support for Hypothesis 1 but not for Hypothesis 2. There was again support for Hypothesis 1 with a small effect, but there was a significant interaction of window size by letter size (Figure 8), driven by higher global letter identification accuracy on broad attentional window trials. The attentional window manipulations successfully created processing differences of global letters within hierarchical letters.

Similar to Experiment 1, Experiment 2 did not provide support for Hypothesis 2. There was no significant difference between narrow attentional window trials and broad window trials for accuracy of local letter identification (Figure 8).

The overall accuracy for global letter identification was lowered in the second experiment, which is discussed further in the general discussion section.

Window side effectiveness

The results of Experiment 2 also replicated the results of Experiment 1 in relation to the window side effectiveness, providing support for Hypothesis 3. There was a significant interaction of window side by letter position (Figure 9), with an advantage for identifying letters positioned on the side matching the narrow window side. Narrow attentional windows ending on either the left or right of the screen created an advantage for identifying both global (Figure 10) and local (Figure 11) letters positioned on the left or right side of the screen, respectively.

Global advantage and processing time

After eliminating the ISI between the attentional window manipulation and the hierarchical letters, along with decreasing the hierarchical letter pair presentation time in Experiment 2, the findings related to *window size effectiveness* and *window side effectiveness* were similar to those of Experiment 1. These findings show an advantage for processing global letters. The narrow attentional window manipulation was also found to be effective for differentially influencing the processing of global letters, and was found to be effective at directing attention to either side of the screen to create an advantage for the hierarchical letter on the matching side. Further analyses comparing Experiment 1 and Experiment 2 are detailed below.

Global Advantage and Processing Time Results (Experiments 1 & 2)

In order to compare the global letter processing advantage found across experiments, a mixed model 2 (window size: broad or narrow) X 2 (letter size: global or local) X 2 (window side: left or right) X 2 (letter position: left or right) X 2 (experiment: 1 or 2) ANOVA was conducted with experiment as the between-subjects variable.

There was a significant interaction of letter size X experiment [$F(1,104) = 11.589$, $p < 0.001$]. This interaction was driven by a significant decrease in accuracy for identifying global letters in Experiment 2 (65.6%) compared to Experiment 1 (80.8%) ($p < 0.001$), as seen in Figure 12. There was also an increase in accuracy for identifying local letters in Experiment 2 (45.3%) compared to Experiment 1 (40.4%), though this difference was not significant.

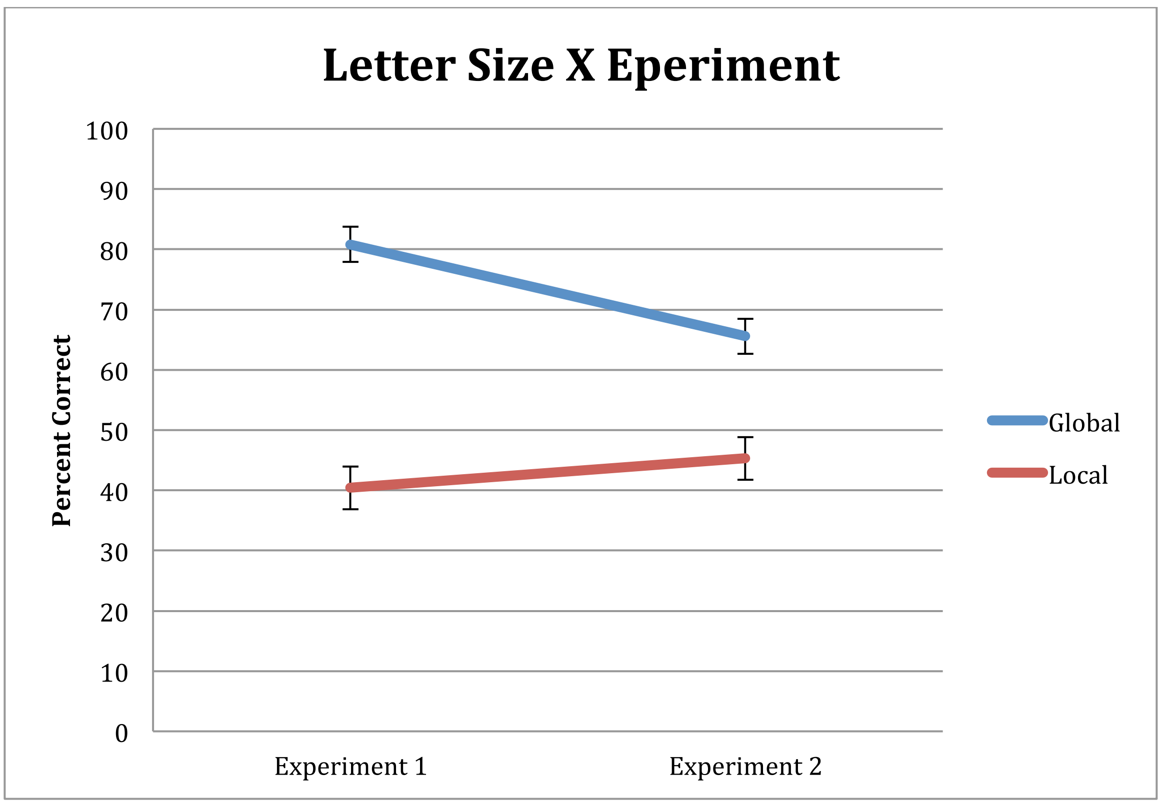

Figure 12. Letter size accuracy by experiment. Experiment 1 (longer processing time) and Experiment 2 (shorter processing time).

The three-way interaction of experiment X window size X letter size was not found to be significant [$F(1,104) = 0.004$, $p = 0.95$]. This indicates the shorter processing time did not significantly decrease the advantage for global letter processing with a broad window and/or did not significantly increase the processing of local letters with a narrow window.

Both experiments showed a consistent advantage for processing global letters (72.8%) compared to local letters (43.0%) ($p < 0.0001$), as seen in Figure 12. There was also an advantage for letters presented on the left side of the screen (61.5%) compared to the right side (54.2%) across experiments ($p < 0.0001$).

GENERAL DISCUSSION

Window Size Effectiveness

The attentional window manipulation was shown to be effective at differentially influencing the processing of global letters. The narrow attentional window manipulation consistently decreased the accuracy of identifying global letters. This narrow attentional window manipulation was designed to narrow the spread of attention to an area that did not include one of the hierarchical letters in the simultaneously presented pair, while including two local letters within the other hierarchical letter.

While this manipulation was successful at creating a difference in processing global letters, it was not successful at creating a difference in processing local letters. Overall, participants identified local letters similarly across attentional window conditions, suggesting there was no advantage for local letters and there was still a preference for the global level. This finding is consistent with previous research that indicates global elements interfere with the processing of local elements within hierarchical stimuli (e.g. Navon, 1977; Kimchi, 1988; Poirel et al., 2008). This global interference prioritizes the processing of global elements over the local elements, creating a preference for the global elements.

Window Side Effectiveness

The narrow attentional window manipulation was shown to be effective at creating an advantage for hierarchical letters on the side on which the narrow window ended. This finding is similar to findings related to spatial cueing in previous research (e.g. Posner et al., 1980). When cued to view information on one side of the screen, participants tend to miss the information that is not close to the cued location.

There was a consistent advantage for identifying global and local letters positioned on the left side of the screen. This finding may be explained by the participants' natural tendency to first process letters (and words) on the left and continue towards the right, as is the case in reading of the English language. This finding may potentially be eliminated with the use of non-letter stimuli, such as shapes or objects.

Global Advantage and Processing Time

The advantage for processing global letters, compared to local letters, was consistent. This supports the Global Precedence Effect found in previous research outlined above. Though when processing time was decreased this global advantage was also decreased (Figure 12), which supports Hypothesis 4. This suggests different processing conditions influence the efficiency of identifying hierarchical letters, at least at the global level.

Shorter processing time also showed a trend of increased accuracy for identifying local letters, though this finding was not significant. This trend could be of interest to investigate in future research. This increase could be associated with participants' inability to readjust their attentional window after hierarchical stimulus onset. With the longer processing time in Experiment 1, participants may have been able to readjust their attentional window to identify letters at both levels more consistently. One possibility is that when participants are processing local letters of the hierarchical stimuli, features of the global letter may provide them with enough partial information about the global letter to identify that global letter without perceiving the whole letter.

Limitations

The findings from these experiments may not be completely comparable to previous studies using hierarchical letter stimuli. The current studies focused on only the accuracy of identifying letters and did not include reaction time as a dependent measure. This difference was due to the instructions to identify both global and local letters at the same time, rather than being instructed to attend to only one level of the hierarchical letters each trial. Participants also reported the letters in an open-ended format with unlimited time. Previous studies often employ a detection task with a target, while all letters presented in the current study were task-relevant. As noted by Dale and Arnell (2013), this global/local task may be measuring different global/local processes than have been measured in past research incorporating different global/local tasks. This is a newly developed global/local task and further testing may be necessary to insure its validity and relation to other global/local tasks.

The open-ended response method also poses a potential limitation. Sperling (1960) showed that participants could report partial information from briefly presented stimuli with higher accuracy, compared to when instructed to report all of the information from the stimuli, due to limited capacity of memory. The amount of information available to the observer to report fades as time goes by and information decays from immediate visual memory. Therefore, information reported immediately after stimulus presentation is often more accurate than the information reported after any delay.

The attentional window manipulation used in the current study may have allowed participants to adopt unintended strategies for identifying letters. Participants may have been able to adopt a large attentional window and still attend to the narrow attentional window manipulation. Though the manipulation check of requiring participants to identify misaligned boxes during the attentional window manipulation was used in attempt to eliminate this possibility. Further testing of this attentional window manipulation may be necessary.

Another potential limitation of the current research was the lack of eye tracking during the tasks. Eye tracking could be implemented to ensure participants are attending to the stimuli and completing the tasks as instructed.

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