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GLOBAL/LOCAL PROCESSING IN INCIDENTAL PERCEPTION OF  
HIERARCHICAL STRUCTURE

by

Mark Mills

A DISSERTATION

Presented to the Faculty of  
The Graduate College at the University of Nebraska  
In Partial Fulfillment of Requirements  
For the Degree of Doctor of Philosophy

Major: Psychology

Under the Supervision of Professor Michael D. Dodd

Lincoln, Nebraska

August, 2016

GLOBAL/LOCAL PROCESSING IN INCIDENTAL PERCEPTION OF  
HIERARCHICAL STRUCTURE

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University of Nebraska, 2016

Advisor: Michael D. Dodd

The goal of the current thesis is to provide a framework for investigating and understanding visual processing of hierarchical structure (i.e., local parts nested in global wholes, such as trees nested in forests) under incidental processing conditions—that is, where processing of information at global and local levels is both uninformative (cannot aid task performance) and task-irrelevant (need not be processed to perform the task). To do so, a novel method combining two widely-used paradigms (spatial cueing and compound stimulus paradigms) is used for implicitly probing observers' perceptual representations over the course of processing. This compound arrow cueing paradigm was used in five experiments to address a series of objectives. First, which level (global or local) is more dominant in the evolution of a percept? Relatedly, is the temporal structuring of global and local processing fixed or flexible? And what is the time course of level-specific advantages—do they occur earlier or later in the course of processing, and do they follow a transient or protracted time course? Finally, what controls level-specific selection (sensory, perceptual, and/or attentional factors)? The results of the five experiments addressing these issues contribute to a greater understanding of visual perception by elucidating the nature of global and local processing under incidental processing conditions.

### **Acknowledgements**

I would like to thank the University of Nebraska for the opportunity, space, and financial resources to pursue my graduate studies, without which this thesis could not have been undertaken. I would also like to thank my lab mates, Gerald McDonnell, Monica Rosen, and Brett Bahle, for their insight and support throughout the development of this thesis. In addition, I would like to thank my brother, Eric Mills, for sage advice when it was critically needed, as well as my parents, Charles Mills, Gerda Mah, Cheryl Goodgine, and Bill Goodgine, for their steady support—I am indebted. I would also like to acknowledge the training and mentorship of Lesa Hoffman, without whom many of my research pursuits would not have been possible. Finally, none of this would have been possible at all without my advisor, Mike Dodd—I am eternally grateful for his guidance, support, and encouragement during the development of this thesis and throughout the course of my PhD studies.

## Table of Contents

<b>List of Tables</b>	<b>vii</b>
<b>List of Figures</b>	<b>viii</b>
<b>Chapter 1 Preface: Thesis Summary and Outline</b>	<b>1</b>
<b>Chapter 1: Overview of Global and Local Processing</b>	<b>8</b>
1.0 Chapter Overview	8
1.1 Challenges to Visual Perception	8
1.2 Global/Local Processing	14
1.3 Limitations of Previous Work	32
1.4 Incidental Processing	34
1.5 Visual Attention	34
<b>Chapter 2: Thesis Objectives, Methods, and Hypotheses</b>	<b>41</b>
2.0 Chapter Overview	41
2.1 Primary Objectives	41
2.2 Compound Arrow Cueing Paradigm	42
2.3 Experiments in Order of Presentation	45
2.4 Analytic Method	57
<b>Chapter 3: Experiment 1—Global/Local Processing in Incidental Perception</b>	<b>61</b>
3.0 Chapter Overview	61
3.1 Introduction	62
3.2 Experiment 1.1	65
3.2.1 Methods	65
3.2.2 Results	67
3.3 Experiment 1.2	69
3.3.1 Methods	70
3.3.2 Results	71
3.4 Interim Summary and Overview of Experiments 1.3 and 1.4	73
3.5 Experiment 1.3	75
3.5.1 Methods	75
3.5.2 Results	76

3.6 Experiment 1.4	80
3.6.1 Methods	80
3.6.2 Results	81
3.7 Discussion	83
<b>Chapter 4: Experiment 2—Capturing Time Sensitive Effects</b>	<b>86</b>
4.0 Chapter Overview	86
4.1 Methods	87
4.2 Results	90
4.3 Discussion	96
<b>Chapter 5: Experiment 3—Role of Top-Down Task Set</b>	<b>98</b>
5.0 Chapter Overview	98
5.1 Introduction	99
5.2 Methods	106
5.3 Results	109
5.4 Discussion	116
<b>Chapter 6: Experiment 4—Role of Bottom-Up Salience</b>	<b>121</b>
6.0 Chapter Overview	121
6.1 Introduction	121
6.2 Methods	122
6.3 Results	123
6.4 Discussion	125
<b>Chapter 7: Experiment 5—Role of Attentional Focusing and Adjustments</b>	<b>127</b>
7.0 Chapter Overview	127
7.1 Methods	130
7.2 Results	132
7.3 Discussion	136
<b>Chapter 8: General Discussion</b>	<b>137</b>
8.0 Chapter Overview	137
8.1 Summary of Experimental Results	137
8.2 Thesis Objectives Revisited	144

8.3 Relation to Current State of Knowledge	145
8.4 Action Addressability Principle	154
8.5 Implications of Current Thesis	158
8.6 Future Directions	160
8.7 Concluding Remarks	161
<b>References</b>	<b>163</b>
<b>Appendix A: Model Parameters for Each Experiment</b>	<b>188</b>

**List of Tables**

Table P.1: Summary of issues addressed in the present experiments	2
Table P.2: Summary of the main research question and finding in each experiment	4
Table 4.1: Sample characteristics for the generated SOA values in Experiment 2	88
Table 4.2: Data structure required to fit the piecewise model in Experiment 2	90
Table 4.3: Piecewise jump and slope model parameters in Experiment 2	92
Table 5.1: Mean RT and error rates for each cue by SOA condition in Experiment 3	110
Table 8.1: Summary of experimental conditions where cueing effects were observed	143



### List of Figures

Figure 1.1: Visual symbols with hierarchical structure	9
Figure 1.2: Navon's (1977) compound stimulus paradigm	15
Figure 1.3: Posner's (1980) spatial cueing paradigm	38
Figure 2.1: Compound arrow cueing paradigm	45
Figure 2.2: Example stimuli and trial sequence by task in Experiment 3	51
Figure 2.3: Example go/no-go stimuli by attention condition in Experiment 5	56
Figure 3.1: Compound arrow cues used in Experiments 1.1 and 1.2	67
Figure 3.2: Mean RT and cueing effects by cue type and SOA in Experiment 1.1	68
Figure 3.3: Mean RT by cue type, validity state, and SOA in Experiment 1.2	72
Figure 3.4: Mean cueing effects by cue type and SOA in Experiment 1.2	73
Figure 3.5: Global-neutral cue and cue-target proximity conditions in Experiment 1.3	75
Figure 3.6: Mean cueing effects by cue type and SOA in Experiment 1.3	77
Figure 3.7: Mean cueing effects in Experiment 1.3	79
Figure 3.8: Few-element compound arrow cue stimuli in Experiment 1.4	81
Figure 3.9: Mean cueing effects by cue type and SOA in Experiment 1.4	81
Figure 4.1: Mean cueing effects at 250, 500, and 750 ms SOAs in Experiment 2	91
Figure 4.2: Mean RT for consistent and inconsistent cues in Experiment 2	94
Figure 4.3: Mean RT for local- and global-neutral cues in Experiment 2	96
Figure 5.1: Mean task effect on accuracy in the secondary task in Experiment 3	111
Figure 5.2: Mean cueing effects in Experiment 3	113
Figure 6.1: Mean cueing effects by cue type and SOA in Experiment 4	125
Figure 7.1: Mean cueing effects in Experiment 5	133
Figure 7.2: Mean attention effect by cue type and SOA in Experiment 5	134
Figure 7.3: Mean cueing effects by N-1 cue in Experiment 5	135

## CHAPTER 1 PREFACE: THESIS SUMMARY AND OUTLINE

Visual environments (scenes, objects, faces) can be conceptualized as containing global and local information, where global information corresponds to overall form and local information to finer-grain detail. An important question concerns how information across levels contributes to scene understanding. To investigate this, a common approach is to present observers with compound stimuli (i.e., stimuli containing hierarchical structure such as larger figures constructed of smaller figures) and measure responses to a target presented at either the global or local level. The preponderant findings are global advantage (speeded responses to targets presented at the global versus local level) and global interference (greater difficulty ignoring global versus local distractors). On the basis of these findings, Navon (1977) proposed a perceptual global precedence hypothesis which states that identification of global aspects is a faster and obligatory process completed before identification of local aspects, which is a slower and optional process. As a result, global aspects are dominant in the percept (giving rise to global advantage) and their availability for selection is constant (together giving rise to global interference). Subsequent work has corroborated the empirical findings of global advantage and interference but ultimately rejected Navon's claim that the nature of these effects is obligatory and their source perceptual.

The current thesis reviews issues in global/local research (summarized in Table P.1), highlights some limitations of how previous work has addressed these issues, and then reports a series of experiments aimed at circumventing these limitations. It is argued that rejection of perceptual global precedence is premature—namely, because in all

previous studies observers have been required to process the imperative compound stimulus in a task- or stimulus-driven manner. Accordingly, the most important aspect of the current experiments is that visual processing of global and local levels was measured under incidental processing conditions—that is, where processing of global and local levels is uninformative (does not aid task performance) and task-irrelevant (need not be processed to perform the task). In these experiments, participants made simple detection responses to a peripheral target that was preceded by a centrally presented compound stimulus (big, global arrow composed of smaller, local arrows). Critically, the compound stimulus was irrelevant to the detection task (i.e., it did not need to be processed in order to respond to the peripheral target) and also spatially uninformative (i.e., the direction of global and local arrows did not predict target location). Thus, processing of the compound arrow was not necessary to perform the task and could not be used for making reliable inferences regarding the location of the target, meaning any evidence that it was processed can be taken as incidental.

Table P.1. Summary of the main issues in global/local research addressed in the current experiments.

<u>Main Issues Addressed in the Current Experiments</u>
Issue #1: Temporal organization in the percept (global-to-local or local-to-global)?
Issue #2: Temporal availability in percept (stationary or variable)?
Issue #3: Nature of global/local precedence effects (obligatory or voluntary)?
Issue #4: Source of global/local precedence effects (perceptual or attentional)?

Experiment 1 was a multi-experiment study that examined global and local processing under incidental processing conditions. The critical manipulation was processing duration (operationalized as stimulus-onset-asynchrony; SOA). The rationale

was that the priming potency of a level (i.e., global or local) should vary with SOA in correspondence with how early that level was processed (Kimchi, 1998; Navon, 1991). Accordingly, the finding of a level-specific spatial cueing effect would reflect a processing advantage for that level, and a non-significant interaction with SOA would reflect a stationary advantage of that level over the course of processing. Experiment 2 replicated Experiment 1 using a more widely-tuned and finer-grained manipulation of processing duration in order to characterize precisely the functional form of change in level-specific advantage over time. The finding of significant “jumps” in the size of level-specific advantage in the course of processing would reflect discrete change in the availability of that percept, whereas non-significant “jumps” and smooth or no change would reflect gradual change in the availability of that percept. Experiments 3-5 modified the compound arrow cueing paradigm in order to examine control of level-specific selection in perception of hierarchical structure. To examine the role of attention in level selectivity, Experiment 3 manipulated the task-relevance of a level via task instructions that called for processing of either a global or local aspect of a compound arrow. The finding of a task-compatible, level-specific advantage (i.e., a local advantage in the local orienting task and a global advantage in the global orienting task) that was independent of processing duration would reflect an influence of top-down attentional control. Experiment 4 examined the role of bottom-up salience in level selectivity. To do so, the local level was modified to include a color singleton. The finding of a larger and more rapidly arising local advantage with cues containing a local color singleton compared with those that are homogeneously colored would reflect a bottom-up attentional source of

level-specific advantage. Finally, Experiment 5 examined the role of attentional focusing and adjustments in level selectivity. To do so, the compound arrow cueing paradigm was modified to include a go/no-go component, which served as a manipulation of attentional focus. The finding of a window-compatible, level-specific advantage regardless of processing duration may suggest an alternative account of global/local processing phenomena, one predicated on the focusing an attentional window rather than availability in the percept.

Table P.2. Summary of the primary research question in each experiment and the main finding addressing it.

Exp.	Primary Question Addressed	Main Finding
1.1-1.4	Is global precedence observed in incidental perception of hierarchical structure?	Global-to-local shift in advantage over time.
2	Does change in availability of global/local features proceed gradually, or discretely?	Gradual, as opposed to discrete, shift in advantage in over time.
3	Does top-down task set control level selectivity? In particular, will a global orienting task cause global precedence and a local orienting local precedence?	Task-compatible, level-specific advantage with conflict cues; global advantage with task-incompatible, level-specific neutral cues.
4	Does bottom-up salience control level selectivity?	Local salience reduces, but does not reverse, global advantage.
5	Do top-down and bottom-up factors interact to control level selectivity--e.g., if advantage depends on salience, is such bottom-up influence contingent on the focal scope of attention (focused or diffuse)?	Focal scope of attention modulates global advantage, though, not independent of physical salience.

The main finding in each of the five experiments, and the research question it addressed, are summarized in Table P.2. The emerging picture is that something like global precedence guides perceptual microgenesis (i.e., the time course of development in the percept) in incidental perception of hierarchical structure: processing of the global level was obligatory, whereas processing of the local level was somewhat optional. In short, the experiments show that interactions between task demands and the structure of the input information selectively modulate the relative needs of visual information at different levels of stimulus structure. It seemed that a global-to-local shift in advantage was obligatory when there was conflict between levels and processing was incidental, as well as that processing could be restricted to a task-relevant global level but not to a task-relevant local level. These findings suggest that level-specific advantages may not have been due to top-down task set per se but rather to conflict between levels, with the effect of task set serving to modulate the availability of level-specific information, effectively prolonging (in the case of task-relevant global information) or expediting (in the case of task-relevant local information) the advantage at a given level. To select symbols at different levels of structure, therefore, the current thesis concludes that at least two factors need to be considered: the observer's current task, which specifies the demands of visual information from the input, and the globality of this visual information across the percept, which specifies the availability of the percept for selection.

In sum, a novel compound arrow cueing paradigm was used in five experiments to examine fundamental issues of broad theoretical interest (entry point of visual perception and its flexibility; selection of competing symbols at different levels of

stimulus structure). The results of these experiments contribute to a greater understanding of visual perception by elucidating the nature of global/local processing under incidental processing conditions, which closely reflect the manner in which a great deal of information is processed in the real world. Though attention, perception, and action can be strongly influenced by goals and intentions, processing of stimuli routinely occurs in a passive manner given the overwhelming number of inputs available at any given time. As such, the results reported have broad implications for the study of attentional control in general and perception of hierarchical structure in particular.

### **Thesis Outline**

Chapter 1 (Overview of Global and Local Processing) reviews fundamental issues in the study of visual perception and how contemporary theories have addressed these issues. Chapter 2 (Thesis Objectives, Methods, and Hypotheses) describes the primary objectives of the current thesis, the methods used to achieve these objectives, and the hypotheses underlying each experiment. Chapters 3-7 are empirical chapters, with chapters 3-4 reporting experiments that investigate global/local processing in incidental perception, and chapters 5-7 reporting experiments that investigate control of level-specific selection. Chapter 3 (Experiments 1.1 through 1.4: Global and Local Processing in Incidental Perception) introduces the compound arrow cueing paradigm and incidental viewing procedure designed to investigate the role of globality (i.e., an item's relative position—more global or local—in hierarchical space) in perception of hierarchical structure under incidental processing conditions. Chapter 4 (Experiment 2: Capturing Time Sensitive Effects) investigates the time course of the availability of global and local

information in the microgenesis of the percept. Chapter 5 (Experiment 3: Role of Top-Down Task Set) investigates top-down mechanisms of level selection. Chapter 6 (Experiment 4: Role of Bottom-Up Saliency) investigates bottom-up mechanisms of level selection. Chapter 7 (Experiment 5: Role of Attentional Focusing and Adjustments) investigates hybrid mechanisms of level selection. Finally, Chapter 8 (General Discussion) summarizes and discusses the experiments reported in the preceding chapters, as well as identifies current issues in the study of global/local processing and makes recommendations for future research.



## **CHAPTER 1: OVERVIEW OF GLOBAL AND LOCAL PROCESSING**

### **1.0 Chapter Overview**

Chapter 1 provides an overview of fundamental issues in global/local research (focusing primarily on the visual domain), highlights a number of limitations in how previous work has addressed these issues, and concludes with a discussion of how the experiments reported in the current thesis circumvent these limitations. To introduce the concepts involved in the issues at hand, Chapter 1 begins with an example illustrating some of these.

### **1.1 Challenges to Visual Perception**

#### **1.1.1 An Illustrative Example**

Figure 1.1 shows two common visual symbols with hierarchical structure, a STOP sign and an EXIT sign. An important question is how does the visual system know that the word (“STOP” or “EXIT”) and form (octagon or rectangle) should be paired to represent a STOP sign and an EXIT sign, respectively? In cases of a busy intersection, a red sign with big, bold, white block letters is critical to driver safety. Similarly, in cases of a fire, a red sign with big, bold, white block letters will guide one to safety. Of course, the effect of these two symbols on behavior are polar opposite, with the latter activating a behavior (to move toward the exit) and the former suppressing a behavior (to stop moving toward the intersection). Thus, with the exception of form, a “STOP” sign is perceptually equivalent to an “EXIT” sign, yet cues an opposing behavior (to ‘stop’ rather than to ‘go’). Moreover, the cueing properties of each are also similar, as each sign likely has relatively automatic or effortless effects on behavior. How, then, does the same

basic symbol elicit two opposing, automatic responses? What are the control processes involved and how is this flexibility in behavior achieved? The current thesis aims to understand the control processes involved in coordinating the time course of visual processing in support of flexible, goal-directed behavior.

Continuing with the example in Figure 1.1, it is proposed that the binding of word and form occurs because each is trying to communicate a single, coherent message (to STOP or to EXIT)—that is, they group by common function (i.e., communication of symbolic value). In this view, then, the reason STOP and EXIT signs cue rapid and effortless, but opposing, responses in spite of reasonably equivalent perceptual features is because their messages differ, meaning that the function on which their respective constituents group differs, which in turn leads to a different percept and a different response. That is, as different functions or tasks are likely to tap different stages of processing or to evoke different optional strategies available to the processing system, this leads to different percepts and thus different responses.

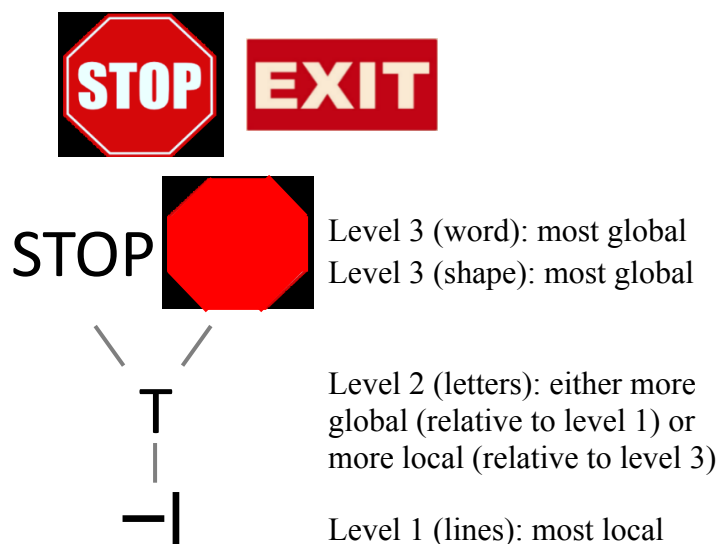


Figure 1.1. Visual symbols with hierarchical structure (STOP and EXIT signs), in which lines are nested within letters, which in turn are nested within a word and a form and where word and form are crossed at the highest level of globality (i.e., relative position in hierarchical space) given that each line-letter combination appeared with both word and form in a given sign.

### **1.1.2 Selection Problem in Perception and Action**

A control process is any process that helps to overcome rigid responding. Cognitive control processes are particularly required in situations of task uncertainty, in which no cue is given for the selection of the relevant action, or in situations that produce problems in selecting which action or task to perform at any given moment. Many common behaviors and visual scenes constitute such situations (Monsell, 2003). This is because everyday visual environments contain more information than can be processed within a glance, which can be appreciated by considering that humans make 3-4 eye movements each second (Henderson, 2003; Henderson & Hollingworth, 1998) or several billion ( $10^9$ ) over the lifespan. Despite this seemingly impressive rate of orienting, real-world visual environments are often too complex to allow for visually guided behavior. Even under the obtuse assumption that eye movements are random, at this sampling rate, localizing a target in scene with only 24 distractor locations would take 3-4 seconds. Humans and other animals, therefore, have to cope with an enormous amount of perceptual data.

Similarly, everyday visual environments also continuously bombard humans and other animals with various opportunities for action. Some stimuli automatically elicit the

same behavioral response from an observer each time that particular stimulus is encountered (e.g., visual transients cause reflexive oculomotor orienting), whereas other stimuli afford a variety of alternative responses depending on situational constraints, learned associations, and the goals of the observer (e.g., when standing in front of a sink there are numerous behaviors that could be activated such as washing one's hands, brushing one's teeth, washing dishes, getting a drink of water, or fixing one's hair amongst a multitude of other options). Because one cannot perform all possible actions at the same time, there must be mechanisms to reduce the number of potential actions. To overcome the computational limitations imposed by the environment and enable efficient, flexible behavior amenable to the current goals of the observer, goal-driven perception and action depend on selective attention for allocating limited resources towards a subset of relevant items—that is, effective and efficient goal-directed behavior depends on a combination of processes that suppress irrelevant responses from interfering with one's goals and that select and initiate responses relevant to the completion of that goal (collectively regarded as executive control processes). But what gets selected, a whole scene or just certain parts? And how is efficient selection achieved? The current thesis aims to understand the factors that control orienting and enable efficient selectivity in sampling behavior.

**Approaches to selectivity.** One way to deal with this selection problem is through extensive filtering, which should minimize the use of resources and processing effort, as both of these are limited. Another approach to the selection problem is to make the scene virtually larger—by zooming out the focus of attention—so that the information

can be held in low-cost storage. Yet another approach is to offload work with automated visual routines (e.g., obligatory grouping and parsing processes involved in perceptual organization), which aid object constancy and thereby effectively shift cognitive processing load to the perceptual system. Each of these approaches to the selection problem is intended to decrease the costs for performing information-intensive tasks (resource accounts), or, alternatively, to increase the scope of the information that can be utilized for the same cost (adaptation accounts). The current thesis describes these approaches in greater detail below and then reports a series of empirical studies addressing these possibilities.

### **1.1.3 Hierarchical Structure**

An important property of real-world objects is that they tend to be structured hierarchically. The human body, for example, is composed of a number of parts that cannot exist independently. A hand, for instance, cannot exist without an arm, which cannot exist without a torso, and so on. Accordingly, visual scenes (scenes, objects, faces) are generally conceptualized as containing global and local information, where global information corresponds to overall form and local information to finer-grain detail (Neisser, 1967). Hierarchical levels of structure (fingers within hands within arms within person), therefore, may be ordered from global (body) to local (fingers), where more global levels contain or encompass local constituents. Such structure poses a challenge to the visual system because the identity of an item with hierarchical structure is potentially ambiguous in that its interpretation depends on which level of globality (i.e., the relative position of an item in hierarchical space) is dominant. For example, a herd of sheep

arranged in a circular pattern is a potentially ambiguous stimulus: given strict interpretation of the global level, it would be interpreted as a plain circle; given strict interpretation of a more local level, it would be interpreted as a herd of sheep. Visual perception, therefore, requires the coordinated processing of objects on both global and local levels. During global processing local elements are grouped into perceptual wholes (Koffka, 1935; Kohler, 1947; Wertheimer, 1955), whereas during local processing scene elements are analyzed as individual objects (Titchener, 1909; see also Han, Weaver, Murray, Kang, Yund, & Woods, 2002).

The visual world is cluttered and complex, typically containing a multitude of objects that can appear in an infinitude of orientations, sizes, shapes, colors, and so on and which are often degraded by atmospheric conditions and occluded by other objects. Despite such vagaries of sensory experience, the phenomenological experience of perception is one of instantaneous completeness and coherence imbued with meaning. How is this meaning apprehended? A challenge to understanding the temporal dynamics of visual perception is that even when the physical properties of a stimulus are constant over time, one's perception of that stimulus may still change as a function of processing duration. For instance, a brief glimpse of an unfamiliar object or scene may be sufficient to categorize it at a basic level (e.g., table or indoor room), but to perceive the table as a 'coffee table' or the indoor room as a 'kitchen' tends to require additional processing time (Potter, 1975, 1976). Captured in this example is the notion that there is a temporal order to visual processing, wherein the skeletal-structure of a stimulus tends to be processed more rapidly than finer grain details. That is, visual processing is held to

progress in global-to-local fashion (Navon, 1977). In terms of metaphor, the one most commonly applied in describing the typical course of visual processing is “perception of the forest before the trees”. Whether or not the speeded processing of global properties has meaningful consequences for cognitive and behavioral activity is still under investigation (see Hegdé, 2008; Kimchi, 1992, 2003a,b, 2012, 2014; Navon, 2003; Morrison & Schyns, 2001; for reviews). Can people actually use global information to classify and act on objects and scenes? Or is this information processed simply to constrain local processing?

## **1.2 Global and Local Processing**

### **1.2.1 Compound Stimulus Paradigm**

To investigate how the availability and use of information at different levels of hierarchical structure contributes to scene understanding, researchers have made extensive use of compound stimuli (i.e., stimuli containing hierarchical structure such as larger figures constructed of smaller figures), introduced first by Asch (1962) and later by Kinchla (1974, 1977), and popularized by Navon (1977). In Navon’s compound stimulus paradigm (Figure 1.2), observers are presented with a compound letter (e.g., a large, global F constructed from smaller, local Fs) and instructed to respond to either the larger (global) or the smaller (local) letter in separate blocks of trials.<sup>1</sup> Importantly, the relation

---

<sup>1</sup> There are actually two versions of Navon’s (1977) compound letter paradigm, which differ in terms of whether attention is directed to a particular level via task instructions or stimulus manipulations that directly call for the selection of one level while ignoring the other or is divided between levels. As the directed attention version is the more widely used one, it is this version to which the current proposal refers where discussed, unless otherwise noted.

between levels is either consistent (global F, local Fs) or inconsistent (global F, local Hs). The preponderant finding is that the global letter is responded to faster (global advantage) and is more difficult to ignore (global interference). The allure of the paradigm, apart from its elegant simplicity, is that it serves to equate the complexity, identifiability, familiarity, codability, and relative diagnosticity of the levels, such that they differ only in level of globality (i.e., relative position in hierarchical space). Additionally, the two structures can be independent such that one cannot necessarily be predicted from the other. Compound letters, therefore, satisfy two conditions considered by Navon (1977, 1981, 2003) to be critical for testing the global precedence hypothesis.

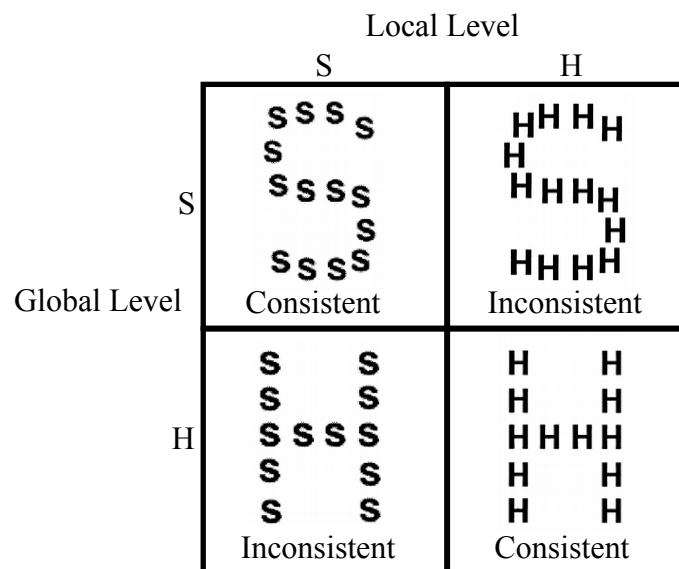


Figure 1.2. Example hierarchical stimuli in Navon's (1977) compound stimulus paradigm, in which a compound letter is presented (e.g., large, global F constructed from small, local Hs) and observers are instructed to identify the letter at either the global or local level in separate blocks of trials. Importantly, the relation between levels is either consistent (global F, local Fs) or inconsistent (global F, local Hs).

### 1.2.2 Global Precedence



Navon's global precedence hypothesis (1977) is concerned with the temporal organization of perceptual processes in the course of identifying an attended object. Global precedence refers to a priority in perceptual processing for the more global features of a form or object, suggesting that perceptual processing is temporally organized and proceeds from analysis of global structure towards analysis of more local details. More specifically, it states that the perceptual system is predisposed to process "clusters", with this disposition setting the stage for dominance of global compared with local information in the evolution of the percept. Thus, Navon's hypothesis is one about a processing disposition, with the essence of global perceptual precedence being the inevitability of global processing. According to Navon (1977), global precedence occurs because identification of global information occurs first and constitutes an obligatory stage of perceptual processing. In other words, global processing is viewed as an obligatory process that is complete upon identification of global information, at which point processing of more local information that has become available is optional.

**Functional Advantages.** A disposition to process clusters of information (i.e., global precedence) may have some functional advantages. First, an initial, crude, global analysis may be useful for locating local stimuli or stimulus features and for perceptual organization (Marr, 1982; Neisser, 1967). Second, the processing of global structure may be more informative regarding the processing of individual elements than vice versa. The global structure of stimuli tends to be more unique than local features. For any given pair of a global feature and a local one (e.g., global octagon shape and local white letters of the STOP sign in Figure 1.1), the number of stimuli that have that global feature ( $N = 1$ )

is probably smaller, on average, than the number of stimuli that have that local feature ( $N = 4$ ). An idea about general structure, therefore, may be more suggestive of the identity of the stimulus than a few isolated details. Having such an idea may be valuable when only partial analysis is possible because of rapid changes in input (e.g., pedestrians occluding one or more letters of the whole word on the STOP sign), or when task demands call for rapid scanning of stimuli (e.g., approaching a busy intersection). Considering that perception may be an interplay of input-driven and concept-driven processes (Broadbent, 1977; McClelland, & Rumelhart, 1981; Norman & Bobrow, 1976; Palmer, 1975), global precedence can help in setting off concept-driven processes by quickly narrowing down the range of possible identities of the whole stimulus. Finally, for the same reason, global features may be more efficient in priming local features than local features are in priming global features (Navon, 1991). Thus, global precedence seems desirable.

**Empirical Support.** Within the compound stimulus paradigm, support for Navon's (1977) perceptual global precedence account is based on the joint occurrence of two effects: speeded responses to global versus local targets (global advantage) and a greater difficulty ignoring irrelevant global versus local distractors (global interference). That global information interferes with local responses but not vice versa can be seen as evidence that information at the global level is present at the time of the local response but not the reverse. Moreover, the global response time advantage together with global interference can be seen as evidence reflecting a global-to-local order of processing. On the basis of these findings, Navon (1977) proposed that global precedence occurs because

identification of global aspects is a fast, obligatory process completed before identification of local aspects, which is a slower and optional process.

**Summary.** To summarize, global precedence (Navon, 1977) is a hypothesis concerned with the temporal organization of perceptual processes in the course of identifying an attended object, stating that the perceptual system is predisposed to process global compared with local information. It provides a theoretical explanation of global advantage and global interference findings whereby the availability of global information occurs early in the course of visual processing and does not attenuate over time. In turn, earlier registration of global features yields a processing priority for global information and, therefore, accounts for global advantage, whereas stationary availability of global information over time results in global information being available even when local information is the focus of processing and, therefore, accounts for global interference.

### 1.2.3 Theory

An unresolved issue in understanding the temporal dynamics of visual perception is the question of how perceptual processing is temporally organized. Are global configurations such as the roundness of a human face processed prior to local elements such as the eyes and mouth (global-to-local), or are local elements processed prior to the global configuration (local-to-global)? Or, are elements at each level processed independently? A related question is the nature of this order (fixed or flexible)? A common view throughout much of the temporal visual processing literature is that, although global and local levels may both contribute to scene understanding, processing of global structure tends to precede processing of local structure (see Hegdé, 2008, for a

review). The relevant points on which subsequent explanations of this phenomenon differ concern a) whether or not the order in which global and local information is acquired relates to scene understanding, b) whether or not dependencies exist between levels, such that processing at one level depends on the outcome of processing at another level, and c) whether the source of the phenomenon resides in perception or attention.

**Perceptual Accounts.** Perceptual accounts (Andres & Fernandes, 2006; Han, Fan, Chen, & Zhuo, 1997; Han & Humphreys, 1999; Kimchi, 1998; Koivisto & Revonsuo, 2004; Miller & Navon, 2002; Navon, 1977, 1991, 2003; Paquet, 1999; Paquet & Merikle, 1988; Sanocki, 2001) suggest that processes involved in property extraction and detection operate global-to-local. Perceptual accounts of global/local phenomena attribute findings of advantage and interference to availability of percept (i.e., the global level is registered earlier or processed faster than the local level). According to perceptual accounts, global precedence is due to earlier identification of global features than local features, which is possible because global information is available earlier than local information.

**Attentional Accounts.** Attentional accounts suggest that decision and response selection processes operate global-to-local (Boer & Keuss, 1982; Hübner, 2014; Hübner & Volberg, 2005, 2007; Miller, 1981a,b; Ward, 1982). According to attentional accounts, information about both levels is available at the same time, but it is simply easier to attend to and base decisions on information from the global level. Attentional accounts of global/local phenomena attribute advantage and interference not to availability in the percept but to executive functions. A number of accounts have been proposed for how

information at the global- or local-level of a hierarchically structured stimulus is prioritized for selection. An early account was based on the zoom-lens analogy of attention. This regional selection account proposes that the size of the attentional window determines selection of global or local information. Such an account might assume that the spotlight is initially set to encompass the global shape of the stimulus and then to gradually shrink until it encloses only a single local item. Accordingly, this account would predict that selectivity improves continuously as the size of the attentional window narrows. This account is somewhat paradoxical, though. In particular, if the most important information processing operations require a fine-grained attentional “spotlight” in order to unfold efficiently, then why should the spotlight narrow or zoom at all? The current thesis argues that the answer is because important operations do in fact take place at more coarse resolutions. A finer resolution simply allows operations to continue and for higher level processing (i.e., operations to be performed on operations).

At least three mechanisms could affect the efficiency of level selection (and/or processing) in a global/local identification task (Hübner, 2000). First, attentional resources could be voluntarily allocated to a given level. That such control is possible is demonstrated by negative effects of invalid cues, whereby cues directing attention to a non-target level produce costs (Robertson, Lamb, & Zaidel, 1993). Second, sensory factors (e.g., physical salience) could push attention involuntarily to a given level, as demonstrated by the finding of a global advantage even when the local level is validly cued (Stoffer, 1993, 1994). Third, proactive exogenous factors, which affect subsequent selection efficiency and which resist voluntary control, could prime a given level and

thereby enhance its likelihood of being selected. This sort of control is supported by findings demonstrating that the availability of valid cues does not prevent level repetition effects. Finally, the work of Lamb et al. (e.g., Lamb, Pond, & Zahir, 2000; Lamb, London, Pond, & Whitt, 1998) suggests that the efficiency of identifying targets at different levels of structure is determined by the combined effects of voluntary and involuntary control processes.

#### **1.2.4 Research**

Much of the research following Navon's (1977) seminal work has been focused on the localization of visual awareness (namely, whether global configurations can be used in the classification of a stimulus), delineating boundary conditions of the global advantage, examining its source and its localization in the brain. The following sections review these issues.

**1.2.4.1 Temporal Availability in the Percept.** A crucial assumption of Navon's (1977) global precedence hypothesis is that the availability of the global level is constant and does not attenuate over time (stationary assumption). A stationary account of global precedence suggests that global advantage is observed and is constant across time because not only is global information registered earlier or faster (which accounts for the global advantage) but because its availability does not change, not even when local information is being processed (which accounts for the obligatory nature of global advantage and the global-to-local interference pattern in compound stimulus paradigms). Testing this assumption, however, requires a paradigm that can measure the relative availability of global and local features at some point in the course of processing

following the onset of the stimulus, which necessarily relegates compound stimulus paradigms that measure precedence in terms of Stroop-like interference (e.g., Figure 1.2) unusable.

To test the stationary assumption, Navon (1991) manipulated processing duration, operationalized as stimulus-onset-asynchrony (SOA), within an auditory-visual interaction paradigm (cf. Navon, 1977, Experiment 2). Participants responded to an auditory letter stimulus while freely viewing a compound letter in preparation for a memory test to be delivered at the end of the experiment—it was suggested that this constituted “minimal, or close to minimal, instructions that just call for looking without any specific assignment or focus and without even describing the nature of the stimulus” (Navon, 1991, pp. 175). The auditory stimulus was either globally consistent with the visual letter (the auditory stimulus and the global level of the visual stimulus contained the same letter), globally inconsistent with the visual letter (the auditory stimulus and the global level of the visual stimulus contained different letters), or globally neutral (the global level of the visual stimulus contained a rectangle, not a letter). Local consistency was defined in the same way but with reference to the local rather than global level. The test of precedence was whether the global or local level of the visual stimulus would interfere with the response to the auditory stimulus. It was found that only the global level interfered. The test of the stationary assumption was whether this global consistency by local consistency interaction varied as a function of SOA (i.e., the time interval between the onsets of the visual and auditory stimuli). The SOAs used were 0, 50, 100, 150, 200, and 250 ms. In five out of six experiments, Navon reported non-significant

interactions of global advantage and SOA, which was taken to support the stationary assumption and suggests that the availability of global features does not vary with processing duration.

Three points should be noted, however. First, exposure duration was also manipulated, and it is not entirely clear how this should interact with the SOA by global- and local-consistency effect. Second, the lack of an SOA effect does not necessarily imply that global properties are available throughout processing because performance can be based on later rather than earlier representations, particularly in discrimination and classification tasks (Kimchi, 2014). Finally, although the instruction to ‘freely view a stimulus in preparation for a later test’ might seem innocuous, it has since been demonstrated that this is not the case. For example, eye movements in a free-view task exhibit different spatial and temporal characteristics with different time course profiles than eye movements in scene search, memorization, and evaluation tasks (Mills, Hollingworth, Van der Stigchel, Hoffman, & Dodd, 2011). It is not at all clear, therefore, whether the lack of interaction between global advantage and SOA is even meaningful, let alone indicative of a stable global advantage.

Subsequent work suggests that the stationary assumption may be too strong. In particular, there is evidence that the availability of different levels of structure indeed change over time. Kimchi (1998) examined the microgenesis of the perceptual organization of hierarchical stimuli (i.e., the time course of the development of the percept) using a variant of Beller’s (1971) primed matching paradigm. Observers were presented with a prime (either a few- or many-element hierarchical pattern) followed by a



pair of test figures to be matched for identity. In the element-similarity test pair condition, the test figures were similar to the prime in their elements but different in their global configuration. In the configuration similarity test pair condition, the test figures were similar to the prime in their global configuration but different in their elements. By varying the duration of the prime and constructing test figures that were similar to different aspects of the prime, this paradigm allowed changes in observers' implicit perceptual representations over time to be measured. With few-element patterns, elements were primed at brief exposures whereas the configuration was primed at longer exposures. In contrast, with many-element patterns, the configuration was primed at brief exposures whereas elements were primed at longer exposures. Thus, the results of the microgenetic analysis show that the relative dominance of the global configuration and the local elements varies during the evolution of the percept, presumably as a result of grouping and individuation processes that operate in early perceptual processing (Kimchi, 1998).

Compatible findings have been observed using hybrid images (i.e., stimuli in which low-spatial frequency components of one picture are superimposed on the high-spatial frequency components of a different picture). Using such stimuli, Schyns and Oliva (1994) showed that with short viewing durations the low-spatial frequency picture is perceived whereas with longer viewing durations the high-spatial frequency picture is perceived. It is interesting that changes in the availability of global features have been detected when the compound stimulus contained response-related elements (Kimchi, 1998; Schyns & Oliva, 1994) but not when it did not (Navon, 1991). This suggests that

global and local processing may differ as a function of the locus of response-related elements.

**1.2.4.2 Source of Global Precedence.** Whether the source of global precedence resides in perception or attention is a matter of intense debate (Kimchi, 1992, 2014; Miller, 1981a,b; Navon, 1981, 2003). Two broad classes of mechanisms of level selection can be discriminated on the basis of how the issue of source is handled. Perceptual accounts (Andres & Fernandes, 2006; Broadbent, 1977; Han et al., 1997; Han & Humphreys, 1999; Kimchi, 1998; Koivisto & Revonsuo, 2004; Miller & Navon, 2002; Navon, 1977, 1991, 2003; Paquet, 1999; Paquet & Merikle, 1988; Sanocki, 2001) are based on the concept of availability in the percept and suggest that global precedence arises as a result of early perceptual organizational processes (Han & Humphreys, 2002; Kimchi, 1998, 2000, 2003a,b). It has also been suggested that global dominance arises from a sensory mechanism—faster processing of low spatial frequencies than high spatial frequencies (Badcock, Whitworth, Badcock, & Lovegrove, 1990; Han et al., 2002; Hughes, Fendrich, & Reuter-Lorenz, 1990; Shulman, Sullivan, Gish, & Sakoda, 1986; Shulman & Wilson, 1987). Although the differential processing rate of low and high spatial frequencies may play a role in global and local perception, it cannot account for several findings, such as the effects of meaningfulness and goodness of form on global precedence (Poirel, Pineau, & Mellet, 2006; Sebrechts & Fragala, 1985) among others (Behrmann & Kimchi, 2003; Kimchi, 2000). In contrast, attentional accounts (Boer & Keuss, 1982; Miller, 1981a,b; Ward, 1982) are based on the concepts of physical salience of features and attentional resources (i.e., effort). This view is supported by findings

demonstrating that attention can modulate global precedence (Kinchla et al., 1983; Lamb et al., 2000; Robertson, 1996). Of course, as noted by Navon (2003), attention can magnify biases that originate prior to the focusing of attention. Similarly, an effect that arises at the perceptual level can be magnified by post-perceptual processes, such as those related to response (Miller & Navon, 2002). Perceptual accounts were the first to be proposed, but quickly gave way to attentional accounts. The evidence precipitating this shift is discussed next.

Evidence for an attentional source of global advantage has been observed in studies examining whether global advantage is sensitive to manipulations of attention. In light of such findings, it has been suggested that relative discriminabilities of the global and local levels determine global or local precedence effects (Pomerantz, 1983). Several findings are in accordance with this notion. Kinchla and Wolfe (1979) found that when the large (global) letter was small, the target was located faster on the global level than the local level. In contrast, the effect was reversed for larger displays. Kinchla and Wolfe suggested that there is an optimal size for stimuli, with forms larger/smaller than this optimum disadvantaged in speed of processing. These findings suggest that Navon's (1977) finding of global precedence may have been due to the fact that the global level was simply easier to perceive than the local. Martin (1979) varied the number of local letters used to construct a global letter. With dense global letters (i.e., many-element patterns), global precedence was observed, whereas with sparse global letters (i.e., few-element patterns), local precedence was observed. Hoffman (1980) manipulated the relative discriminability of the global and local levels directly by selectively distorting the

form of the stimuli at the two levels. When the local level was distorted (via elimination of fragments of the local letters), global precedence was observed. In contrast, when the global level was distorted (via elimination of fragments of the global letter), local precedence was observed. Miller (1981a) found that participants searching for a target letter in a letter composed of letters respond faster when targets are present at both levels, global and local, relative to when a target was present only at the global level. This suggests that both levels became available at roughly the same time. It was further demonstrated that a race model, which assumes that detection of targets at the global level occurs often, but not necessarily faster than local ones (Hoffman, 1980), was incompatible with the observed distribution of response times. In light of this finding, Miller concluded that global precedence is not perceptual, instead residing in a post-perceptual stage of attention or decision. In other words, decision and response selection processes, rather than those of property extraction and detection, operate global-to-local.<sup>2</sup> Similarly, Ward (1982) suggested that the source of global advantage may be at the stage of feature integration, a stage which has been assumed to require focal attention

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<sup>2</sup> Three points are worth noting (Navon, 1981). First, asymmetric interference effects (Miller, 1981a, Experiment 2) do not necessarily entail perceptual precedence. Though perceptual precedence is not the only explanation for asymmetric interference (i.e., perceptual dominance), it is in some cases the most reasonable one. Second, finding that a stimulus-specific response is faster to the presence of the stimulus in two levels than to its presence in just one level does not rule out perceptual precedence of one of those channels. As global precedence does not entail that global and local information cannot interact in their effects on responses, the finding that they do is not incompatible with global precedence. Third, the notion that effects considered to be attentional must be post-perceptual is debatable. In particular, it is questionable that attention or decision are applied only to the resultant of perception rather than determining it or constituting part of it.

(Treisman & Gelade, 1980). Moreover, Boer and Keuss (1982) found initial similar time courses for global and local detection, concluding that the absence of an initial global advantage argues for a post-perceptual locus of the effect, somewhere between perception and response selection. Likewise, Hughes et al. (1984) suggested that global precedence is the result of greater inhibitory influences from global than from local channels of information (but see Paquet & Merikle, 1988). Taken together, these studies make a compelling case that a host of factors determine baseline discriminabilities at the local and global levels. Yet, none was informative as to whether global or local precedence will occur once discriminabilities have been matched. Pomerantz (1983) provided key data in this regard, showing that while some cases of global precedence are due to greater discriminability of the global level and thus demonstrate only that more discriminable stimuli are harder to ignore (i.e., factors involved in discriminability dictate the precedence of the global or local level), other cases of global precedence can be observed even once the levels had been equated on discriminability.

**Caveat.** Following these studies, the preponderant conclusion in the literature was a rejection of a perceptual source of global advantage in favor of a post-perceptual one. Even Navon (2003) was tempted to attribute the effect to allocation of visual attention, for two reasons. First, the effect clearly reflects some sort of bias, and bias tends to be associated with attentional selection. Second, direct and indirect manipulations of attention often modulate the effect. Importantly, however, as attention may enhance biases generated before the focusing of attention, it is plausible that the bias in favor of the global level may originate in preattentive processing. In support, global effects are

exerted by unattended objects (Paquet, 1992; Paquet & Merikle, 1988) and resist attempts to eliminate them via manipulations of attention (Paquet, 1992, 1994; Paquet & Wu, 1994).

At this point, it is important to distinguish between a global-to-local bias for perceptual processing on the one hand, and a global-to-local bias for categorization on the other. It is one thing to say that the global level is perceptually available prior to the local level, whereas it is quite another to say that the global level is categorized prior to the local level. The critical question is whether a global-to-local perceptual bias would be so constraining as to impose a global-to-local categorization scheme. There is some evidence suggesting this may be the case. Paquet and Merikle (1988) examined whether global advantage originates during preattentive processing by evaluating the effects of global and local aspects of nonattended figures on the processing of attended figures. They found that the global aspect of a nonattended figure was categorized regardless of whether attention was directed toward the global or the local aspect of the attended figure, though, it was not invariably identified. In agreement with previous findings in directed attention global/local tasks (e.g., Navon, 1977), global advantage was observed with attended figures. On the basis of these findings, they suggested that a mandatory global processing, at least to the level of stimulus categorization, takes place during preattentive perceptual processing and that it might be the reason for the dominance of the global level of attended objects. Recent evidence from studies of natural scene perception also support this conclusion (e.g., Greene & Oliva, 2009). In contrast, Schyns and Oliva's (1997, 1999) work with spatial scale suggests that this is probably not the

case as scale selection can vary flexibly depending on the nature of the categorization task. This work suggests that biases in early vision do not necessarily translate into the same biases in categorization.

To determine the extent of processing of unattended information, it is common to manipulate semantic or identity information of the unattended items. If there is no effect of their identity on target processing, it is assumed that unattended items are not identified. Duncan (1981) questioned this logic by pointing out that even though selection may be efficient (i.e., ignored items have little effect on responses to targets), this does not imply that the unselected items have not been analyzed semantically. However, it is equally clear that the influence of unattended items is clear evidence that those items have been analyzed to at least the semantic level. A major problem is that most studies of selective attention have involved only one measure of semantic processing—that is, Stroop-type interference with the processing of the attended items as a function of the identity of the unattended items, or, in other words, whether the response indicated by this unattended item is compatible or incompatible with the response indicated by the attended item (e.g., Eriksen & Eriksen, 1974; Kahneman & Henik, 1981; Paquet & Merikle, 1988). An obvious weakness of any study of selective attention that relies on one measure of the processing of unattended items is that the failure to find an effect of their identity does not mean that they have not been identified. It is entirely conceivable that some other measure might have revealed extensive semantic analysis (Allport, Tipper, & Chmiel, 1985; Driver & Tipper, 1989).

Taken together, these studies highlight the difficulty in localizing the source of global advantage. In turn, the issue of source remains controversial, with differing views emphasizing different points in the course of processing the global advantage manifests. There are at least two reasons for this difficulty in localizing global advantage. One is that the manifestation of an effect in a post-perceptual process (e.g., response competition) does not, by itself, rule out the possibility that the effect originated in earlier perceptual processing. The second is that different tasks may tap different stages of processing or elicit different optional strategies available to the processing system. With hierarchical stimuli and separable dimensions, selective attention may be possible in one task but not in another, depending on the likelihood of dimensional output conflict. This suggests that dimensional analysis is a necessary but not sufficient condition for successful selective attention to a stimulus dimension. Similarly, local properties may be extracted before the stage of complete identification of the global configuration, depending on task demands; however, this does not rule out the possibility that in early stages of perceptual processing, global properties are available before the local ones. Further complicating matters is that speed of processing and interference, the two experimental effects on which the global precedence hypothesis was based, do not always covary (Amirkhiabani & Lovegrove, 1999; LaGasse, 1993; Lamb & Robertson, 1988, 1989; Navon & Norman, 1983) and, therefore, may reflect different modes of processing (Navon & Norman, 1983) or even separate mechanisms (Robertson & Lamb, 1991). A better method of testing for advantage, therefore, seems prudent, a point elaborated on next.



### 1.3 Limitations of Previous Research

**Inappropriate conditions for assessing the obligatory nature of precedence effects: Need to equate likelihood of level-specific processing between levels.** Navon's global precedence hypothesis (1977) relates to the processing of stimulus structure and is concerned with the temporal organization of perceptual processes in the course of identifying an attended object. It states that the perceptual system is predisposed to process global compared with local information. Thus, Navon's hypothesis is one about a processing disposition. Testing for the existence of a disposition is not quite straightforward since it constitutes just one vector in a complex space in which vectors are not necessarily orthogonal and so might be counteracted by modulating factors in certain real-world situations. Hence, the test of any disposition (e.g., in favor of the left side of the visual field) requires proper control and possibly special conditions.

To test the global precedence hypothesis, therefore, global and local structure must carefully be controlled for. In particular, if the question is whether global precedence may be conceptualized as a processing disposition (Navon, 1977), then it is prudent to test for such a disposition under conditions unlikely to modulate it. Such conditions, in which attempts are made to equate processing load between, have been discussed at length (Navon, 1977, 1981, 2003). Testing whether a disposition exists, however, requires a further equivalency consideration: the likelihood of processing, not only the load of processing. In other words, testing whether a disposition exists requires that each level be equated in terms of likelihood of processing—not only the option to process either level but also the option to process neither level (Navon, 2003). For

instance, even if one finds evidence in a divided attention paradigm for obligatory global processing, it may be that this evidence depended on the global level being task-relevant (not just task-relevant on a given trial, as any conclusion drawn is based on the whole task; Iglesias-Fuster, Santos-Rodríguez, Trujillo-Barreto, & Valdés-Sosa, 2014).

To examine this, one would ideally need to incorporate a compound stimulus that can be ignored while simultaneously generating a measurable response. In all previous studies of global and local processing dynamics, however, participants have been required to process the critical compound stimulus in a goal-directed manner via task and stimulus parameters that emphasize global or local characteristics. Importantly, this assumes that the task itself has no bearing on processing, which may not be the case. For instance, if a task representation for letter identification biased attention toward more local levels, it could be that the local level was salient and therefore attention bypassed the global level. Or, it could be that global processing still occurred but progressed to a more local level without significant cost (an especially likely possibility given that the task was always repeated). Moreover, processing of global cues—as a disposition—may not automatically lead to subsequent processing of local levels. A disposition account makes no claims as to how task-relevant global features are processed, it only makes claims about how global features of an attended object tend to be processed *ceteris paribus* or before accounting for moderating factors such as task—as is the essence of a disposition (i.e., that which existed before experience). As such, the intent to process one level and ignore another precludes any possibility of establishing whether processing of one level was obligatory. This is because signal amplification and suppression

mechanisms of attention are dissociable (Remington & Folk, 2001). This means that a critical piece of the global/local puzzle has been ignored: does early global precedence and late local precedence also occur obligatorily in the absence of task demands and, furthermore, is the temporal ordering of processing fixed or flexible? The challenge is how to do it.

#### **1.4 Incidental Processing**

**Proposed method: Incidental processing and the compound arrow cueing paradigm.** One method for simply sidestepping the non-trivial issue of task-relevancy is to use a less invasive measure of processing. The method suggested in the current thesis is to measure global and local processing in a situation that does not require participants to process or respond to the critical hierarchical stimulus. The current thesis refers to the sort of processing in such a situation as incidental (cf. Craik & Lockhart, 1972; Hyde & Jenkins, 1973; Morris, Bransford, & Franks, 1977). Operationally, incidental processing is defined in the compound arrow cueing paradigm as processing of a hierarchical stimulus when information at different levels of structure is uninformative (does not aid task performance) and task-irrelevant (does not need be processed to perform the task). In the compound arrow cueing paradigm, the basic methodology of traditional global/local tasks is retained but instead of measuring performance on a classification task, performance will be measured on a Posner-style spatial cueing task. The importance of visual attention and the spatial cueing paradigm with respect to the current thesis is described next.

#### **1.5 Visual Attention**

This section reviews concepts, paradigms, and theories in the visual attention literature with respect to their importance in pursuing the objectives of the current thesis outlined in Table P.1. Namely, this section describes bottom-up and top-down control of attention; their measurement within the spatial cueing paradigm; and, most critically to the current thesis, symbolic control of attention.

### **1.5.1 Bottom-Up and Top-Down Control of Attentional**

Everyday visual environments generally contain more information than can be processed within a glance. As such, goal-directed perception and action depend on mechanisms of selective visual attention for prioritizing an endless stream of sensory input, giving more weight or resources to a subset of relevant objects, locations, or events that require immediate or sustained processing. To understand how attention is prioritized and allocated to visual stimuli, a useful distinction is that between bottom-up and top-down attentional control, with the former driven by the physical characteristics of a stimulus and the latter by the current goals of the observer (Corbetta & Shulman, 2002; Desimone & Duncan, 1995; Egeth & Yantis, 1997; Itti & Koch, 2000; Jonides, 1981; Posner, 1980; see Yantis, 2000, for a review). For example, an abrupt visual onset may on the one hand capture attention in a purely stimulus-driven manner (Enns, Austen, Di Lollo, Rauschenberger, & Yantis, 2001; Remington, Johnston, & Yantis, 1986; Theeuwes, 1990, 1994; Yantis & Jonides, 1984). On the other hand, capture may be contingent on the top-down attentional set of an observer such that the onset captures attention only if it shares a feature with an item in the set (Folk & Remington, 1998; Folk, Remington, & Johnston, 1992). Thus, with bottom-up attention, selection is driven

by the physical properties of a stimulus, such as its luminance and contrast, and this is considered to be automatic (i.e., involuntary, unconscious, and capacity free; Schneider & Shiffrin, 1977). With top-down attention, selection is driven by current selection goals, task instructions, and associative learning, and is considered to be effortful (i.e., voluntary, conscious, and capacity limited). It is not the case, however, that one operates independent of the other at all times. Rather, both frequently operate in parallel, with either bottom-up or top-down attentional selection having greater influence at different points in time (van Zoest, Donk, & Theeuwes, 2004; van Zoest & Donk, 2005). These two forms of attention have been studied widely within the spatial cueing paradigm, as described next.

### **1.5.2 Spatial Cueing Paradigm**

One of the most widely used methods for studying both the bottom-up and top-down control of attention is the spatial cueing paradigm. Introduced by Posner (1980; Posner, Snyder, & Davidson, 1980), the spatial cueing paradigm (Figure 1.3) requires observers to respond to a target appearing at a peripheral location previously indicated by a spatial cue (valid condition) or at a different location (invalid condition). Attentional influence on performance is measured in terms of spatial cueing effects, or the difference in response time (RT) between valid and invalid cues. Two broad categories of cues have been used to tap into bottom-up and top-down attentional orienting: peripheral cues (e.g., the brightening of a peripheral location), which are thought to reveal characteristics of bottom-up control (Posner, 1980), and central cues (e.g., a spatially informative directional arrow presented at a centrally fixated location), which are thought to reveal

characteristics of top-down control (Jonides, 1981). Importantly, peripheral cues are spatially non-predictive of the target's location, allowing cueing effects to be attributed to bottom-up capture. When a cue is presented and it does not predict target location, then there is no reason to voluntarily allocate attentional resources to the cued location and so any effect of the cue can therefore be regarded as involving bottom-up capture (e.g., Prinzmetal, McCool, & Park, 2005; Wright & Richard, 2000). The temporal characteristics of attentional influence are commonly investigated by manipulating the interval between the cue stimulus and the onset target (i.e., stimulus-onset-asynchrony; SOA). With peripheral cues, the standard finding is that responses to the valid location are facilitated at short SOAs (within as little as 100 ms after the cue; Posner, Cohen, & Rafal, 1982; Warner, Joula, & Koshino, 1990). After some critical SOA (~300 ms after the cue), participants are typically slower on valid trials than on invalid trials, a phenomenon known as inhibition of return (IOR; Posner & Cohen, 1984).

In contrast, central cues are spatially predictive of the target's location, allowing cueing effects to be attributed to top-down control. When a cue is presented and it does predict target location (e.g., the direction of the arrow predicts the target's location on 75% of trials), then there is reason to voluntarily allocate attentional resources to the cued location and so any effect of the cue can therefore be regarded as involving top-down attention. The standard finding with central cues is that responses to the valid location are facilitated for all SOAs longer than some critical SOA (~500 ms after the cue), with no evidence of IOR at these longer intervals (Posner & Cohen, 1984; Wright & Richard, 2000). If the SOA is very short, cueing effects tend to be small or absent, presumably

because it takes time for the cue to be encoded (Müller & Rabbitt, 1989) and for its impact on control processes to unfold (Pratt & Hommel, 2003). Thus, the effects of top-down attention (measured with predictive, central cues) can be statistically independent of bottom-up attention (measured with non-predictive, peripheral cues; Berger, Henik, & Rafal, 2005; see also Lupiáñez, Decaix, Siéroff, Chokron, Milliken, & Bartolomeo, 2004).

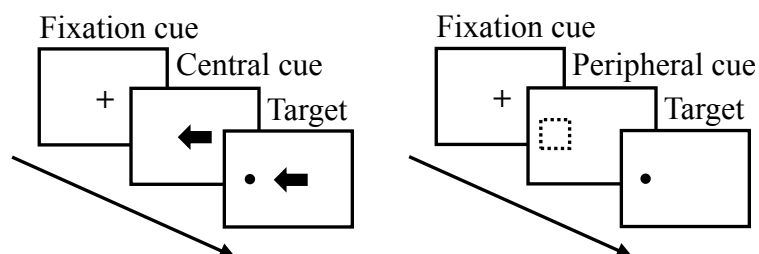


Figure 1.3. Posner's spatial cueing paradigm. Two broad categories of cues have been used within the spatial cueing paradigm to measure bottom-up and top-down attentional control: peripheral cues such as the brightening of a peripheral location (right panel), which are thought to reveal characteristics of bottom-up control (Posner, 1980), and central cues such as a spatially predictive directional arrow (left panel), which are thought to reveal characteristics of top-down control (Jonides, 1981).

### 1.5.3 Symbolic Control of Attention

As noted above, in the spatial cueing paradigm (Posner, 1980; Posner, Snyder, & Davidson, 1980) observers respond to a target appearing either at a peripheral location previously indicated by a spatial cue (valid condition) or at a different location (invalid condition). Two measurable effects of cue-target validity on responses can be observed: facilitation and inhibition. The signature of peripheral cueing is a biphasic pattern of response times such that early facilitation is followed by later inhibition of processing at

the cued location, whereas the signature of central cueing is a slowly arising, stationary pattern of facilitation (Funes, Lupiáñez, & Milliken, 2005). Though pervasive, the pattern is not universal. In particular, over the last decade numerous reports indicate that behaviorally relevant symbolic stimuli such as directional arrows can influence attentional control in ways that are distinct from the traditional top-down/bottom-up taxonomy (Gibson & Kingstone, 2006; Hommel, Pratt, Colzato, & Godijn, 2001; Hommel & Akyürek, 2009; Pratt & Hommel, 2003; Ristic & Kingstone, 2006, 2012). For example, Hommel et al. (2001) presented a centrally located directional arrow (e.g., <, >) or word (e.g., left, right) which was followed by a peripheral target requiring a detection response. Targets were detected more quickly when they appeared at the location indicated by the arrow or word (valid condition) than at another location (invalid condition). Importantly, this occurred even though these symbols were entirely irrelevant to the detection task, and observers were explicitly told that the symbols did not predict the location of the upcoming target (see also, Friesen, Bayliss, & Tipper, 2007; Ristic & Kingstone, 2006, 2012; Ristic, Landry, & Kingstone, 2012).

Similar findings have been observed for temporal words (e.g., tomorrow, yesterday; Weger & Pratt, 2008; see also Ouellet, Santiago, Funes, & Lupiáñez, 2010), words relating to concrete concepts (e.g., head, foot; Estes, Verges, & Barsalou, 2008), words relating to abstract concepts (e.g., god, devil; Chasteen, Burdzy, & Pratt, 2010), pictures relating to abstract concepts (e.g., liberal, conservative; Mills, Smith, Hibbing, & Dodd, 2015), numbers (Fischer, Castel, Dodd, & Pratt, 2003), and letters (Dodd, Van der Stigchel, Leghari, Fung, & Kingstone, 2008). Taken together, these findings indicate that



a broad range of visual symbols can produce unintentional shifts of attention (but see Fattorini, Pinto, Rotondaro, & Doricchi, 2015, for alternative conclusions). Outside of the traditional top-down/bottom-up dichotomy, therefore, considerable evidence exists indicating that various kinds of symbolic information presented at fixation produce unintentional shifts of attention to peripheral locations compatible with the meaning of the symbol. In particular, symbolic cues elicit early facilitation (similar to exogenous cues), but this facilitation is prolonged and unaccompanied by inhibition (similar to endogenous cues). Critical to the current thesis, symbolic cueing effects occur even when the cue is spatially uninformative and completely irrelevant to the primary target detection task, thereby displaying key properties of involuntary processes (Hasher & Zacks, 1979). This is critical because it is this involuntary aspect of symbolic attentional orienting on which the compound cueing paradigm used in the experiments reported in the current thesis capitalizes. As described in the next chapter, this paradigm is a novel method that combines spatial cueing and compound stimulus paradigms, and which draws on involuntary attentional orienting elicited by a spatially uninformative central arrow cues, in order to investigate global/local processing under incidental processing conditions, wherein global/local levels were uninformative (do not aid performance) and task-irrelevant (need not be processed to perform the task).

## CHAPTER 2: THESIS OBJECTIVES, METHODS, AND HYPOTHESES

### 2.0 Chapter Overview

The goal of the current thesis is to investigate visual processing of hierarchical structure under incidental processing conditions. To do so, the current thesis pursues two broad objectives, each of which is met with multiple experiments. Chapter 2 describes these objectives (Section 2.1), as well as the general compound arrow cueing paradigm (Section 2.2) and the specific experiments (Section 2.3) designed to meet them. General analytic methods are also described (Section 2.4).

### 2.1 Primary Objectives

There were two primary objectives, each met with a different set of experiments and a number of specific aims. Experiments 1-2 pursued the first objective and Experiments 3-5 pursued the second, which will be described in turn.

**Objective #1: To examine global and local processing in incidental perception of hierarchical structure.** Two experiments investigate global and local processing in a situation that does not require an observer to process a critical hierarchical stimulus (i.e., incidental processing conditions; see Section 1.4). Experiment 1 tests Navon's (1977) global precedence hypothesis under such conditions, namely, the temporal organization (Issue #1), availability (Issue #2), and nature (Issue #3) issues. Experiment 2 investigates these issues along a broader time course using a more sensitive manipulation of processing duration.

**Objective #2: To examine control of level-specific selection in perception of hierarchical structure.** According to Desimone and Duncan (1995), objects in the visual

field compete for limited processing capacity and control of behavior. This competition is biased by bottom-up and top-down mechanisms, where bottom-up processing tends to parse figures from background and top-down processing tends to select objects relevant to current behavioral goals. Navon's (1977) global precedence hypothesis relates global advantage and interference to the evolution of the percept, claiming that global properties have temporal precedence during the microgenesis of percept, possibly due to their earlier registration or speeded processing. Global precedence, therefore, can be seen as relative to bottom-up aspects of attentional processing, suggesting that attention may first be captured by properties of the global level. If so, biasing attention via top-down task-set representations or via bottom-up salience might affect global and local processing. Three experiments investigate top-down and bottom-up aspects of attentional control in selection of level-specific information (Issue #4). In particular, these experiments examine the roles of current task goals (Experiment 3), physical salience (Experiment 4), and attentional focusing (Experiment 5) in controlling level-specific selection.

To meet these objectives, global and local processing was measured within a novel, compound arrow cueing paradigm. This paradigm is described next (Section 2.2), followed by a description of the specific aims, measures, and hypotheses for each experiment (Section 2.3).

## **2.2 Compound Arrow Cueing Paradigm**

The current thesis introduces a method that combines spatial cueing and compound stimulus paradigms (Figure 2.1), and which capitalizes on the involuntary aspect of attentional orienting elicited by central arrow cues, in order to investigate global

and local processing under incidental processing conditions—that is, where global and local levels are spatially uninformative (do not predict target location and thus cannot aid detection performance) and task-irrelevant (do not need to be processed in order to perform the detection task). The task is peripheral target detection—a target is presented to the left or right of a centrally presented, spatially uninformative, task-irrelevant compound arrow cue, and observers are instructed to press a button as quickly as possible once a target is detected. Compound arrow cues are either consistent (global and local arrows pointed at the same location), inconsistent (global and local arrows pointed at opposite locations), local-neutral (global arrow composed of local rectangles), or global-neutral (global rectangle composed of local arrows). Consistent cues are valid when arrows at both global and local levels point to the location where the target is presented and are invalid otherwise. Local-neutral cues are valid when the arrow at the global level points to the location where the target is presented and are invalid otherwise. Global-neutral cues are valid when arrows at the local level point to the location where the target is presented and invalid otherwise. As inconsistent cues are technically always valid given that either the global or local arrow is always pointed to the location where the target is presented, the validity states for this cue type are referred to as global-valid and local-valid. Accordingly, inconsistent cues are global-valid when the arrow at the global level points to the location where the target is presented and local-valid when arrows at the local level point to the location where the target is presented. The response time difference between global-valid and local-valid conditions is used to measure level-specific spatial cueing effects (i.e., global or local advantage, where global advantage

refers to a speed advantage in responding to targets presented at the global-valid location relative to the local-valid location and local advantage refers to a speed advantage in responding to targets presented at the local-valid location relative to the global-valid location). SOA is manipulated to test whether global or local advantage varies with relative stimulus availability. The rationale is that the priming potency of a level varies with SOA in correspondence with how early that level is processed (cf. Navon, 1991; Kimchi, 1998). Critically, as the compound arrow cue is incidental to the target detection task, and can therefore safely be ignored, this provides an opportunity to determine whether the global-to-local processing sequence is obligatory.

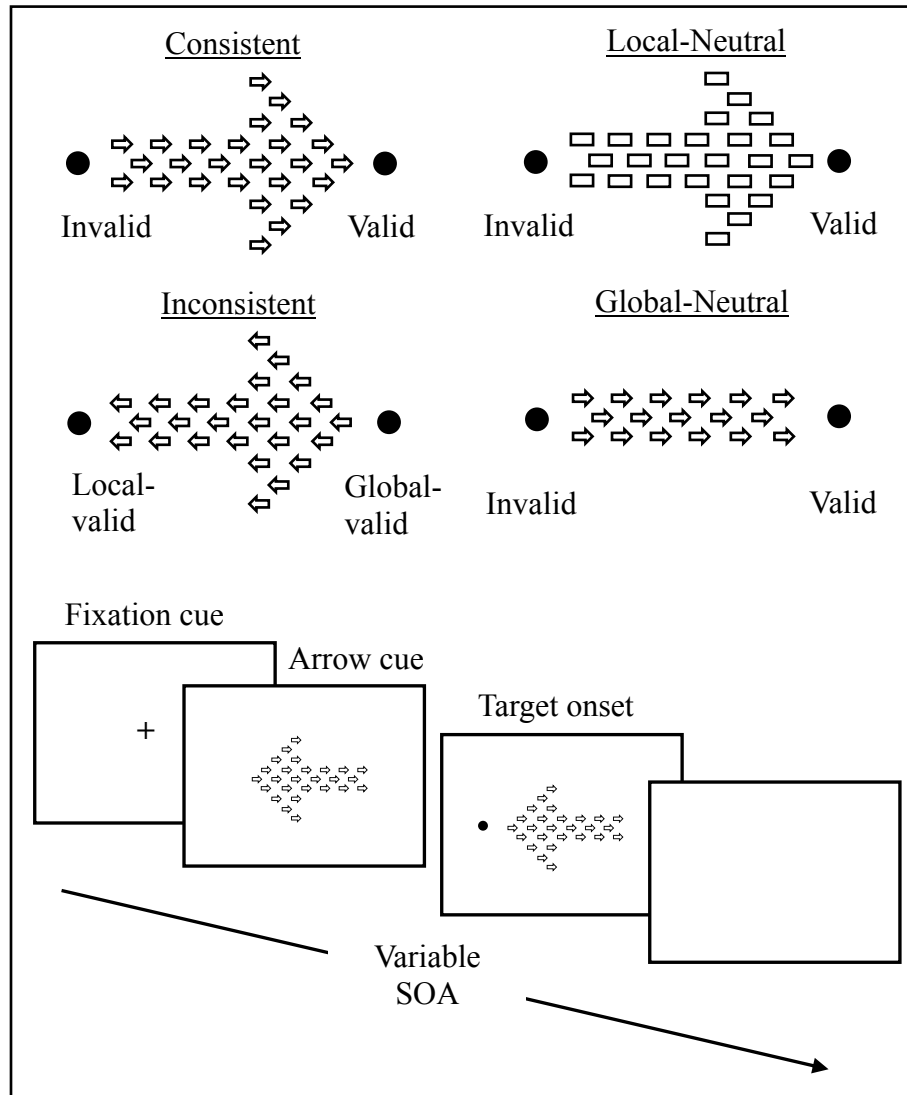


Figure 2.1. Compound arrow cues, validity conditions, and example trial sequence in the compound arrow cueing paradigm used to measure global and local processing in the experiments reported in the current thesis.

## 2.3 Experiments in Order of Presentation

### 2.3.1 Experiment 1: Global and Local Processing in Incidental Perception

Experiment 1 investigates the effect of globality (i.e., cue-level: global or local) and processing duration (i.e., SOA) on symbolic control of attentional orienting under incidental processing conditions. To do so, the compound arrow cueing paradigm

described in Section 2.2 is used (see Figure 2.1 for example cue stimuli and trial sequence). There are two specific aims. The first aim is to determine whether early global dominance and a shift from global to local processing are obligatory by presenting task-irrelevant symbolic cues that have both global and local interpretations. By capitalizing on the well-known effects of non-predictive, task-irrelevant central arrow cues on fixation (i.e., obligatory orienting in the direction consistent with the meaning of the cue, even when the cue is task-irrelevant), the compound arrow cueing paradigm is able to determine the manner in which global/local processing modulates symbolic cueing effects—importantly, this provides an opportunity to determine whether early global precedence and late local precedence occurs even in the absence of task demands. A second aim is to test the prediction that the availability (i.e., priority or dominance) of global information is stationary throughout the course of processing (Navon, 1977). The SOA factor represents a manipulation of the availability of processed visual information, with the test for stationarity given by the interaction of globality and SOA (Kimchi, 1998; Navon, 1991).

**Measures.** Global/local phenomena have been measured almost exclusively with Stroop-like interference, though, this is not the only available measure and, even by Navon's (2003) own account, probably not the best and sometimes not even appropriate (e.g., Navon, 1991). Thus, although Stroop-like interference is almost always used to measure global/local phenomena, this is not a requirement (contrary to some claims, e.g., Pomerantz, 1983) and was not adopted for measuring precedence in the current experiments. Rather, in the compound arrow cueing paradigm used here, global/local

advantage was measured by comparing response times to global-valid targets with response times to local-valid targets (global-valid minus local-valid). Thus, positive values would reflect a cueing effect due to the local level (local advantage), whereas negative values would reflect a cueing effect due to the global level (global advantage). Moreover, along the lines of Hoffman (1980), interference was measured by comparing RTs in trials with cues whose levels agreed (consistent cues) with those in which they conflicted (inconsistent cues). Finally, change in availability of the percept was measured by the function relating level-specific cueing effects with SOA.

**Hypotheses.** Navon's (1977) global precedence hypothesis suggests that information at the global level is prioritized in the development of the percept. In the compound arrow cueing paradigm, a significant spatial cueing effect with inconsistent cues would indicate a processing advantage at one level, with the direction of the cueing effect (whether the global or local level is directed at the target) indicating which of the levels held the advantage. As symbolic cueing effects are obligatory (Gibson & Kingstone, 2006; Hommel et al., 2001; Hommel & Akyürek, 2009; Pratt & Hommel, 2003; Ristic & Kingstone, 2006, 2012), and given that there is no a priori reason to process or select one level over the other, the finding of global advantage would provide strong evidence for the inevitability of global processing. Furthermore, according to Navon's (1977) global precedence hypothesis, global advantage is attributable to global information being more available or active in all stages of processing (i.e., there is stationary availability in the global percept). In the compound arrow cueing paradigm, the SOA manipulation represents a manipulation of availability in the percept. Accordingly,



global precedence predicts that global advantage should not vary with SOA. In contrast, if the availability of a particular level is modulated, then the effect of globality should vary with SOA. Thus, an effect of SOA on global advantage would not support Navon's (1977) perceptual global precedence hypothesis. It would be consistent with a weaker version, however, in which the availability of global level can be modulated over time (Navon, 1991).

### **2.3.2 Experiment 2: Capturing Time Sensitive Effects**

Experiment 2 examines the time course of global and local processing with the goal of mapping the time course of change as it relates to the global and local processing advantage. Critically, in Experiment 2, a more sensitive method and analytic approach for making fine-grain measurements of the effect of processing duration on global and local processing biases is used. To do so, SOA was manipulated by sampling values across a broad range SOAs within three discrete, theoretically motivated intervals  $U(a, b)$ , where  $a$  is the minimum SOA value within interval  $U$  and  $b$  is its maximum: the first interval,  $U(100, 300)$ , reflects SOA values for which global processing is expected to dominate; the second interval,  $U(400, 600)$ , reflects values for which global processing is expected to transition to local processing; and the third interval,  $U(700, 900)$ , reflects values for which local processing is expected to dominate.

**Measures.** Advantage, interference, and availability are measured the same as in Experiment 1. Two additional measures are 1) micro-level change in the magnitude of spatial cueing effects (i.e., change within an SOA interval), which tests whether change in advantage proceeds more continuously or discretely, and 2) macro-level change in the

magnitude of spatial cueing effects (i.e., change between SOA intervals in how much change occurred within an SOA interval). As local processing is generally conceived as volitional, at least more so than global processing, examination of macro-level change affords a test of whether volitional biases are constant over time, or at least change over time less so than automatic biases associated with global processing.

**Hypotheses.** A stationary account of global precedence predicts that a global cueing effect should be observed and should remain stationary across SOAs given that, not only is global information available earlier (which accounts for the global advantage), but that its availability does not decline over time, not even when local information is being processed (which accounts for the obligatory nature of global advantage and the preponderance of asymmetric, global-to-local interference patterns in global/local tasks). Accordingly, as in Experiment 1, support for this account is the finding that, with inconsistent cues, global advantage does not vary with SOA. In contrast, if the availability of a particular level is modulated, then the effect of globality should vary with SOA. The test of micro-level change (reflecting incremental change within an SOA interval) is the jump by validity interaction. If the interaction is not significant, this would indicate that there was no change in the availability of the percept between SOA intervals, which would suggest that change progressed more gradually. If the interaction is significant, this would indicate that there was significant change in the availability of the percept between SOA intervals, which would suggest that change progressed more discretely. The test of macro-level change (reflecting change between SOA intervals in how much change occurred within an SOA interval) is the within-SOA slope by validity

interaction for conditions conspiring to produce local precedence (e.g., longer SOAs). If the interaction is not significant when examined around the point in time that local processing is expected to occur or dominate,  $U(700, 900)$ , this would indicate that there was no change in the percept during this interval, which would suggest that local processing was volitional and constant over time. In contrast, if the interaction is significant for  $U(700, 900)$ , this would indicate that there was change in the percept during this interval, which would in turn suggest that local processing was less volitional than previously considered. This would especially be the case given that, under incidental processing conditions, its ebb and flow in dominance was likely obligatory as there was no top-down or bottom-up basis for biasing level-specific information toward a particular level, let alone in a temporally prescribed order.

### **2.3.3 Experiment 3: Role of Top-Down Task Set**

Task-relevant items may be located at different levels of stimulus structure (global or local level). Previous research suggests that processing of items at one level tends to dominate processing of items at the other, with level-dominance determined by the task-relevancy of items at a given level (Grice, Canham, & Boroughs, 1983; Morrison & Schyns, 2001; Schyns & Oliva, 1997). Experiment 3, therefore, examines whether the influence of competing symbolic stimuli at different levels of structure on attentional control depends on top-down selection processes (manipulated via level-specific orienting tasks). Each trial consists of two major events (Figure 2.2). First, a spatially uninformative compound arrow cue is presented at fixation. Second, after a variable SOA, a peripheral target is presented requiring a simple detection response. Participants

are instructed that their primary task is target detection, but that they should also perform one of two secondary tasks. In the global-orienting task, arrow cues are oriented either perfectly in-line with or slightly above or below the horizontal line and participants are instructed to try and remember the orientation of the big arrow. In the local-orienting task, one of the local arrows is a color singleton and participants are instructed to try and remember its location. Following the detection response, a test display is shown presenting two compound arrows, and participants are instructed to select the one that matches what they had just seen.

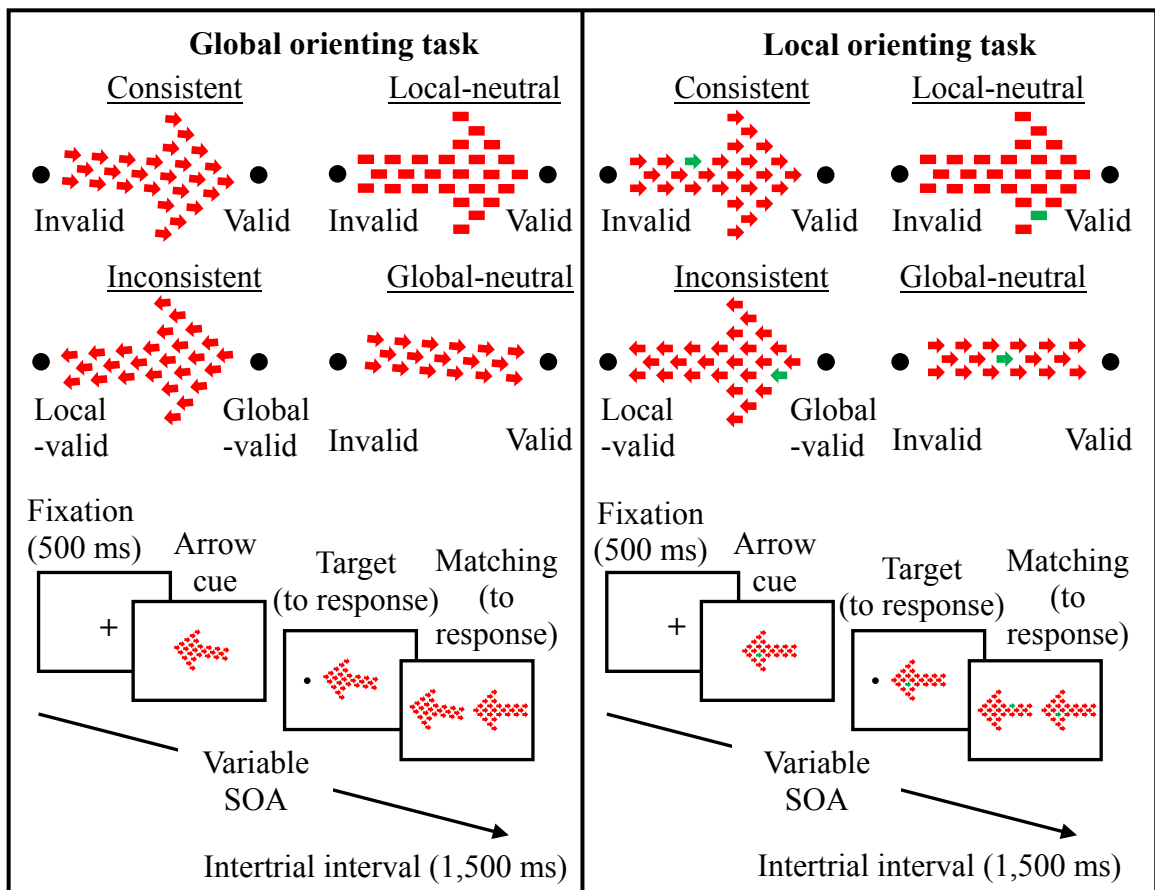


Figure 2.2. Compound arrow cues and validity conditions, as well as example trial sequences, in Experiment 3. The left panel shows example cue stimuli used for the global

orienting task, in which the orientation of the global arrow was task-relevant. The right panel shows example cue stimuli used for the local orienting task, in which the location of a color-singleton local arrow was task-relevant.

**Measures.** Advantage, interference, and availability are measured the same as in Experiment 1.

**Hypotheses.** One possibility is that the level that is relevant to the current task goal will be selected, and the arrow at this task-relevant level will then produce an unintentional shift of attention. Evidence for this hypothesis comes from research on the role of control settings in attentional capture. The framework of attentional control settings (Folk et al., 1992) proposes that the processing of a stimulus feature is contingent on the task goal at hand such that only stimuli possessing a task-relevant feature can pass through a perceptual filter and enter working memory. Thus, the control setting account predicts that only the arrow that shares a critical feature specified by top-down control settings will be selected to control the allocation of attention. Another possibility is that the global level will be selected first regardless of task, and this global arrow will then produce an unintentional shift of attention. Evidence for this hypothesis comes from research on the role of global precedence in perception of hierarchical structure (Navon, 1977). Such studies indicate that global properties can be extracted rapidly, suggesting that the potency of an arrow to evoke an unintentional shift of attention may depend on its globality (i.e., its relative position in hierarchical space). Thus, the global precedence account predicts that the global arrow will be selected to control the allocation of attention, independent of task.

### **2.3.4 Experiment 4: Role of Bottom-Up Salience**

Recent work has provided direct behavioral and neurophysiological evidence that salient but irrelevant singletons can be actively suppressed when top-down guidance is deployed (Gaspelin, Leonard, & Luck, 2015). It is unlikely, therefore, that differential local salience between tasks could be responsible for any differences between tasks or for the pattern of cueing effects in the local orienting task. Nonetheless, to be sure, an experiment testing this possibility is conducted. In this experiment, arrow cues are the same as those used in the local orienting task (i.e., cues contain a local color singleton) of Experiment 3. Participants perform the same target detection task as before but without any secondary orienting task. If the local color singleton captures attention, then participants should be faster to respond to targets appearing at the location indicated by a local singleton arrow relative to targets appearing at the mirror location (i.e., a local cueing effect). In the same vein, there should not be a cueing effect with cues in which the local color singleton is a rectangle (i.e., local-neutral cues). Alternatively, if the local color singleton is suppressed, then participants should be slower to respond to targets appearing at the location indicated by a local singleton arrow relative to targets appearing at the mirror location (i.e., an inhibition of return-like effect, or local anticueing effect). Furthermore, if the IOR-like effect is indeed due to suppression of the salience signal—as opposed to influence from the global level—then inconsistent cues (for which influence from the global level is possible) and global-neutral cues (for which influence from the global level is not possible) should show the same pattern of slower responses to targets

appearing at the local-valid (inconsistent cues) or the valid (global-neutral cues) location relative to the mirror location.

**Measures.** Advantage, interference, and availability are measured the same as in Experiment 1.

**Hypotheses.** The finding of a larger and more rapidly arising local advantage with cues containing a local color singleton compared with those that are homogeneously colored would reflect a bottom-up attentional source of level-specific advantage. Alternatively, a finding of global advantage regardless of local salience would indicate that local salience does not invariably capture attention and produce cueing effects, at least not before the global level does, and would speak to a perceptual source. Similarly, the finding that local salience eliminates, but does not reverse, global advantage might suggest that global processing passively interfered with local processing (Navon, 1977, 2008; Sanocki, 2001) or that local salience biased competition for selection between levels (Hommel et al., 2001; Hommel & Akyürek, 2009; Pratt & Hommel, 2003), for instance, by attenuating the availability of the global level and/or by enhancing the availability of the local level. In any case, either of these latter two possibilities would indicate that a local-level entry point for visual processing is not obligatory, even under conditions in which it might be expected.

### **2.3.5 Experiment 5: Role of Attentional Focusing and Adjustments**

The zoom-lens metaphor of spatial attention captures the idea that visual attention can be allocated to differently sized regions of the visual field. Changing the level attended, therefore, can be seen as a redistribution of resources over a region that is

proportionally larger than the height of the level in the hierarchy (Castiello & Umiltà, 1990; Eriksen & St. James, 1986). Accordingly, it is possible that global-local response time differences reflect the time needed to refocus attention from the global to the local level. There is ample evidence that a tradeoff exists between the size of the visual field over which attention is distributed and its resolution (Eriksen & St. James, 1986; Eriksen & Yeh, 1985) and that the size of such attentional focusing plays an important role in attentional control (Theeuwes, 2004). To this point, each of the current experiments require only simple detection responses to a 1° target. It is possible that such a simple (coarse) judgement might permit what Theeuwes (2004) has referred to as a wide attentional window. These studies suggest that the size of the attentional window is an important factor in determining whether an irrelevant color singleton will capture attention. For example, Belopolsky, Zwann, Theeuwes, and Kramer (2007) manipulated the size of the attentional window by requiring observers to detect either a global or a local shape prior to performing a search task. They found that attention was captured more often when the attentional window was induced to be wide (global shape detection) than when it was induced to be narrow (local shape detection). If detection responses to a 1° target permit a wide attentional window, then the spatial cueing task may introduce a top-down bias towards global processing across all conditions.

To examine this possibility, in Experiment 5, attentional focus is manipulated (Figure 2.3) along the lines of previous work (e.g., Belopolsky et al., 2007). If it is assumed that global and local levels are equated on salience, then the focused attention condition should prime a local advantage (because the effective visual field is smaller,



potentially omitting grouping cues). This would be evident by larger local cueing effects (with inconsistent and global-neutral cues) in the focused versus diffuse attention condition. In contrast, the diffuse attention condition should prime a global advantage (because the effective visual field is larger, encompassing all the items). Thus, in the diffuse attention condition there should be a bias toward global processing, which would be evident by a larger global cueing effect (with inconsistent and local-neutral cues) in the diffuse versus focused attention condition. However, if the local level contains a salient color singleton, then the focused attention condition should prime a local advantage (because the effective visual field is smaller, as well as because attention is allocated automatically to the singleton), and the diffuse attention condition should prime a local advantage commensurate with the focused attention condition (because, though the effective visual field may encompass the whole cluster of items, attention is allocated automatically to the singleton).

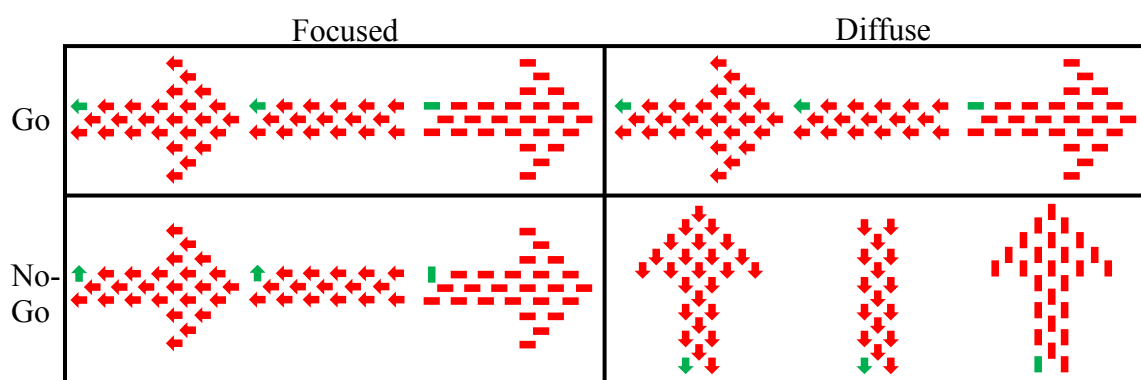


Figure 2.3. Examples of the displays used to manipulate the size of the attentional window (focused or diffuse) in Experiment 5. In the focused attention condition, participants were to respond only when the local shape of the color singleton was a left/right arrow or rectangle (go trials) and to withhold responding when the local shape

of the color singleton was an up/down arrow or rectangle (no-go trials). In the diffuse attention condition, participants were to respond only when the global shape was a left/right arrow or rectangle (go trials) and to withhold responding when the global shape was an up/down arrow or rectangle (no-go trials).

**Measures.** Advantage, interference, and availability were measured the same as in Experiment 1.

**Hypotheses.** The finding of a window-compatible, level-specific advantage regardless of processing duration would imply an alternative account of global/local processing phenomena, one predicated on the focusing an attentional window rather than availability in the percept (Cave & Chen, 2016).

## 2.4 Analytic Method

Response times less than 100 ms or greater than 1.5\*interquartile range above condition means were removed (unless noted otherwise). Multilevel models with participants and display items as crossed (Experiment 1 and Experiments 3-5) or nested (Experiment 2) random effects (Hoffman & Rovine, 2007; Hoffman, 2015) were used to account for the imbalance in the number of observations across participants and arrow conditions. Although repeated measures designs have historically been analyzed via least squares analysis of variance (ANOVA) of subject or item means, this approach has significant limitations (e.g., listwise deletion, random intercepts only, use on aggregated data, limitations on kind of predictors, untestable and untenable assumptions). With respect to the current experiments, the main limitation relates to missing data and the

impact this might have on the (in)ability to estimate crucial random effect parameters, namely, by-subject random slopes.

Previous simulation work has shown that random slope models that control for between-unit variability in the effects of predictors by estimating random slope parameters are critical in analysis of repeated measures designs (Barr, Levy, Scheepers, & Tily, 2013; Barr, 2013; Bates, Kliegl, Vasishth, & Baayen, 2015; Hoffman, 2015; Schielzeth & Forstmeier, 2009). For instance, Schielzeth and Forstmeier (2009) demonstrated that for data sets with between-subject grouping variables and within-subject predictors, random slope models are superior to random intercept models both in reducing Type II errors for the between-subject predictor as well as reducing Type I errors for the within-subject predictors. Furthermore, if random intercept models were used inappropriately in such situations, they found a considerable risk of inflated Type I errors, depending on how pronounced the random slope variation was. These studies indicate that random slope models should be used in situations where effects of experimental manipulations are known or suspected to differ between subjects.

The idea that the magnitude of the effect of an experimental manipulation can vary across subjects is not one typically entertained in repeated measures designs, though this is likely only because it is not possible to model such effects with least squares ANOVA. Least squares ANOVA does not tolerate missing data. As such, apart from fully-crossed designs with complete and balanced data—none of which apply to the current experiments—least squares ANOVA would not permit estimation of random slopes. This is especially problematic for the current experiments because global and

local processing biases are known to vary between individuals, meaning the ideal analysis would need to consider the effects of experimental manipulations only once random variation between individuals in the effect of that manipulation had been controlled for. Multilevel modeling, in contrast, offers substantial flexibility in this regard, including the capacity to a) explicitly represent and quantify how individuals differ in their effects of experimental manipulations, b) predict how individual differences can account for differential sensitivities to manipulations, and c) allow for the inclusion of incomplete data under the assumption that data are missing at random after controlling for the effects of predictors and for the outcomes from the same sampling unit (subjects or display items), which is more reasonable than that assumed by least squares ANOVA (missing completely at random).

Data were analyzed via general (response times) and generalized (errors) linear mixed models with subjects and display items specified as crossed random effects (Baayen, Davidson, & Bates, 2008; Hoffman, 2015) and by-subject random slopes for within-subject manipulations (Barr, 2013; Barr et al., 2013), data permitting. The significance of fixed effects was evaluated via Wald test  $p$ -values. The significance of random effects was evaluated via  $-2\Delta LL$  tests (i.e., deviance difference test—likelihood ratio test using degrees of freedom equal to the difference in the number of estimated parameters). Where relevant, effect sizes were computed using Pseudo- $R^2$  statistics (Singer & Willett, 2003), which reflect the change in each of the relevant variance components before and after including the effects of predictors. Response time models were estimated within SAS PROC MIXED using restricted maximum likelihood

estimation and Satterthwaite denominator degrees of freedom. Given that accuracy was a dichotomous outcome (correct or incorrect), for analysis of errors, a generalized linear function modeling the logit of the probability of an errant response was selected.

Parameter estimates, therefore, are on a logit scale, which is unbounded and symmetric around zero. A logit of zero means that a response was equally likely to be incorrect as correct—i.e., a logit of zero is equivalent to a probability  $p$  of .50, where  $p = \exp(\text{logit}) / (1 + \exp(\text{logit}))$ . To facilitate interpretation, the mean logit of an error in each condition was transformed back onto the probability scale for plotting purposes using the equation above. Error models were estimated within SAS PROC GLIMMIX using maximum likelihood (ADQ) estimation (Laplace estimation was used if maximum likelihood estimates failed to converge) and either Satterthwaite or Kenward-Rogers denominator degrees of freedom (depending on which estimator was used).

Ultimately, the present analytical approach is not a rejection of ANOVA in favor of multilevel modeling—ANOVA is a multilevel model (trials nested within subjects), it is simply one instantiation of a multilevel model that implies a very specific (co)-variance structure. The goal in using multilevel modeling was simply to assess this structure empirically, to account for extra sources of dependency if necessary (if there are no extra sources of dependency then the multilevel model and ANOVA yield identical inferential statistics for fixed effects), and to benefit from the advantages that multilevel modeling offers (more powerful and accurate assessment of fixed effects afforded via use of all observed responses instead of by-subject or by-item condition means).

## **CHAPTER 3: WHICH WAY IS WHICH? GLOBAL AND LOCAL PROCESSING IN INCIDENTAL PERCEPTION OF HIERARCHICAL STRUCTURE**

### **3.0 Chapter Overview**

A novel method combining spatial cueing and compound stimulus paradigms draws on involuntary attentional orienting elicited by a spatially uninformative central arrow cue to investigate global/local processing under incidental processing conditions, wherein global/local levels were uninformative (do not aid performance) and task-irrelevant (need not be processed to perform the task). The task was peripheral target detection. Cues were compound arrows, which were either consistent (global/local arrows oriented in same direction) or inconsistent (global/local arrows oriented in opposite directions). Global/local processing was measured by spatial cueing effects (response time difference between target locations validly cued by an arrow and targets at different locations), with the test of global/local advantage represented by the effect of cue-level for inconsistent cues (response time difference between global-valid and local-valid cues). The temporal asynchrony between presentation of the cue stimulus and the target onset (stimulus-onset-asynchrony; SOA) was manipulated to test whether global/local advantage varied with relative stimulus availability. Experiment 1.1 observed a cue-level by SOA interaction such that an early, large global cueing effect was followed by a later, smaller local cueing effect, indicative of a global-to-local shift in advantage. This occurred despite knowledge that global/local arrows were uninformative and task-irrelevant and could therefore be ignored, thus displaying key properties of an involuntary process. Experiment 1.2 added neutral cues (arrow at one level, rectangle at

the other) and determined that the reversal was not due to inhibition of the globally-cued location or to attenuation of global information but rather to the presence of conflicting spatial information. Experiments 1.3 and 1.4 ruled out alternative accounts for these results. These data indicate global precedence in attended but incidentally processed objects.

### **3.1 Introduction**

Visual scenes (scenes, objects, faces) can be conceptualized as containing global and local information, where global information corresponds to overall form and local information corresponds to finer-grain detail (Neisser, 1967). To examine how information across levels contributes to scene understanding, Navon (1977) presented a compound stimulus—a large global letter composed of smaller local letters—and instructed participants to respond to one level while ignoring the other. Navon found that the global level was responded to faster (global advantage) and was more difficult to ignore (global interference). To explain this finding, a global precedence hypothesis was proposed, whereby a disposition to register form grants processing priority to global information, resulting in early and temporally stable availability of this information. Thus, early availability explained the global advantage and temporal stability explained global interference.

Global precedence is therefore a hypothesis about processing disposition. It provides a theoretical account of global advantage/interference but is not entailed by it, as highlighted by evidence that advantage and interference do not co-vary systematically (Amirkhiabani & Lovegrove, 1999; LaGasse, 1993; Lamb & Robertson, 1989; Navon &

Norman, 1983). That is, global precedence describes the course of visual processing, whereas global advantage and interference are simply phenomena that may or may not be observed as visual processing unfolds. Though advantage and interference may be related, they are independent and thus may arise for a variety of reasons. As such, global precedence can accommodate the observation of advantage or interference, but neither is required for its existence. To determine whether a disposition exists, each level must be equated in terms of likelihood of processing (Navon, 2003), which requires not only the option to process either level but also the option to process neither level. To examine this, one would ideally need to incorporate a compound stimulus that is task-irrelevant. In all previous studies of global/local processing, however, participants have been required to process a compound stimulus in a goal-directed or stimulus-driven manner via task instructions and stimulus parameters that emphasize global or local characteristics. As such, a crucial test of global precedence is missing: does global precedence characterize global/local processing in the absence of a direct demand for global or local processing? To examine this issue, the present study combines Navon's (1977) compound stimulus paradigm with Posner's (1980) spatial cueing paradigm to capitalize on recent evidence that central presentation of overlearned spatial symbols influences the distribution of spatial attention, even when these symbols are task-irrelevant. To our knowledge, this is the first time these paradigms have been combined.

In the traditional spatial cueing paradigm, participants respond to a target appearing at a peripheral location previously indicated by a spatial cue (valid condition) or at a different location (invalid condition). Cueing effects are measured as the



difference in response time (RT) between valid and invalid cues, with facilitation evidenced by faster RTs to cued locations. Traditionally, cueing effects have been dichotomized as either exogenous or endogenous on the basis of their magnitude and time course. Exogenous (involuntary) cueing effects are characterized by large, early, and transient facilitation followed by a period of inhibition (slower responses at cued versus uncued locations) whereas endogenous (voluntary) cueing effects are smaller, later, temporally stable, and unaccompanied by inhibition (see Funes et al., 2005, for a review). Over the last decade, however, numerous reports indicate that behaviorally relevant symbolic stimuli such as directional arrows can influence attentional control in ways that are distinct from the traditional exogenous-endogenous taxonomy (Gibson & Kingstone, 2006; Hommel et al., 2001; Hommel & Akyürek, 2009; Pratt & Hommel, 2003; Ristic & Kingstone, 2006, 2012). In particular, symbolic cues elicit early facilitation, similar to exogenous cues, and prolonged facilitation unaccompanied by inhibition, similar to endogenous cues. Critically, symbolic cueing effects occur even when the cue is spatially uninformative and completely irrelevant to the primary target detection task (Friesen, Bayliss, & Tipper, 2007), thereby displaying key properties of involuntary processes (Hasher & Zacks, 1979).

Given that attention is involuntarily oriented in the direction consistent with the meaning of an arrow, the present study sought to measure global/local processing in terms of spatial cueing effects elicited by presentation of a compound arrow cue. Accordingly, when levels of a cue are inconsistent (directed at opposite locations), a global advantage would be revealed by a global cueing effect (faster RTs to targets at

global-valid versus local-valid locations). To examine whether availability of global information changes over time, stimulus-onset-asynchrony (SOA—time interval between compound-stimulus onset and target presentation onset) was varied (Navon, 1991).

### **3.2 Experiment 1.1: Effect of Cue Globality on Peripheral Target Detection**

The purpose of Experiment 1.1 was to test global precedence under incidental processing conditions. If a global advantage is attributable to earlier availability of global information, then inconsistent cues should elicit a global cueing effect. Furthermore, if the availability of global information is stable over time, then the magnitude of the global cueing effect should be stable across SOA.

#### **3.2.1 Methods**

##### **Participants**

Fifty-two undergraduates from the University of Nebraska-Lincoln participated in exchange for course credit. All participants had normal or corrected-to-normal vision, were naïve to the purpose of the experiment, and were informed of their rights of participation according to the University of Nebraska-Lincoln institutional review board. Three participants completed fewer than half of all trials and were excluded from analysis.

##### **Stimuli**

Cues were structured such that 26 local arrows (each subtending  $.625^\circ \times .50^\circ$  visual angle) yielded a single global arrow ( $7.5^\circ \times 5.0^\circ$ ). Local arrows were outlined in black and presented on a white background. Testing took place on a Pentium IV computer with 17" monitor in a room equipped with soft lighting and sound attenuation.

## **Design and procedure**

There were 240 trials. A central fixation point began each trial and was replaced by the cue after 500 ms, which remained onscreen until a response. A variable SOA (250, 500, 750 ms) preceded the onset of the target (a black circle subtending 1° visual angle). The intertrial interval was 1,500 ms. Cue direction and target location were presented with equal probability leftward or rightward and to the left or right of fixation, respectively. Participants were seated ~48 cm from the monitor and instructed to press the spacebar as quickly as possible when the target appeared while maintaining central fixation throughout. Participants were informed that central arrows were irrelevant to their task and did not predict target location.

Compound arrow cues are shown in Figure 3.1a, the combinations of which may be classified by three factors: consistency (consistent, inconsistent), validity (valid, invalid), and cue-level (global, local). Consistent cues (global and local arrows oriented in the same direction) were either valid (both levels oriented toward the target) or invalid (both levels oriented away from the target). Inconsistent cues, in contrast, were always valid given that either the global or local level was always oriented toward the target. As such, this was a nested design with validity nested within consistent cues and cue-level (whether the global or local level was valid) nested within inconsistent cues. Furthermore, as the ratio of valid to invalid trials was consequently 3:1, the design was also unbalanced. To account for this fact, individual RTs were analyzed with the consistency factor specified as a multivariate outcome.

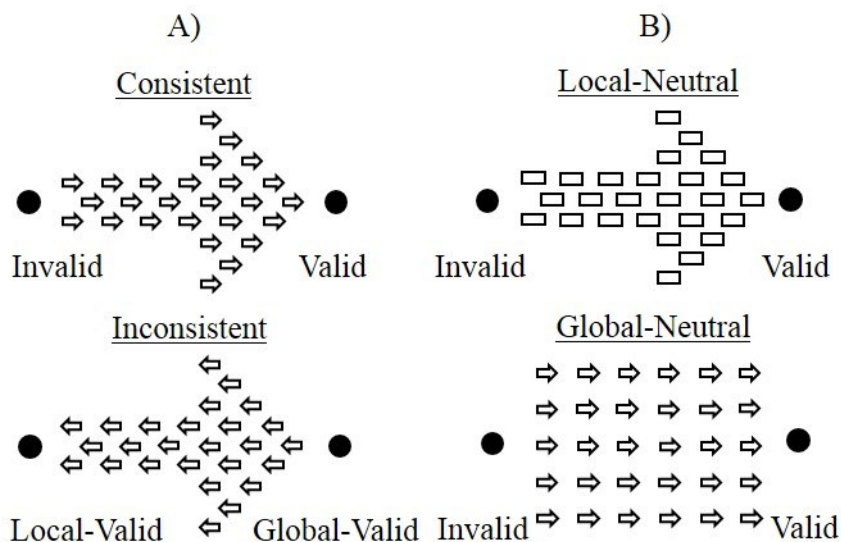


Figure 3.1. Compound arrow cues. A) Consistent and inconsistent cue conditions. B) Local-neutral and global-neutral cue conditions.

### 3.2.2 Results

RTs less than 100 ms or greater than 2.5 *SDs* above condition means were removed (4.2%). Condition mean RTs are shown in Figure 3.2a. Overall, there was a significant main effect of SOA,  $F(2, 94) = 330.51, p < .001$ , reflecting faster RTs with increasing SOA. The main effect of consistency was not significant ( $F < 1$ ); nor was its interaction with SOA,  $F(2, 94) = 2.49, p = .12$ . Importantly, cueing effects were observed with both consistent and inconsistent cues, which are shown in Figure 3.2b.

For consistent cues, the effect of validity was significant,  $F(1, 47) = 50.13, p < .001$ , such that RTs were faster for valid ( $M = 312$ ) versus invalid cues ( $M = 326$ ). The interaction of validity and SOA was not significant ( $F < 1$ ) indicating that the cueing effect was stable across SOA. For inconsistent cues, the effect of cue-level was not significant ( $F < 1$ ) but the interaction with SOA was,  $F(2, 94) = 14.36, p < .001$ . At SOA = 250 ms, there was a significant global cueing effect such that RTs were faster for

global-valid ( $M = 342$ ) versus local-valid ( $M = 358$ ) cues,  $t(48) = 4.50, p < .001$ . At SOA = 500 ms, the effect of cue-level was not significant,  $t(48) = -.80, p = .42$ . At SOA = 750 ms, there was a significant local cueing effect, such that RTs were faster for local-valid ( $M = 291$ ) versus global-valid ( $M = 301$ ) cues,  $t(48) = -2.79, p = .005$ .

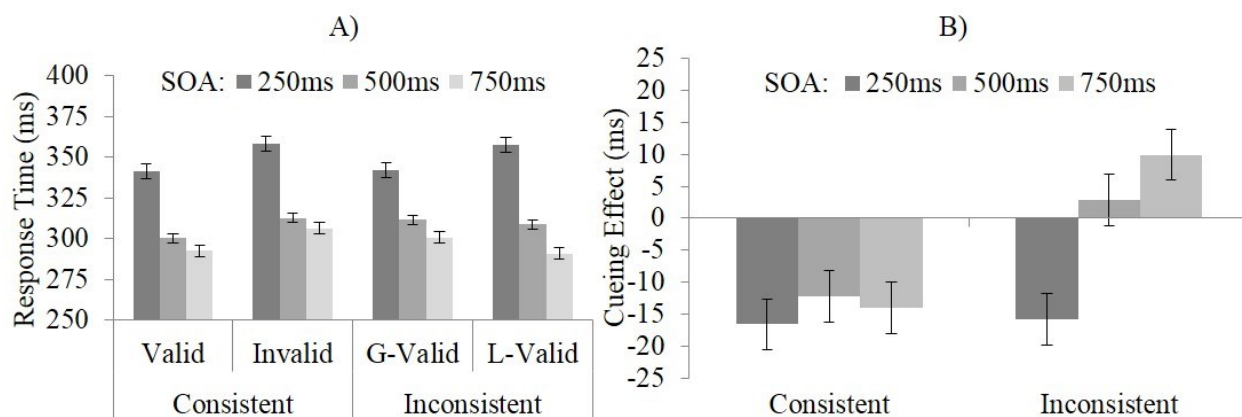


Figure 3.2. Mean RTs and spatial cueing effects in Experiment 1.1 data. A) Mean RT for each cue by validity state as a function of SOA. B) Mean cueing effects for consistent (valid minus invalid) and inconsistent (global-valid minus local-valid) cues as a function of SOA. Error bars represent  $\pm 1$  standard error.

The presence of a global advantage despite the fact that the cue was uninformative and task-irrelevant suggests that the global advantage was a) obligatory, and b) generalizes to conditions in which objects are incidentally processed, which is consistent with global precedence. Interestingly, a local advantage was observed at the latest SOA. As there was little reason to favor one level over the other, let alone to favor both levels in a temporally prescribed order, this suggests that the global-to-local shift in advantage was obligatory. On the one hand, the effect of SOA may suggest that the availability of global information attenuated over time, thereby producing a null effect at intermediate SOAs and permitting the local level to dominate at later SOAs. This

contrasts with global precedence in that the availability of global information should not attenuate and thus should always elicit a global cueing effect. On the other hand, Hommel and Akyurek (2009) found that spatial symbols with incompatible meaning produced conflict between symbolic and voluntary attentional control modes, resulting in competition. Assuming focus shifts induced by irrelevant arrows are more likely to be undone in the presence of competition and that this process takes time, this would explain the null effect at intermediate SOAs. This would be consistent with global precedence as selection of local information would have occurred only after global information had been processed. It is worth noting, however, that the pattern of results for inconsistent cues mirrors that which is typically observed with exogenous cues (early facilitation followed by later inhibition) making it unclear whether the later local advantage was attributable to inhibition of the globally-cued location or to a shift in processing advantage. Neutral cues should delineate among these possibilities.

### **3.3 Experiment 1.2: Testing an Inhibitory Account of Global-To-Local Shifts in Dominance**

Experiment 1.2 replicates and extends Experiment 1.1 by including two neutral conditions in which directional meaning was represented at only one level. In the global-neutral condition, the global level was a rectangle and the local level consisted of arrows. In the local-neutral condition, the global level was an arrow and the local level consisted of rectangles. If attenuation of global information over time gave rise to the local advantage in Experiment 1.1, then the magnitude of the local-neutral cueing effect should decrease with SOA. If the global-to-local shift in advantage was due to inhibition of the

globally-cued location, then the local-neutral cueing effect should show an early global cueing effect and late local cueing effect. If conflicting spatial information between levels gave rise to the local advantage, then the magnitude of the local-neutral cueing effect should be stable across SOA given that the conflicting level does not contain spatial information.

### **3.3.1 Methods**

#### **Participants**

Forty-four undergraduates from the University of Nebraska-Lincoln participated in exchange for course credit. All participants had normal or corrected-to-normal vision, were naïve to the purpose of the experiment, and were informed of their rights of participation according to the University of Nebraska-Lincoln institutional review board. None of the participants took part in Experiment 1.1.

#### **Stimuli**

Global-neutral cues were 30 local arrows arranged to form a global rectangle whereas local-neutral cues were 26 local rectangles arranged to form a global arrow. Consistent and inconsistent cues were the same as in Experiment 1.1, as was the size of global and local elements.

#### **Design and procedure**

These were identical to Experiment 1.1 with two exceptions. First, there were 480 trials. Second, there were two blocks of trials, with consistent and inconsistent cues in one block and neutral cues in the other. Blocking was used to ensure that perception of neutral cues was not biased by the consistent/inconsistent cues between trials. Each block

was performed twice (120 trials/block), with block order counterbalanced across participants. Neutral cues could be any of the four patterns presented in Figure 3.1b, the combinations of which may be classified by the factors validity (valid, invalid) and neutral-level (global-neutral, local-neutral).

### 3.3.2 Results

RTs less than 100 ms or greater than 2.5 *SDs* above condition means were removed (2.4%). Condition mean RTs are shown in Figure 3.3. Overall, there was a significant main effect of SOA,  $F(2, 84) = 313.29, p < .001$ , reflecting faster RTs with increasing SOA. Neither the main effect of consistency nor its interaction with SOA was significant ( $F_s < 1$ ). Importantly, there were significant cueing effects for each cue type, which are shown in Figure 3.4.

For consistent cues, the effect of validity was significant,  $F(1, 42) = 48.31, p < .001$ , such that RTs were faster for valid ( $M = 336$ ) versus invalid cues ( $M = 354$ ). The interaction of validity and SOA was not significant ( $F < 1$ ) indicating that the cueing effect was stable across SOA. For neutral cues, the effect of validity was significant,  $F(1, 42) = 35.52, p < .001$ , such that RTs were faster for valid ( $M = 337$ ) versus invalid cues ( $M = 350$ ), on average. There was also a significant validity x neutral-level interaction,  $F(1, 42) = 5.06, p = .02$ , indicating that the cueing effect was larger for local-neutral (17 ms) versus global-neutral cues (9 ms). The SOA x validity x neutral-level interaction was not significant ( $F < 1$ ) indicating that these effects were stable across SOA.

For inconsistent cues, the effect of cue-level was not significant ( $F < 1$ ) but the interaction with SOA was,  $F(2, 84) = 13.40, p < .001$ . At SOA = 250 ms, there was a



significant global cueing effect (18 ms) such that RTs were faster for global-valid ( $M = 361$ ) versus local-valid ( $M = 379$ ) cues,  $t(43) = 4.27, p < .001$ . At SOA = 500 ms, the effect of cue-level was not significant,  $t(43) = -.23, p = .82$ . At SOA = 750 ms, there was a significant local cueing effect (10 ms) such that RTs were faster for local-valid ( $M = 319$ ) versus global-valid ( $M = 329$ ) cues,  $t(43) = -2.37, p = .02$ .

Experiment 1.2 replicated the global-to-local shift in dominance as a function of SOA observed in Experiment 1.1 and determined that this shift was not attributable to attenuation of global information over time or to inhibition of globally-cued locations, as evidenced by a temporally stable cueing effect for local-neutral cues.

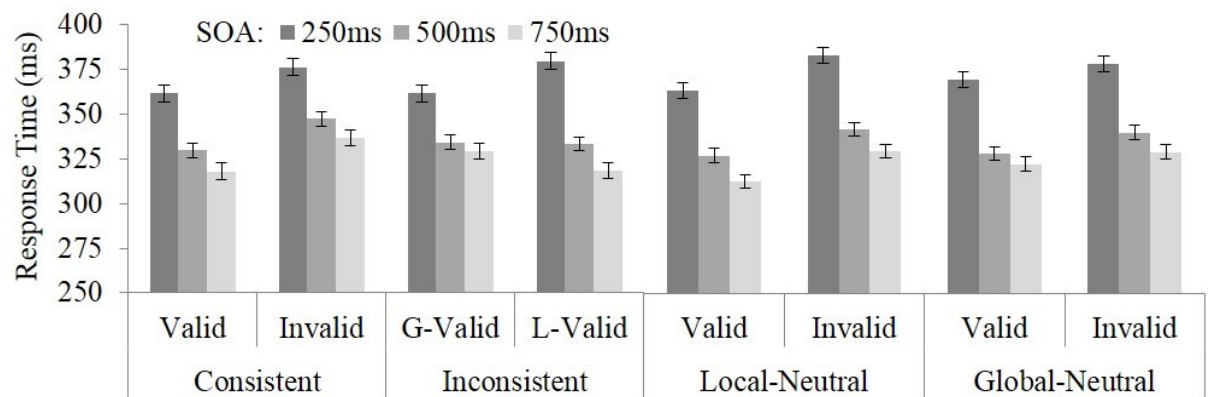


Figure 3.3. Mean RT for each cue by validity state as a function of SOA in Experiment 1.2. Error bars represent +/-1 standard error.

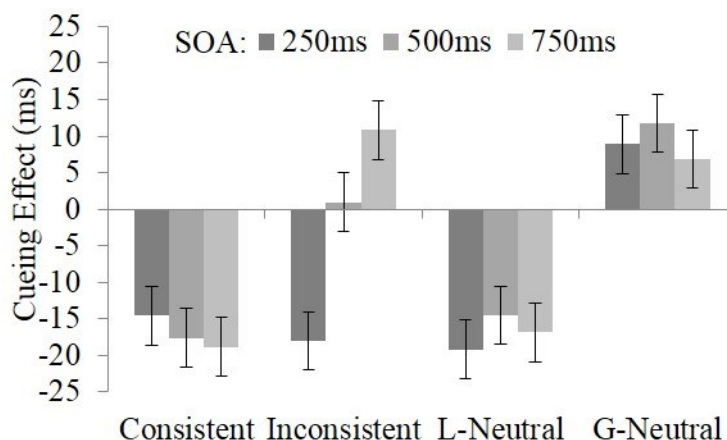


Figure 3.4. Mean spatial cueing effects for consistent (valid minus invalid), inconsistent (global-valid minus local-valid), local-neutral (valid minus invalid), and global-neutral (valid minus invalid) cues as a function of SOA in Experiment 1.2. Note that the global-neutral cueing effect has been remapped (i.e., multiplied by -1) in order to reflect the fact that this cueing effect was due to the local level (given that the global level was a rectangle). Error bars represent +/- 1 standard error.

### 3.4 Interim Summary and Overview of Experiments 1.3 and 1.4

Experiment 1.2 suggests that the early global advantage was due to global precedence and that the global-to-local shift in dominance was attributable to conflicting spatial information between levels. There are at least two alternative interpretations, however, that need to be ruled out. In Experiments 1.1 and 1.2, the global arrow was closer to the location it indicated than were many of the local arrows. One possibility, therefore, is that the global advantage observed at short SOAs was due not to global precedence but to spatial proximity (i.e., the proximity of the global arrow boundaries to the target may have led to a sensory bias in favor of global information). Relatedly, given that the detection task required attention to extend beyond the global arrow boundaries, it

is possible that task demands and spatial proximity together encourage or prime global processing in an indirect manner. Experiment 1.3 examined this possibility by manipulating target eccentricity such that targets appeared either inside or outside the boundaries of the global arrow. If the global advantage was due to spatial proximity, then a local advantage would be expected for targets appearing inside the boundaries of the global arrow and a global advantage would be expected for targets appearing outside.

A second possibility is that global and local levels differed in their validity power. Given that the baseline power of global-neutral cues was half that of local-neutral cues, it is possible that this difference reflects the cue's basic potential rather than its globality. For example, the arrow cues used Experiments 1.1 and 1.2 were relatively small and contained many local elements. Patterns composed of many relatively small elements (many-element patterns) may be perceived as overall form associated with texture, such that local elements lose their function as individual parts of the form, whereas patterns composed of few relatively large elements (few-element patterns) may be perceived as overall form and figural parts (Kimchi, 1992; Pomerantz, 1983). It is possible, therefore, that the use of many-element cues rendered the global level more salient, resulting in a priority for global information (Kimchi, 1990; Kimchi & Palmer, 1982). Although the low cueing power of local arrows cannot explain the global-to-local shift in dominance, it could account for the early global advantage. To examine this possibility, Experiment 1.4 made the local level more salient with the use of few-element cues. Accordingly, if the early global advantage can be attributed to differential salience between global and local levels, then making the local level more salient should lead to an early local advantage.

It is worth noting that the magnitude difference between global-neutral and local-neutral cueing effects is not necessarily incompatible with global precedence. For one, previous work has demonstrated that global rectangles interfere more with local forms than local rectangles interfere with global form (Navon, 1991, Experiment 5), meaning that the difference in baseline could be due to stronger global versus local interference which would be consistent global precedence. For another, the neutral forms of the global and local levels were not perceptually equivalent (though both forms were rectangles with an area equivalent the arrow at the corresponding level, the neutral form of the global level was clearly more square), so a difference in baseline should not be too surprising. For this reason, Experiments 1.3 and 1.4 modified the global-neutral cue to be more rectangular at the global level (see Figure 3.5).

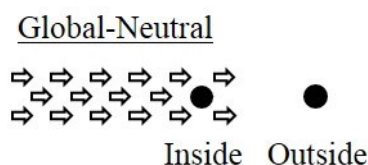


Figure 3.5. Global-neutral cue used in Experiment 1.3. Also shown are the possible target locations for the inside and outside proximity conditions.

### **3.5 Experiment 1.3: Effect of Target Eccentricity**

#### **3.5.1 Methods**

##### **Participants**

Thirty-five undergraduates from the University of Nebraska-Lincoln participated in exchange for course credit. All participants had normal or corrected-to-normal vision, were naïve to the purpose of the experiment, and were informed of their rights of

participation according to the University of Nebraska-Lincoln institutional review board.

None of the participants took part in Experiments 1.1 or 1.2.

### **Stimuli, design, and procedure**

These were identical to Experiment 1.2 except that, a) on 50% of trials the target appeared inside the boundaries of the global arrow (see Figure 3.5), and b) a different global-neutral cue was used. Global-neutral cues were 17 local arrows (each subtending  $1.25^\circ \times 1.0^\circ$  visual angle) arranged to form a single global rectangle ( $7.5^\circ \times 3.0^\circ$ ).

### **3.5.2 Results**

RTs less than 100 ms or greater than 2.5 *SDs* above condition means were removed (2.5%). Cueing effects for each cue type as a function of SOA are shown in Figure 3.6. Overall, there was a main effect of SOA,  $F(2, 68) = 597.31, p < .001$ , reflecting faster RTs with increasing SOA. The main effect of proximity (i.e., whether the target appeared inside or outside of the cue) was not significant ( $F < 1$ ), though, there was an SOA x proximity interaction,  $F(2, 68) = 6.81, p = .009$ , such that the effect of SOA was larger for outside versus inside targets. Neither the main effect of consistency nor its interaction with SOA was significant ( $F_s < 1$ ). Likewise, neither the proximity x consistency nor proximity x consistency x SOA interaction was significant ( $F_s < 1$ ).

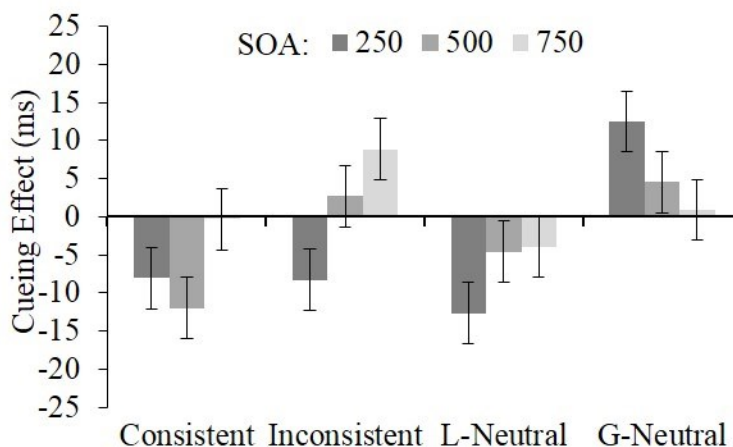


Figure 3.6. Mean spatial cueing effects, averaging over the proximity factor, for consistent (valid minus invalid), inconsistent (global-valid minus local-valid), local-neutral (valid minus invalid), and global-neutral (valid minus invalid) cues as a function of SOA in Experiment 1.3. Note that the global-neutral cueing effect has been remapped (i.e., multiplied by -1) in order to reflect the fact that this cueing effect was due to the local level. Error bars represent +/-1 standard error.

Importantly, if spatial proximity can account for the results of Experiments 1.1 and 1.2, then a local advantage should be observed for targets appearing inside the boundaries of the global arrow and a global advantage should be observed for targets appearing outside. In contrast, and consistent with Experiments 1.1 and 1.2, the SOA x cue-level interaction was significant for inconsistent cues,  $F(2, 68) = 6.92, p = .009$ , the pattern of which replicated the global cueing effect at SOA = 250 ms,  $t(34) = 2.24, p = .025$ , and the local cueing effect at SOA = 750 ms,  $t(34) = -2.45, p = .014$ ; the effect of cue-level was not significant at SOA = 500 ms,  $t(34) = -.75, p = .45$ . There were also effects of validity for consistent,  $F(1, 34) = 8.94, p = .005$ , and for neutral cues,  $F(1, 34) = 14.36, p < .001$ , reflecting significant cueing effects for these cues. Critically, proximity

did not interact with cue-level for inconsistent cues or with validity for consistent cues ( $F_s < 1$ ). Thus, spatial proximity did not significantly alter the global-to-local sequence.

Only responses to neutral cues were influenced by proximity. First, there was a significant proximity x level x SOA interaction,  $F(2, 68) = 5.23, p = .02$ , such that the level x SOA interaction (i.e., effect of level—faster RTs for global-neutral versus local-neutral cues—decreased with increasing SOA) was significant only for outside targets. As the three-way interaction was driven by the null effect of level x SOA for inside cues, it reflects an inconsequential effect of proximity that does not alter the interpretation of the critical finding. Second, there was a significant proximity x validity x SOA interaction,  $F(2, 68) = 4.23, p = .04$ , indicating that the validity x SOA interaction (i.e., smaller cueing effect with increasing SOA) was larger for inside versus outside targets. Looking at Figure 3.7, which shows the pattern of cueing effects for inside and outside targets, it is clear that this interaction was driven by the much larger cueing effect for inside targets at SOA = 250 ms relative to the cueing effect for outside targets. Although this might reflect a spatial proximity effect for global-neutral cues given that its local cueing effect was larger for inside versus outside targets, the fact that local-neutral cues still led to a global cueing effect for inside targets and that this global cueing effect was similarly much larger for inside versus outside targets (as well as the fact that these global and local cueing effects were the same magnitude) provides strong evidence that the global advantage in the present experiments was not due to spatial proximity.

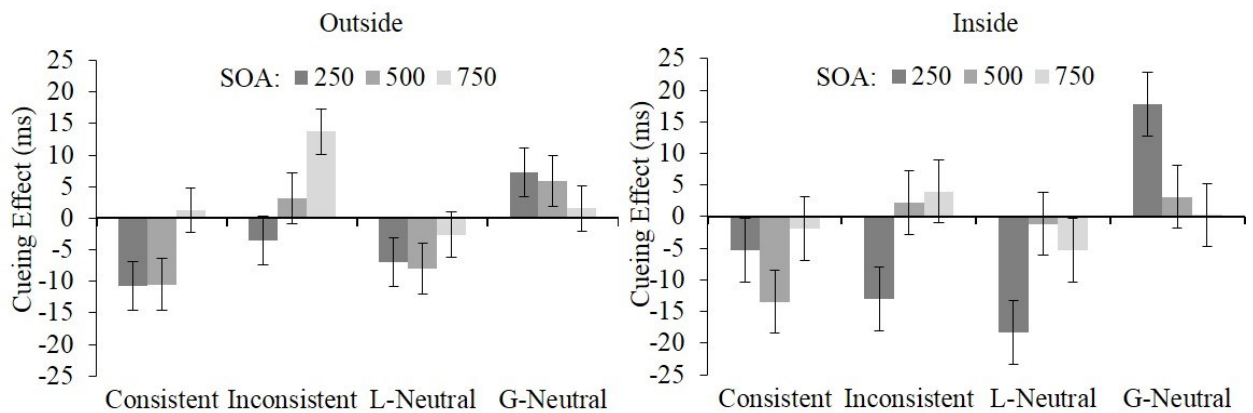


Figure 3.7. Mean spatial cueing effects for consistent (valid minus invalid), inconsistent (global-valid minus local-valid), local-neutral (valid minus invalid), and global-neutral (valid minus invalid) cues as a function of SOA in Experiment 1.3, plotted separately for targets appearing outside (left panel) and inside (right panel) the boundaries of the global arrow cue. Note that the global-neutral cueing effect has been remapped (i.e., multiplied by -1) in order to reflect the fact that this cueing effect was due to the local level. Error bars represent +/-1 standard error.

Interestingly, for consistent cues, there was a marginally significant validity x SOA interaction,  $F(2, 68) = 2.98, p = .08$ , such that the effect of validity was smaller at SOA = 750 ms relative to the 250 ms,  $t(34) = 1.48, p = .13$ , and 500 ms SOAs,  $t(34) = 2.14, p = .03$ . For neutral cues, the validity x SOA interaction was significant,  $F(2, 68) = 7.67, p = .006$ , such that the effect of validity was smaller at the 750 ms,  $t(34) = 2.87, p = .004$ , and 500 ms SOAs,  $t(34) = -1.93, p = .05$ , relative to the 250 ms SOA. Thus, for consistent and neutral cues, cueing effects appear to dissipate at large SOAs. It is unclear what might have caused this. Intertrial effects of proximity, cue type, SOA, and target location were investigated as a possible explanation, but in each case consistent and neutral cueing effects at SOA = 750 ms were either absent or severely diminished. As



such, the introduction of spatial uncertainty from the proximity manipulation is likely at play. For example, Kimchi and Merhav (1991) found mutual interference between global and local levels (i.e., no advantage) under spatial uncertainty. Assuming this was the case here, the present results suggest that such mutual interference takes time to develop (given that an advantage was always observed at SOA = 250 ms) and may interact with eccentricity (given that an advantage was observed with neutral cues at SOA = 500 ms for outside but not inside targets).

### **3.6 Experiment 1.4: Effect of Few- Versus Many-Element Cues**

#### **3.6.1 Methods**

##### **Participants**

Twenty-four undergraduates from the University of Nebraska-Lincoln participated in exchange for course credit. All participants had normal or corrected-to-normal vision, were naïve to the purpose of the experiment, and were informed of their rights of participation according to the University of Nebraska-Lincoln institutional review board. None of the participants took part in any of the previous experiments.

##### **Stimuli, design, and procedure**

These were identical to Experiment 1.2 except for the cue stimuli (Figure 3.8). Consistent, inconsistent, and local-neutral cues were 8 local arrows/rectangles (each subtending  $1.25^\circ \times 1.0^\circ$  visual angle) arranged to form a single global arrow ( $7.5^\circ \times 5.0^\circ$ ). Global-neutral cues were 4 local arrows (each subtending  $1.25^\circ \times 1.0^\circ$  visual angle) arranged to form a single global rectangle ( $7.5^\circ \times 1.0^\circ$ ).

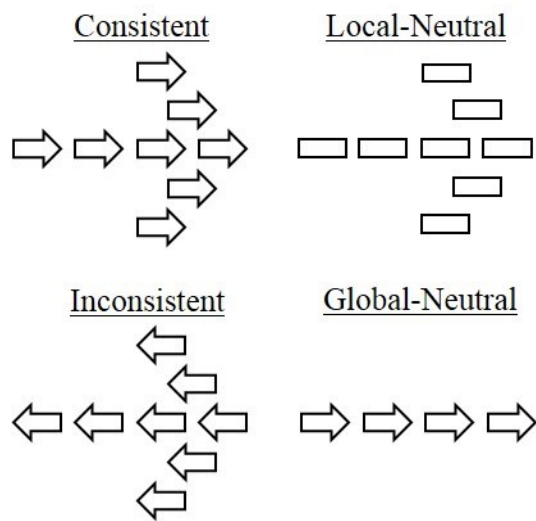


Figure 3.8. Few-element compound arrow cue stimuli in Experiment 1.4.

### 3.6.2 Results

RTs less than 100 ms or greater than 2.5 *SDs* above condition means were removed (2.1%). Cueing effects for each cue type as a function of SOA are shown in Figure 3.9. Overall, there was a main effect of SOA,  $F(2, 46) = 111.09, p < .001$ , reflecting faster RTs with increasing SOA. Neither the main effect of consistency nor its interaction with SOA was significant ( $F_s < 1$ ).

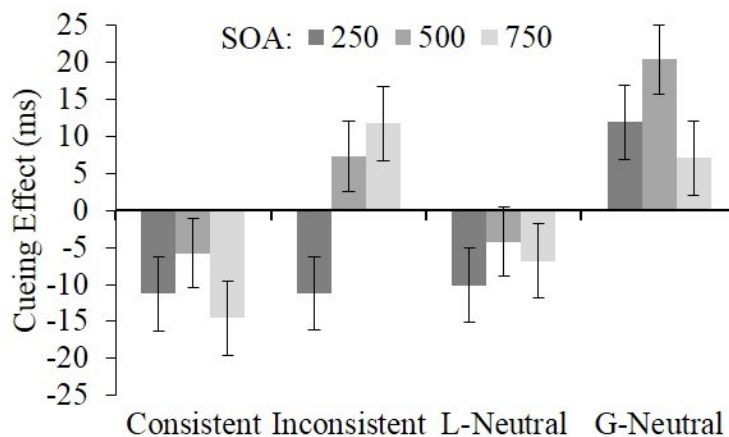


Figure 3.9. Mean spatial cueing effects for consistent (valid minus invalid), inconsistent (global-valid minus local-valid), local-neutral (valid minus invalid), and global-neutral

(valid minus invalid) cues as a function of SOA in Experiment 1.4. Note that the global-neutral cueing effect has been remapped (i.e., multiplied by -1) to reflect the fact that this cueing effect was due to the local level. Error bars represent +/-1 standard error.

For inconsistent cues, the effect of cue-level was not significant ( $F < 1$ ) but its interaction with SOA was,  $F(2, 46) = 4.75, p = .03$ . Consistent with Experiments 1.1-1.3, there was a global cueing effect at SOA = 250 ms,  $t(23) = 1.85, p = .07$ , and a local cueing effect at SOA = 750 ms,  $t(23) = -1.97, p = .05$ ; the effect of cue-level was not significant at SOA = 500 ms,  $t(23) = -1.21, p = .23$ . Thus, few-element cues did not lead to an early local cueing effect. For consistent cues, the effect of validity was significant,  $F(1, 23) = 9.0, p = .01$ , such that RTs were faster for valid ( $M = 317$ ) versus invalid cues ( $M = 328$ ). The interaction of validity and SOA was not significant ( $F < 1$ ), indicating that the cueing effect was stable across SOA. For neutral cues, the effect of validity was significant,  $F(1, 23) = 21.99, p < .001$ , such that RTs were faster for valid ( $M = 317$ ) versus invalid cues ( $M = 327$ ). The validity x neutral-level interaction was not significant,  $F(1, 23) = 1.96, p = .16$ , nor was its interaction with SOA ( $F < 1$ ), indicating that the cueing effect was the same size for local-neutral and global-neutral cues and was stable across SOA. Thus, consistent with Experiment 1.3, global and local arrows did not differ in their baseline validity power, suggesting the difference observed in Experiment 1.2 was attributable either to global-to-local interference or to the shape of the global level rather than differential baseline validity power. It is also worth noting that consistent and neutral cueing effects were stable across SOA, which replicates Experiments 1.1 and 1.2 and points to spatial uncertainty as the source of their dissipation in Experiment 1.3.

### 3.7 Discussion

The present study tested global precedence under conditions where processing of global/local levels was incidental and, therefore, optimally suited for the testing of a hypothesized processing disposition. Participants performed a peripheral target detection task in the presence of a central non-predictive task-irrelevant compound arrow cue. Given evidence that these cues elicit involuntary spatial cueing effects, global/local processing was measured by spatial cueing effects. Supporting the notion that global information is available early and receives priority, a global cueing effect was observed at the earliest SOA despite cue processing being unnecessary. This suggests either that attention to the global level was obligatory or that the locus of the global advantage lies within processes preceding selective attention (e.g., perceptual organization; Neisser, 1967). In either case, the source of the global advantage seems perceptual, consistent with Navon's (1977) proposal. This conclusion is strengthened by the fact that the global advantage was observed within the spatial cueing paradigm, wherein responses (simple target detection) do not depend on post-perceptual processing stages to nearly the same extent as typical global/local tasks (e.g., identification, discrimination, categorization). Interestingly, and somewhat unexpectedly, a local cueing effect was observed at the latest SOA. The observation of a global advantage temporally preceding a local advantage under stimulus and task conditions that provided little if any basis for favoring one level over the other, let alone for favoring both levels in a temporally prescribed order, suggests that the global-to-local processing sequence may be obligatory. Importantly, this shift was not due to attenuation of global information as the magnitude of the cueing

effect for the neutral condition in which only the global level was an arrow remained constant across SOA. It would seem then that the early prioritization of global information leads to large, rapid cueing effects that eventually give way to later processing at other levels—though the conflict between cue levels influences response at these later times (Hommel & Akyurek, 2009). In support of this interpretation, and as predicted by global precedence, the global advantage was twice the size of the local advantage. Taken together, the present data find support for global precedence in attended but incidentally processed objects.

Though the present study was designed to examine global/local processing under incidental processing conditions, the interaction of SOA with cue-level also has the potential to advance understanding of spatial cueing effects more generally. Exogenous and endogenous cues, which differ in magnitude and time course, are traditionally thought to reflect distinct subtypes of attention, with symbolic cues representing a hybrid of these subtypes. The present results demonstrate the importance of cue-level in the magnitude and time course of a cue's effect on attention. Specifically, cues at a global level had larger and earlier effects on attention, meaning differences among cues may reflect differences in representational level rather than, or in addition to, different types of attention.

Finally, it is important to note that the present use of an incidental processing paradigm is important in that it closely reflects the manner in which a great deal of information is processed in the real world. Though attention, perception, and action can be strongly influenced by goals and intentions, processing of stimuli routinely occurs in a

passive manner given the overwhelming number of inputs available at any given time. The present results suggest that under such conditions the perceptual system is more prepared to process global versus local information. This reasoning dovetails with Navon's (1977, 2003) conceptualization of global precedence as a processing disposition. Accordingly, a disposition constitutes just one vector in a complex space in which vectors are not necessarily orthogonal, meaning a disposition could easily be counteracted by any number of modulating factors in real-world situations. It should not be surprising, therefore, that task and stimulus parameters are capable of modulating and reversing asymmetries in processing dominance (e.g., Schyns & Oliva, 1994; Oliva & Schyns, 1997). In this light, the test of any disposition would necessarily require proper control and possibly special conditions. The present study suggests that incidental processing is one such condition.

## **CHAPTER 4: MOVING THOUGHTS MAKE FOR MOVING TARGETS: CAPTURING TIME SENSITIVE EFFECTS IN GLOBAL AND LOCAL PROCESSING**

### **4.0 Chapter Overview**

Chapter 4 reports an experiment in which the goal is to map the time course of global and local processing using a more sensitive method and analytic approach for making fine-grain measurements of the effect of SOA on global and local processing biases. Given that perceptual processing changes over time, experimental methods have been developed to manipulate various timing aspects in order to analyze factors that control this change. Categorical models of change such as analysis of variance are appropriate when there is no meaningful segregation of time. But what about time course studies where the goal is to manipulate rate of change, such as tasks in which SOA is varied to assess change in facilitation and inhibition over time, or as in the compound arrow cueing paradigm in which SOA is varied to assess change in availability over time? Where discrete phases of time are theoretically meaningful, researchers may feel resigned to choose a priori 'where' in time those discrete phases are best probed. One of the problems with having to make a priori choices about 'where' in time to probe attention is the inherent risk of choosing the wrong point in time, which, at best may cause one to miss effects that manifest perhaps only milliseconds before or after the chosen time point and, at worst, provide only a glimpse into the time course function such that the conclusions researchers draw are essentially determined by methodological decisions, creating a sort of moving target. Experiment 2 has three aims: 1) to examine the time

course of global/local processing, 2) to present an approach for manipulating SOA across a broad window, and 3) to propose a model of discontinuous change well-suited for capturing change across meaningful, discrete phases of time.

## **4.1 Methods**

### **Participants**

Forty-one undergraduates from the University of Nebraska-Lincoln participated in exchange for course credit. All participants had normal or corrected-to-normal vision, were naïve to the purpose of the experiment, and were informed of their rights of participation according to the University of Nebraska-Lincoln institutional review board. None of the participants took part in any of the previous experiments.

### **Stimuli, procedure, and design**

The stimuli and experimental procedure were the same as in Experiment 1.2 but the design differed in that SOA was now a trial-level predictor (rather than a display item-level predictor). In terms of design factors and dimensionality, this means that every trial was potentially a unique display item (i.e., there were few, if any, repetitions of display items within a condition within a subject).

### **Generative model for SOA manipulation**

SOA values were generated for trial  $t$  in subject  $s$  by sampling from the continuous uniform distribution,  $SOA_{ts} \sim U(a, b)$ , where  $SOA_{ts} = a + (b - a) * \text{RAND}(\text{"UNIFORM"})$ . Values generated from  $U(a, b)$  were rounded to the nearest integer. The seed value for the random function was PC time. This generation process was used to sample SOAs from three specific intervals, each corresponding to



theoretically meaningful points in time at which processing of global or local information has been shown to dominate or is expected to change. The first interval, U(100, 300), sampled from points in time during which global processing was expected to dominate. The second interval, U(400, 600), sampled from points in time during which global processing was expected to transition to local processing. Thus, sampling multiple points around this point in time afforded a test of whether this transition proceeded more continuously or discretely. Finally, the third interval, U(700, 900), sampled from points in time during which local processing was expected to dominate. Moreover, as local processing is generally conceived as volitional, at least more so than global processing, multiple samples during this time interval afforded a test of whether volitional biases were constant over time, or at least changed over time less so than global processing.

Table 4.1 shows the distributional characteristics of the generated SOA values.

Table 4.1. Sample characteristics for the generated SOA values in Experiment 2.

SOA Interval	<i>Frequency</i>	<i>Percent</i>	<i>Mean</i>	<i>SD</i>
U(100, 300)	6,771	34.41	200.28	58.50
U(400, 600)	6,439	32.72	500.84	57.47
U(700, 900)	6,470	32.88	800.22	57.13
Total	19,680	100.00	495.85	252.70

### **Piecewise jump and slope model for estimating macro- and micro- effects of SOA**

To analyze effects of SOA on change in global and local processing over discontinuous time, a piecewise jump and slope model (Hoffman, 2015) was estimated. The model contained three piecewise slope terms (one for indexing change within each

time interval) and two jump terms (which capture the mean difference between intervals).

The model is presented in Equation 1 below.

$$RT_{ts} = \gamma_{00} + \gamma_{10}(\text{Slope1}_{ts}) + \gamma_{20}(\text{Jump2}_{ts}) + \gamma_{30}(\text{Slope2}_{ts}) + \gamma_{40}(\text{Jump3}_{ts}) + \gamma_{50}(\text{Slope3}_{ts}) + U_t + U_s + e_{ts}. \quad (1)$$

The intercept  $\gamma_{00}$  is the predicted response time (RT) in milliseconds on trial  $t$  from subject  $s$ . The predictor variable for Slope1 captures the slope specifically during the first SOA interval,  $U(100, 300)$ : it starts at 100 and indexes the change in RT during the first interval, but then shuts off afterwards at its last value of 300. If no other jump or slope terms for the other intervals were included, then the model would predict that the RT value expected at an SOA of 300 should remain constant for the rest of the SOAs. The next two intervals are each characterized by a jump and a slope that work together to describe the trajectory during each interval. The predictor variable for Jump2 represents the acute shift in the intercept at the beginning of the second interval: it has a value of 0 before the second interval and a value of 100 afterwards given that SOAs between 300 and 400 were not sampled. Thus, it represents the mean difference in RT between an SOA of 300 and an SOA of 400. The predictor variable for Slope2, then, captures the slope specifically during the second interval: it is 0 until the end of the first interval, indexes the change in RT during the second interval, and then turns off afterwards at its last value of 600. Continuing further along the trajectory, the predictor variable for Jump3 represents the acute shift in the intercept at the beginning of the third interval: it has a value of 0 before the third interval and a value of 100 afterwards given that SOAs between 600 and 700 were not sampled. Thus, it represents the mean difference in RT

between an SOA of 600 and an SOA of 700. The predictor variable for Slope3, then, captures the slope specifically during the third interval: it is 0 until the end of the second interval and indexes the change in RT during the third interval. Table 4.2 provides an illustration of the data structure necessary for fitting this model.

Table 4.2. Illustration of data structure for fitting a piecewise jump and slope model with three linear slope terms and two jump terms.

SOA	SOAc	Slope1	Jump2	Slope2	Jump3	Slope3
100	0	0	0	0	0	0
101	1	1	0	0	0	0
...	...	...	...	...	...	...
299	199	199	0	0	0	0
300	200	200	0	0	0	0
400	300	200	1	100	0	0
401	301	200	1	101	0	0
...	...	...	...	...	...	...
599	499	200	1	299	0	0
600	500	200	1	300	0	0
700	600	200	1	300	1	100
701	601	200	1	300	1	101
...	...	...	...	...	...	...
899	799	200	1	300	1	299
900	800	200	1	300	1	300

## 4.2 Results

Response times less than 100 ms or greater than 2,000 ms were removed (< 1%).

First, to determine whether the pattern of spatial cueing effects in Experiment 1 was replicated in the present experiment, the effects of validity for each cue type were examined specifically at SOAs of 250, 500, and 750 ms. As can be seen in Figure 4.1, which plots mean RT by cue type and validity state specifically at 250, 500, and 750 ms

SOAs, the pattern of spatial cueing effects appears to replicate the pattern observed in Experiment 1: with consistent, local-neutral, and global-neutral cues, a ~10-20 ms cueing effect was observed and which appeared to be temporally stable; with inconsistent cues, a global cueing effect was observed at the shortest SOA whereas a local cueing effect was observed at longer SOAs.

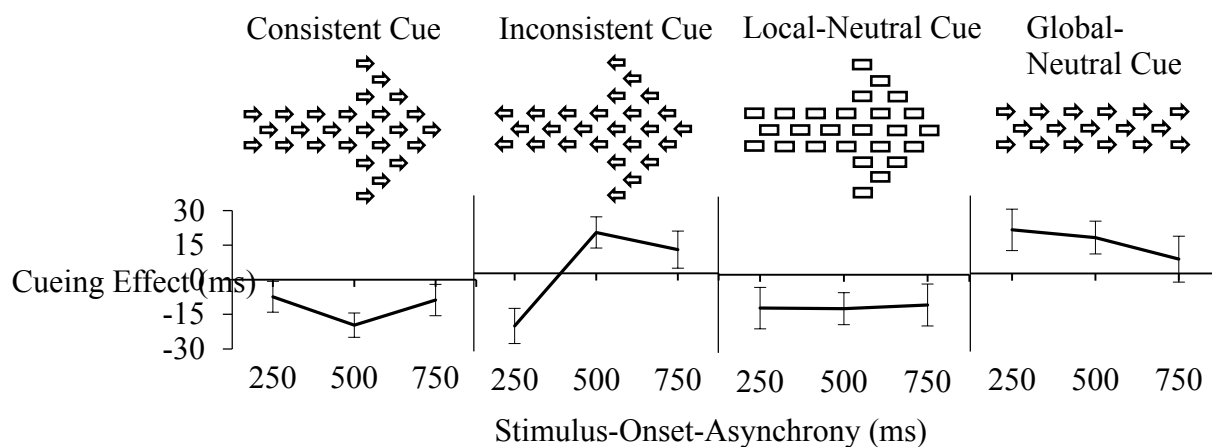


Figure 4.1. Mean RTs by cue type and validity state in Experiment 2, plotted at 250, 500, and 750 ms SOAs. Note that the global-neutral cueing effect has been remapped (i.e., multiplied by -1) to reflect the fact that this cueing effect was due to the local level. Error bars represent +/-1 standard error.

Next, micro- and macro- effects of SOA were evaluated, as estimated by the piecewise jump and slope model described in Section 4.2.4 (in which SOA was centered at 100 ms). Parameters estimates for each cue type are shown on Table 4.3. The intercept  $\gamma_{00}$  is the predicted mean RT in ms on trial  $t$  for subject  $s$ , specifically at SOA = 100 ms. The effect of Slope1  $\gamma_{10}$  is the linear rate of change in RT specifically during U(100, 300). The effect of Jump2  $\gamma_{20}$  is the acute shift in the intercept at the start of U(400, 600) and represents the mean difference in RT between an SOA of 300 and an SOA of 400.

The effect of Slope2  $\gamma_{30}$  is the linear rate of change in RT specifically during U(400, 600). The effect of Jump3  $\gamma_{40}$  is the acute shift in the intercept at the start of U(700, 900) and represents the mean difference in RT between an SOA of 600 and an SOA of 700. The effect of Slope3  $\gamma_{50}$  is the linear rate of change in RT specifically during U(700, 900). The effect of validity  $\gamma_{60}$  is the mean difference in RT between valid and invalid cues (or, for inconsistent cues, between global-valid and local-valid cues), specifically at SOA = 100 ms. Thus, slope by validity and jump by validity interactions reflect the mean difference in the slope or jump term between validity states.

Table 4.3. Parameter estimates for each cue type (consistent, inconsistent, local-neutral, and global-neutral), as estimated by a piecewise slope and jump model for the effect of SOA in Experiment 2. Significant estimates ( $p < .05$ ) are highlighted in bold.

Model Parameter	<u>Consistent</u>		<u>Inconsistent</u>		<u>Local-Neutral</u>		<u>Global-Neutral</u>	
	<i>Est</i>	<i>SE</i>	<i>Est</i>	<i>SE</i>	<i>Est</i>	<i>SE</i>	<i>Est</i>	<i>SE</i>
<u>Fixed Effects</u>								
$\gamma_{00}$ Intercept	<b>418.47</b>	8.27	<b>419.18</b>	8.45	<b>430.48</b>	10.94	<b>421.31</b>	10.74
$\gamma_{10}$ Slope1	<b>-.28</b>	.04	<b>-.29</b>	.04	<b>-.25</b>	.05	<b>-.22</b>	.05
$\gamma_{20}$ Jump2	-7.12	11.00	-9.39	10.51	<b>-23.66</b>	13.26	1.25	12.31
$\gamma_{30}$ Slope2	-.06	.04	-.02	.04	-.02	.05	<b>-.15</b>	.05
$\gamma_{40}$ Jump3	-13.60	10.66	-7.99	10.23	-10.03	12.84	.70	13.08
$\gamma_{50}$ Slope3	.05	.04	-.05	.04	-.02	.05	.00	.05
$\gamma_{60}$ Validity	<b>19.02</b>	9.40	<b>26.14</b>	9.91	-.72	12.13	.10	11.37
$\gamma_{70}$ Validity*Slope1	-.08	.09	-.04	.08	.09	.10	.11	.10
$\gamma_{80}$ Validity*Jump2	26.95	21.34	<b>-41.52</b>	20.44	<b>53.73</b>	25.73	-27.07	24.66
$\gamma_{90}$ Validity*Slope2	-.05	.09	.04	.09	<b>-.29</b>	.11	.09	.10
$\gamma_{10}$ Validity*Jump3	-20.30	21.31	-8.23	20.14	27.08	25.72	-21.97	25.90
$\gamma_{11}$ Validity*Slope3	.10	.09	.07	.08	.00	.11	.03	.11
<u>Random Effects</u>								
$U_{s0}$ Intercept	<b>1708</b>	424	<b>1988</b>	484	<b>3393</b>	820	<b>3461</b>	815
$U_{s2}$ Jump2	<b>327</b>	159	<b>269</b>	145	<b>424</b>	215	.00	.00
$U_{s4}$ Jump3			144	125			181	371
$U_{s6}$ Validity	24	87	<b>255</b>	150			.00	.01
$U_{s8}$ Validity*Jump2			166	203			208	152
$e_{ts}$ Residual	<b>10707</b>	220	<b>9594</b>	200	<b>15144</b>	309	<b>14056</b>	288

Mean spatial cueing effects as a function of SOA are shown for consistent and inconsistent cues in Figure 4.2 and for local-neutral and global-neutral cues in Figure 4.3. For consistent cues, there was a significant  $\gamma_{60} = 19.0$  ms cueing effect at SOA = 100 ms. Furthermore, the non-significant validity by slope interactions indicate that the magnitude of the cueing effect was not predicted to vary within a given SOA interval, and the non-significant validity by jump interactions indicate that the change in magnitude of the cueing effect within an interval was not predicted to differ between intervals. Thus, with consistent cues, a significant, temporally stable cueing effect was observed.

For inconsistent cues, there was a significant  $\gamma_{60} = 26.1$  ms cueing effect at SOA = 100 ms. The positive sign of this effect indicates it was due to the global level. The non-significant validity by Slope1 interaction indicates that the magnitude of the global cueing effect was not predicted to vary within the U(100, 300) SOA interval. Importantly, the significant validity by Jump2 interaction indicates that the magnitude of the cueing effect at the end of the U(100, 300) SOA interval was predicted to be reduced by  $\gamma_{80} = -45.5$  ms at the start of the U(400, 600) SOA interval. As result, the sign of the cueing effect during the U(400, 600) SOA interval was predicted to be negative (i.e.,  $\gamma_{60} + \gamma_{80} = -19.4$  ms), indicating it was due to the local level. The non-significant validity by Slope2 and validity by Slope3 interactions indicate that this local cueing effect was not predicted to vary within the U(400, 600) or U(700, 900) SOA intervals, respectively. Moreover, the non-significant validity by Jump3 interaction indicates that the magnitude of the cueing effect was not predicted to differ between the end of the U(400, 600) SOA interval and the start of the U(700, 900) SOA interval. Thus, with inconsistent cues, a significant and

temporally stable global cueing effect was observed within the U(100, 300) SOA interval, whereas a significant and temporally stable local cueing effect was observed with the U(400, 600) and U(700, 900) intervals.

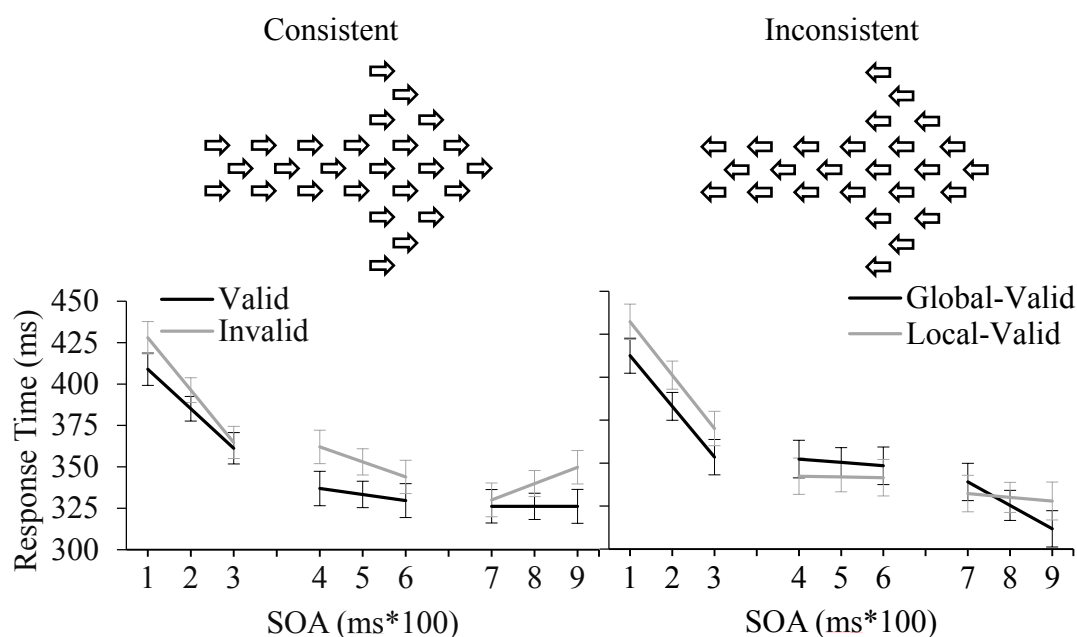


Figure 4.2. Mean RTs by validity state and SOA for consistent and inconsistent cues in Experiment 2. Error bars represent +/-1 standard error.

For local-neutral cues, there was a non-significant  $\gamma_{60} = -0.72$  ms cueing effect at SOA = 100 ms, and the non-significant validity by Slope1 interaction indicates that the magnitude of the cueing was not predicted to vary within the U(100, 300) SOA interval. There was, however, a significant validity by Jump2 interaction such that the magnitude of the cueing effect at the start of the U(400, 600) SOA interval was predicted to be larger by  $\gamma_{80} = 53.7$  ms than its magnitude at the end of the U(100, 300) SOA interval. Moreover, the significant validity by Slope2 interaction indicates that the magnitude of the cueing effect was predicted to be reduced by  $\gamma_{90} = -0.29$  ms per 1 ms increase in SOA

within the U(400, 600) SOA interval. Finally, the non-significant validity by Jump3 interaction indicates that the magnitude of the cueing effect was not predicted to differ between the end of the U(400, 600) SOA interval and the start of the U(700, 900) SOA interval, and the non-significant validity by Slope3 interaction indicates that the magnitude of the cueing effect was not predicted to vary within the U(700, 900) SOA interval. Thus, with local-neutral cues, a slowly rising and transient cueing effect was observed such that the effect did not emerge until ~300-400 ms into the processing episode, at which point it began to gradually diminish in magnitude.

For global-neutral cues, there was a non-significant  $\gamma_{60} = 0.10$  ms cueing effect at SOA = 100 ms. Furthermore, the non-significant validity by slope interactions indicate that the magnitude of the cueing effect was not predicted to vary within a given SOA interval, and the non-significant validity by jump interactions indicate that the change in magnitude of the cueing effect within an interval was not predicted to differ between intervals. Thus, with global-neutral cues, a non-significant, temporally stable cueing effect was observed.



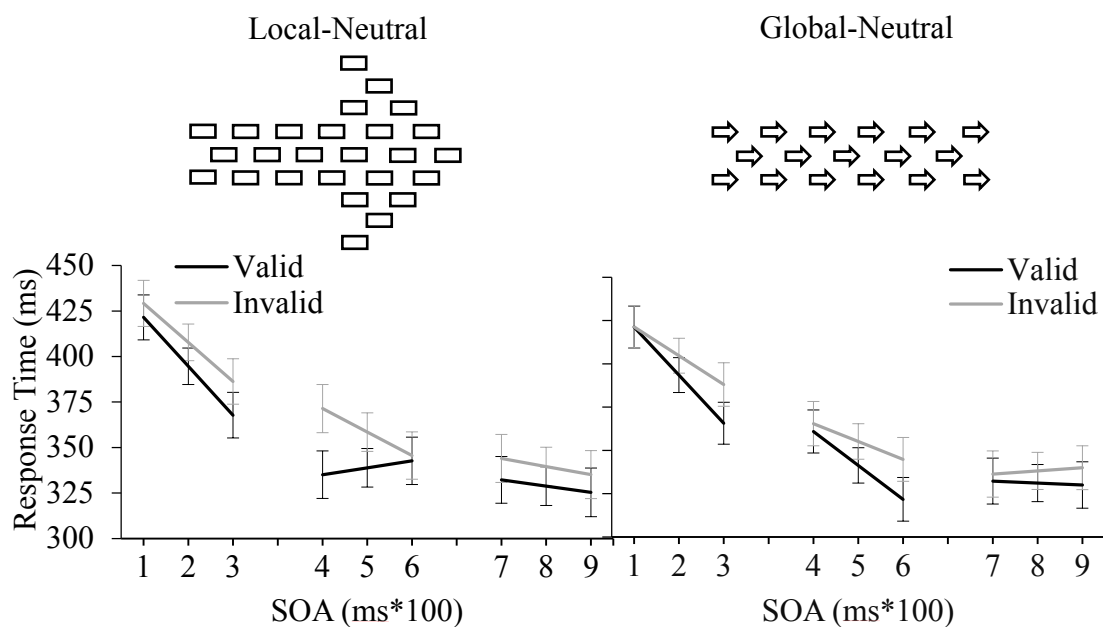


Figure 4.3. Mean RTs by validity state and SOA for local-neutral and global-neutral cues in Experiment 2. Note that the global-neutral cueing effect has been remapped (i.e., multiplied by -1) to reflect the fact that this cueing effect was due to the local level. Error bars represent +/-1 standard error.

### 4.3 Discussion

The results indicated that, on average, processing transitioned from global to local dominance over time, consistent with the results presented in Experiment 1. Examination of time course variation around this average, however, pointed to an ebb-and-flow in dominance rather than strict linear change. The results showed that within the earliest time interval (SOAs between 100 and 300 ms) there was a global advantage. Also, there was more subject variation in the time course trajectories of local cueing effects than in the time course trajectories of global cueing effects. These observations suggest global

processing dominates during automatic perceptual analysis whereas local processing dominates during strategic perceptual analysis.

It is possible to perform the SOA manipulation procedure for any experimental parameter that could in theory be drawn from a population. The main advantage of this procedure is the ability to estimate effects for a very large time window so that experimental effects known or suspected to change over time are not missed due to sampling too narrow of a window and, furthermore, so that effects of time on experimental effects can be predicted within other windows. Also, this approach affords the ability to assess both macro (e.g., three theoretically relevant time intervals) and micro time scales (fixed and random change in and around those time intervals), which can provide additional information for generating and testing hypotheses.

The piecewise jump and slope model is especially well-suited for addressing the present research question in which manipulation of SOA stands at the fore, but likely is equally well-suited for many other common timing-interval manipulations, for instance, preparatory intervals, response-cue intervals, preview and exposure durations, and the like, each of which are central manipulations in several paradigms (e.g., cueing and task switching). Moreover, the model can easily be extended to accommodate non-linear slopes within each interval (e.g., exponential or quadratic).

## CHAPTER 5: ROLE OF TOP-DOWN TASK SET

### 5.0 Chapter Overview

Chapter 5 reports an experiment examining how different orienting tasks influence the global-to-local sequence. Spatial symbols can generate attentional biases toward peripheral locations compatible with the symbol's meaning. An important question concerns how one symbol is selected when competing symbols are present. Studies examining this issue for spatially distinct symbols suggest that selection depends on task goals. The present study examines whether the influence of competing symbolic stimuli (arrows) at different levels of structure on attentional control also depends on task goals. Participants made simple detection responses to a peripheral target preceded by a spatially uninformative compound arrow (global arrow composed of local arrows). In addition, participants were required to perform a secondary task where they matched the orientation of the global arrow (global task) or the location of a uniquely colored local arrow (local task) to a test display presented immediately following a detection response. When global and local arrows pointed at opposite locations, there was a local cueing effect in the local task and a global cueing effect in the global task, indicating that task goals influenced the selection of the level of structure. However, when the local level was spatially neutral (global arrow, local rectangles), a cueing effect was observed independent of task, and when the global level was spatially neutral (global rectangle, local arrows), a cueing effect was observed in the local task only, suggesting that global processing was obligatory and local processing optional. These findings suggest that

attentional effects triggered by the global level are more strongly reflexive than those triggered by the local level.

## **5.1 Introduction**

Everyday visual environments generally contain more information than can be processed within a glance. As such, goal-directed perception and action depend on mechanisms of selective visual attention for prioritizing an endless stream of sensory input, and so giving more weight to those objects, locations, or events that require immediate or sustained processing. To understand how attention is prioritized and allocated to visual stimuli, a useful distinction is that between bottom-up (reflexive) and top-down (volitional) attentional control, with the former driven by the physical characteristics of a stimulus and the latter by the current goals of the observer (Corbetta & Shulman, 2002; Desimone & Duncan, 1995; Egeth & Yantis, 1997; Itti & Koch, 2000; Jonides, 1981; Posner, 1980; see Yantis, 2000, for a review). For example, an abrupt visual onset may on the one hand capture attention in a purely stimulus-driven manner (Enns, Austen, Di Lollo, Rauschenberger, & Yantis, 2001; Remington, Johnston, & Yantis, 1986; Theeuwes, 1990, 1994; Yantis & Jonides, 1984). On the other hand, capture may be contingent on the top-down attentional set of an observer such that the onset captures attention only if it shares a feature with an item in that set (Folk & Remington, 1998; Folk, Remington, & Johnston, 1992).

Outside of the traditional top-down/bottom-up dichotomy, considerable evidence exists indicating that various kinds of symbolic information presented at fixation produce unintentional shifts of attention to peripheral locations compatible with the meaning of

the symbol. For example, Hommel et al. (2001) presented a centrally located directional arrow (e.g., <, >) or word (e.g., left, right) which was followed by a peripheral target requiring a detection response. Targets were detected more quickly when they appeared at the location indicated by the arrow or word (valid condition) than at another location (invalid condition). Importantly, this occurred even though these symbols were entirely irrelevant to the detection task, and observers were explicitly told that the symbols did not predict the location of the upcoming target (see also, Ristic & Kingstone, 2006, 2012; Ristic et al., 2012). Similar findings have been observed for temporal words (e.g., tomorrow, yesterday; Weger & Pratt, 2008), words relating to concrete concepts (e.g., head, foot; Estes, Verges, & Barsalou, 2008), words relating to abstract concepts (e.g., god, devil; Chasteen, Burdzy, & Pratt, 2010), pictures relating to abstract concepts (e.g., liberal, conservative; Mills, Smith, Hibbing, & Dodd, 2015), numbers (Fischer, Castel, Dodd, & Pratt, 2003), and letters (Dodd, Van der Stigchel, Leghari, Fung, & Kingstone, 2008). Taken together, these findings indicate that a broad range of visual symbols can produce unintentional shifts of attention (but see Fattorini, Pinto, Rotondaro, & Doricchi, 2015).

Not all visual symbols capable of producing unintentional shifts of attention are likely to do so in all situations, however. For example, observers are sometimes faced with scenes in which one symbol is nested within another, potentially conflicting symbol (e.g., eyes looking one way nested within a head looking another way). Assuming that shifts of attention cannot be made in two or more directions simultaneously, an important question is which level might be selected (global head or local eyes) to control the

allocation of attention? The present study examines this issue using compound stimuli for which observers should have no a priori basis for selecting one level over the other (global arrow composed of local arrows). One possibility is that the level that is relevant to the current task goal will be selected, and the arrow at this task-relevant level will then produce an unintentional shift of attention. Evidence for this hypothesis comes from research on the role of control settings in attentional capture. The framework of attentional control settings (Folk et al., 1992) proposes that the processing of a stimulus feature is contingent on the task goal at hand such that only stimuli possessing a task-relevant feature can pass through a perceptual filter and enter working memory. For instance, Pratt and Hommel (2003) examined how one symbol is selected to control the allocation of attention when several symbols appear in the visual field. They found that in a field of spatially distinct arrows, the arrow most likely to affect attentional control was that which possessed a task-relevant feature of an expected target. This suggests that the unintentional effects of arrows depend on the cognitively represented task goal. Thus, the control setting account predicts that only the arrow that shares a critical feature specified by top-down control settings will be selected to control the allocation of attention.

Another possibility is that the global level will be selected first regardless of task, and this global arrow will then produce an unintentional shift of attention. Evidence for this hypothesis comes from research on the role of global perceptual precedence in perception of hierarchical structure, as well as the previous experiments reported in the current thesis. Global precedence (Navon, 1977, 2003) proposes that perceptual processing is predisposed to favor the processing of “clusters” such that the global form

of a hierarchical structure is registered earlier than its local constituents, resulting in greater availability of the global versus local percept. As such, processing of global information is assumed to be obligatory whereas processing of local information is optional. Navon (1977) tested this notion in experiments involving compound stimuli—stimuli with hierarchical levels of structure (e.g., large, global F constructed from small, local Hs). Observers were presented with these stimuli and instructed to identify the letter at either the global or local level. Importantly, the relation between levels was either consistent (global F, local Fs) or inconsistent (global F, local Hs). The critical finding was that global versus local letters were identified faster (global advantage) and that processing of the local level was slowed to a greater extent than processing of the global level when global and local object-identities were inconsistent (global interference). Such findings indicate that global properties can be extracted rapidly, suggesting that the potency of an arrow to evoke an unintentional shift of attention may depend on its globality (i.e., its relative position in hierarchical space).

Navon's (1977, 2003) global precedence hypothesis assumes that the availability of the global level is constant and, therefore, findings of global advantage should not vary over time. Subsequent work, however, suggests that this assumption may be too strong. In particular, there is evidence that the availability of different levels of structure of hierarchical patterns change over time. Kimchi (1998) examined the microgenesis of the perceptual organization of hierarchical stimuli using a primed matching task. Observers were presented with a prime (either a few- or many-element hierarchical pattern) followed by a pair of test figures to be matched for identity. In the element-similarity test

pair condition, the test figures were similar to the prime in their elements but different in their global configuration. In the configuration similarity test pair condition, the test figures were similar to the prime in their global configuration but different in their elements. By varying the duration of the prime and constructing test figures that were similar to different aspects of the prime, this paradigm allowed changes in observers' implicit perceptual representations over time to be measured. With few-element patterns, elements were primed at brief exposures whereas the configuration was primed at longer exposures. In contrast, with many-element patterns, the configuration was primed at brief exposures whereas elements were primed at longer exposures. Similar findings have been obtained with compound arrows. Mills and Dodd (2014; the present thesis) presented a spatially uninformative and task-irrelevant compound arrow (a large, global arrow constructed from smaller, local arrows) at fixation which was followed by a peripheral target requiring a simple detection response. The direction of the global and local arrows were either consistent (same direction) or inconsistent (different directions). The critical manipulation was stimulus-onset-asynchrony (SOA). The rationale of the paradigm is that the priming potency of a level varies with SOA in correspondence with how early that level is processed (Navon, 1991). Results indicated that inconsistent arrows produced a global cueing effect (target detection was faster when the global versus local level pointed toward the target) at short SOAs, consistent with global advantage. At long SOAs, however, a local cueing effect was observed (target detection was faster when the local versus global level pointed toward the target), indicative of a local advantage.



Taken together, these findings suggest that that the unintentional effects of arrows may depend not only on the globality of an arrow, but also on its availability over time.

In sum, previous work suggests that the potency of symbols to evoke unintentional shifts of attention may vary with their globality and the availability of that percept over time or with their relevance to the current task. Accordingly, the present study investigates whether the relative impact of competing symbolic stimuli on attentional control depends on top-down selection processes. In particular, we use the compound arrow cueing task introduced in Experiment 1 to examine effects of top-down orienting task on selection of information at global and local levels of a compound arrow cue. Each trial consists of two major events (Figure 2.2). First, a spatially uninformative compound arrow cue is presented at fixation. Cues are either consistent (global and local arrows point in the same direction), inconsistent (global and local arrows point in opposite directions), local-neutral (global arrow composed of local rectangles), or global-neutral (global rectangle composed of local arrows). Second, after a variable delay, a target is presented to the left or right of fixation requiring a simple detection response. Participants are instructed that their primary task is target detection, but that they should also perform one of two secondary tasks. In the global orienting task, arrow cues are oriented either perfectly in-line with or slightly above or below the horizontal line and participants are to remember the orientation of the big arrow. In the local orienting task, one of the local arrows is a color singleton and participants are to remember its location. Following the detection response, a test display is shown presenting two compound arrows and participants are to select the one that matches what they had just seen.

For consistent cues, the perceptual precedence and control setting accounts both predict the presence of a spatial cueing effect. For inconsistent cues, however, the two accounts make different predictions. According to the perceptual precedence account, information at the global level is available earlier than information at the local level and therefore receives prioritized processing. For inconsistent cues, then, this account predicts that the global level will be selected first regardless of orienting task, and the arrow at this level will then produce an unintentional shift of attention. If a target does not appear at the location indicated by the global arrow, attention may be re-oriented back to center and a local arrow may be selected, provided that the local level is task-relevant. Thus, the perceptual precedence account predicts an early, task-independent global cueing effect, which may later give way to a local cueing effect when the local level is task-relevant and there is conflict between levels. According to the control setting account, in contrast, only arrows possessing a task-relevant feature will enter working memory and compete for attentional control. Therefore, for inconsistent cues, this account predicts a task-compatible level-specific cueing effect such that a global cueing effect should be observed in the global orienting task whereas a local cueing effect should be observed in the local orienting task.

The two accounts also differ in their predictions for local-neutral cues. The perceptual precedence account predicts that because the global level is always prioritized it will be selected regardless of orienting task, and the arrow at this level will produce an unintentional shift of attention. Furthermore, because there is no conflict between levels, the cueing effect should not vary with SOA. In contrast, the control setting account

predicts that the global level will be selected only when it is task-relevant. Thus, global cueing effects triggered by local-neutral cues should be observed in the global but not local orienting task. The two accounts make a similar prediction for global-neutral cues, albeit for different reasons. The perceptual precedence account predicts that because processing of the global level is obligatory whereas the processing of the local level is optional, the local level should be processed only when it is task-relevant. Therefore, this account predicts a local cueing effect in the local orienting task (given that the local level is task-relevant and contains arrows) but not in the global orienting task (given that the global level does not contain an arrow). Furthermore, because there is no conflict between levels, local cueing effects triggered by global-neutral cues should not vary with SOA. The control setting account predicts that the local level will be selected only when it is task-relevant. Local cueing effects triggered by global-neutral cues, therefore, should be observed in the local but not the global orienting task.

## **5.2 Methods**

### **Participants**

Thirty-eight undergraduates from the University of Nebraska-Lincoln participated in exchange for course credit. All participants had normal or corrected-to-normal vision, were naïve to the purpose of the experiment, and were informed of their rights of participation according to the University of Nebraska-Lincoln institutional review board. None of the participants took part in any of the previous experiments.

### **Stimuli**

Compound arrow cues, validity conditions, and example trial sequences in each orienting task are shown in Figure 2.2. As in Experiment 1.2, consistent and inconsistent cues were structured such that 26 local arrows (each subtending  $.625^\circ \times .50^\circ$  visual angle) yielded a single global arrow ( $7.5^\circ \times 5.0^\circ$ ). Local-neutral cues were 26 local rectangles (each subtending  $.625^\circ \times .50^\circ$ ) arranged to form a global arrow ( $7.5^\circ \times 5.0^\circ$ ). Global-neutral cues were 17 local arrows (each subtending  $.625^\circ \times .50^\circ$ ) arranged to form a single global rectangle ( $7.0^\circ \times 3.0^\circ$ ). In the local orienting task, local arrows/rectangles were filled with red except for a single arrow/rectangle that was filled with green. In the global orienting task, local arrows/rectangles were filled with red, and the global arrow/rectangle was oriented about the horizontal line  $-10^\circ$ ,  $0^\circ$ , or  $10^\circ$ . Cues in both tasks were presented on a white background.

### **Procedure**

An example trial sequence for each orienting task is shown in Figure 2.2. As in Experiment 1, each trial began with a central fixation point (black '+' subtending  $1^\circ$  visual angle) and was replaced by a compound arrow cue after 500 ms, which remained onscreen until a response was made on the primary detection task. After a variable SOA (250, 500, or 750 ms), a target (black circle subtending  $1^\circ$  visual angle) was presented requiring simple target detection. Cue direction and target location were presented with equal probability leftward ('<') or rightward ('>') and to the left or right of fixation, respectively. The combination of these factors indexed each cue's validity state. Thus, cues were either consistent (global and local arrows pointed in the same direction), inconsistent (global and local arrows pointed in opposite directions), local-neutral (global

arrow only), or global-neutral (local arrows only) and either valid (pointed toward target location) or invalid (pointed away from target location). Again, because inconsistent cues were technically always valid given that either the global or local level was always pointed at the target location, the conditions of its validity state are referred to as global-valid (global level pointed at target location) and local-valid (local level pointed at target location). Participants were instructed to press the spacebar as quickly as possible once the target appeared and to maintain central fixation throughout. Moreover, participants were informed that arrow direction did not predict target location and, therefore, was irrelevant to the detection task.

To induce voluntary selection of global or local arrows, a secondary task was used to orient attention toward either the global or the local level. Participants were told that their primary task was target detection but that they should also try to perform a secondary task in preparation for a test given at the end of each trial. The secondary task was a matching task in which participants matched either the orientation of the global arrow (global orienting task) or the location of a uniquely colored local arrow (local orienting task) to one of two alternatives in a test display. Test displays were presented immediately following a detection response and remained present until a discrimination response. The intertrial interval was 1,500 ms. Participants were seated 48 cm from the monitor and used the keyboard to make detection responses (spacebar) and discrimination responses ('a' or 's' key for left or right response, with the mapping counterbalanced across participants). Testing took place on a Pentium IV computer with

17” monitor in a room equipped with soft lighting and sound attenuation. Experimental sessions took place individually and lasted ~30 minutes.

### **Design**

Participants saw each cue (consistent, inconsistent, local-neutral, global-neutral) at each SOA (250, 500, 750) and validity state (i.e., for consistent and neutral cues: valid or invalid; for inconsistent cues: global-valid or local-valid) for each orienting task (global orienting task, local orienting task). These 48 display items were repeated 10 times for a total of 480 trials per participant. Cue type was blocked such that consistent and inconsistent cues were presented in one block and local-neutral and global-neutral cues were presented in another block. Block order was fixed across participants, with the latter always performed last. Within each cue block, orienting task was also blocked, with task order counterbalanced across participants.

### **5.3 Results**

#### **Accuracy on secondary matching task**

Accuracy on the secondary matching task is reported first. Because accuracy was binary (correct or incorrect), the log-odds of the probability of an errant matching response was selected for analysis (Hoffman, 2015). The model included a random intercept for subjects and by-subject random slopes for within-subject manipulations (Barr et al., 2013). Table 5.1 shows the mean probability of an error in each condition. The overall probability of an error was .18. Though this is somewhat high for relatively easy tasks, it was expected because participants were instructed to prioritize speed on the primary target detection task. There was a main effect of cue type,  $F(3, 91.5) = 8.94, p <$

.001, in which the mean probabilities of error were greater with consistent ( $M = .203$ ,  $SE = .040$ ) and inconsistent ( $M = .201$ ,  $SE = .039$ ) cues than with local-neutral ( $M = .177$ ,  $SE = .036$ ) and global-neutral ( $M = .157$ ,  $SE = .033$ ) cues ( $ps < .017$ ). There was also a marginally significant orienting task x cue type x SOA interaction,  $F(6, 85.8) = 2.03$ ,  $p = .069$ . Figure 5.1 shows the mean difference in probability of error between orienting tasks for each cue type and SOA. The effect of orienting task was not significant and did not significantly vary with SOA for consistent, local-neutral, or global-neutral cues ( $ps > .301$ ). For inconsistent cues, the orienting task x SOA interaction was significant ( $p = .050$ ). Whereas there was a greater probability of error in the local ( $M = .259$ ,  $SE = .049$ ) versus global ( $M = .183$ ,  $SE = .038$ ) orienting task at the 250 ms SOA ( $p = .028$ ), no difference between tasks was apparent at the 500 ms ( $p = .94$ ) or 750 ms ( $p = .46$ ) SOAs. This finding may reflect interference from the global level at the 250 ms SOA, which attenuated at longer SOAs. No other effects were significant ( $ps > .11$ ).

Table 5.1. Mean response time (RT) in milliseconds and mean probability of error,  $p(\text{error})$ , in each cue by SOA condition in Experiment 3. Note, GV = global-valid; LV = local-valid.

Condition	Local orienting task				Global orienting task				
	Valid <sup>GV</sup>		Invalid <sup>LV</sup>		Valid <sup>GV</sup>		Invalid <sup>LV</sup>		
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	
RT (ms)									
Consistent									
250	454	14	469	14	436	14	452	14	
500	386	14	405	14	374	14	391	14	
750	376	14	375	14	367	14	393	14	
Inconsistent									
250	489	15	475	15	448	15	454	15	
500	408	15	395	15	378	15	395	15	
750	381	15	378	15	366	15	393	15	

Local-neutral								
250	403	12	426	12	394	12	406	12
500	338	12	352	12	333	12	345	12
750	322	12	332	12	326	13	327	12
Global-neutral								
250	409	12	412	12	407	12	411	12
500	330	12	350	12	334	12	337	12
750	319	12	334	12	331	12	332	12
<i>p</i> (error)								
Consistent								
250	.184	.040	.245	.049	.217	.046	.220	.046
500	.217	.046	.186	.041	.178	.040	.208	.045
750	.252	.051	.185	.041	.158	.037	.202	.044
Inconsistent								
250	.268	.053	.249	.050	.167	.038	.202	.043
500	.203	.044	.162	.037	.191	.042	.168	.038
750	.223	.047	.175	.039	.217	.046	.212	.045
Local-neutral								
250	.163	.041	.182	.045	.173	.043	.187	.045
500	.178	.045	.184	.045	.181	.045	.208	.049
750	.166	.043	.152	.040	.171	.044	.179	.045
Global-neutral								
250	.143	.037	.185	.045	.139	.037	.163	.041
500	.135	.036	.166	.042	.125	.034	.186	.046
750	.165	.043	.134	.036	.176	.045	.174	.044

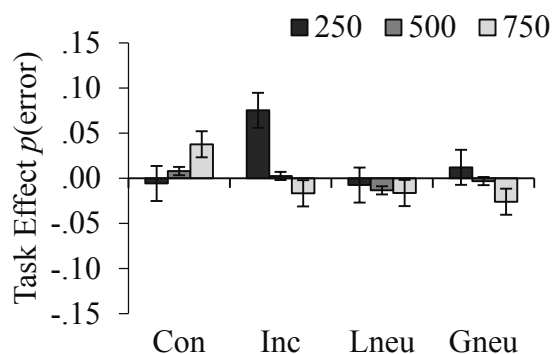


Figure 5.1. Mean orienting task effect (local task minus global task) on probability of error,  $p(\text{error})$ , in the secondary matching task for each cue type and SOA in Experiment 3. Positive values reflect a greater probability of error in the local orienting task, whereas



negative values reflect a greater probability of error in the global orienting task. Error bars represent +/- 1 standard error.

### **RT on primary target detection task**

RTs less than 100 ms or greater than 2.5 *SDs* above condition means were removed (4.8%). Data were analyzed via linear mixed modeling with subjects and items specified as crossed random effects (Baayen et al., 2008; Hoffman, 2015) and by-subject random slopes for within-subject manipulations (Barr et al., 2013). Table 5.1 shows the mean response time in each condition. There were significant main effects of SOA,  $F(2, 66.5) = 130.32, p < .001$  (targets detected faster at longer SOAs) and cue type,  $F(3, 89.8) = 20.43, p < .001$  (targets following local-neutral and global-neutral cues were detected faster than targets following consistent and inconsistent cues). The latter likely reflects a simple practice effect given that the block of neutral cue trials always followed the block of consistent/inconsistent cue trials. The main effect of orienting task was marginally significant,  $F(1, 39.1) = 3.28, p = .078$  (targets detected faster in the global versus local orienting task), though, there was a significant orienting task x SOA interaction,  $F(2, 64.9) = 5.65, p = .006$  (smaller effect of orienting task at longer SOAs). Regarding spatial cueing effects (Figure 5.2), there was a significant validity x orienting task x cue type interaction,  $F(4, 54.9) = 4.51, p = .001$ , indicating that the effect of orienting task on the size of cueing effects differed between cue types.

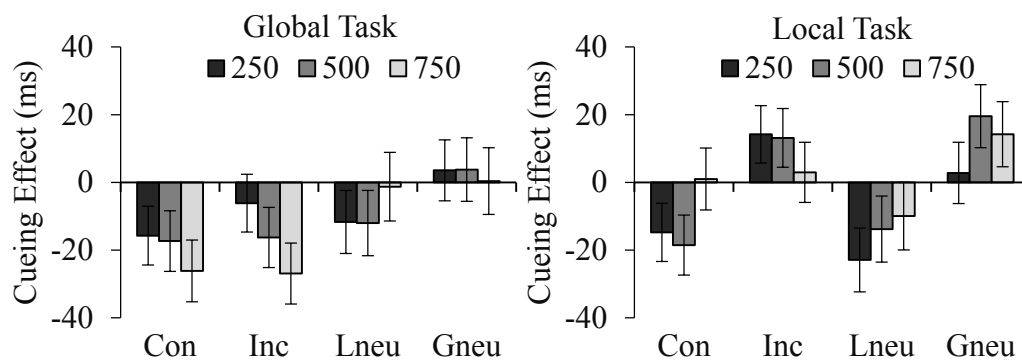


Figure 5.2. Mean spatial cueing effects (valid minus invalid or, for the inconsistent cue, global-valid minus local-valid) for each cue type and SOA in the global orienting task (left) and the local orienting task (right) in Experiment 3. For the inconsistent cue, negative values reflect a cueing effect due to the global level whereas positive values reflect a cueing effect due to the local level. Note that the global-neutral cueing effect was remapped (i.e., multiplied by -1) to reflect that this cueing effect was attributable to the local level. Error bars represent +/- 1 standard error.

With consistent cues, there was a significant cueing effect in both the local ( $M = -10.83$ ,  $SE = 4.64$ ,  $t = -2.33$ ,  $p = .020$ ) and global ( $M = -18.99$ ,  $SE = 4.66$ ,  $t = -4.07$ ,  $p < .001$ ) orienting tasks (targets were detected faster when appearing at the location global and local arrows pointed), the size of which did not significantly differ between tasks ( $M = 8.16$ ,  $SE = 6.57$ ,  $t = 1.24$ ,  $p = .215$ ). Although we did not manipulate any incentive to ignore the arrow cues, the presence of a cueing effect despite the fact that the cue was spatially uninformative is consistent with the notion that directional symbols presented at fixation induce unintentional shifts of attention to locations compatible with the meaning of the cue (e.g., Hommel et al., 2001; Pratt & Hommel, 2003; Ristic & Kingstone, 2006, 2012; Ristic et al., 2012).

With inconsistent cues, there was a significant cueing effect in both the local ( $M = 9.50$ ,  $SE = 4.62$ ,  $t = 2.06$ ,  $p = .040$ ) and global ( $M = -15.98$ ,  $SE = 4.69$ ,  $t = -3.41$ ,  $p < .001$ ) orienting tasks, the sign of which was in opposite directions resulting in a significant difference between tasks ( $M = 25.48$ ,  $SE = 6.58$ ,  $t = 3.87$ ,  $p < .001$ ). In the local orienting task, the positive sign indicates that the cueing effect was due to the local level (targets were detected faster when appearing at the location the local arrows pointed). In the global orienting task, the negative sign indicates that the cueing effect was due to the global level (targets were detected faster when appearing at the location the global arrow pointed). Thus, orienting task determined which level of an inconsistent compound arrow cue was selected, and the arrow(s) at this level then produced an unintentional shift of attention. This pattern is consistent with a control setting account.

With global-neutral cues, there was a significant cueing effect in the local orienting task ( $M = -12.22$ ,  $SE = 6.19$ ,  $t = -1.97$ ,  $p = .050$ ), with targets detected faster when appearing at the location the local arrows pointed. The cueing effect in the global orienting task, however, was not significant ( $M = -3.02$ ,  $SE = 6.47$ ,  $t = -.47$ ,  $p = .641$ ). Thus, when arrows were present at only the local level of a compound cue, cueing effects were observed only when the current task goal specified the local level as task-relevant. Otherwise, these local arrows appeared to have been ignored. As the only difference between the present global-neutral cue and the one in Experiment 1.3, which did produce a significant cueing effect, is the task-relevant nature of the global level, it is reasonable to interpret the present finding with global-neutral cues in terms of global precedence.

With local-neutral cues, there was a significant cueing effect in both the local ( $M = -15.67$ ,  $SE = 6.12$ ,  $t = -2.56$ ,  $p = .011$ ) and global ( $M = -12.40$ ,  $SE = 6.31$ ,  $t = -1.97$ ,  $p = .050$ ) orienting tasks (targets were detected faster when appearing at the location the global arrow pointed), the size of which did not significantly differ between tasks ( $M = -3.33$ ,  $SE = 9.07$ ,  $t = -.37$ ,  $p = .713$ ). Thus, when an arrow was present at only the global level of a compound cue, cueing effects were observed regardless of the current task goal. This pattern speaks to the inevitability of processing global information and the optional processing of local information, in line with a global precedence account.

The four-way interaction was not significant ( $p = .21$ ), indicating that the pattern of cueing effects did not vary with SOA. Considering that Experiments 1 and 2 showed that the cueing effect with inconsistent cues changed with SOA—such that a global cueing effect was observed at a 250 ms SOA, whereas a local cueing effect was observed at a 750 ms SOA—the absence of an influence of SOA in the present experiment may suggest that rather than causing the local or global advantage per se, the effect of orienting task was to enhance, attenuate, or otherwise maintain the availability of level-specific information. This would explain both the presence of a local cueing effect with inconsistent cues at the 250 ms SOA, as well as the lack of an SOA effect with inconsistent cues.

To summarize, a task-compatible, level-specific cueing effect was observed when there was conflict between the two levels of structure (i.e., inconsistent cue), which is in line with a control setting account. Yet, when there was no such conflict, the results were consistent with a global precedence account: when the cue was a global arrow composed

of local rectangles (i.e., local-neutral cue), a cueing effect was observed regardless of orienting task, and when the cue was a global rectangle composed of local arrows (i.e., global-neutral cue), a cueing effect was observed in the local orienting task but not in the global orienting task, findings compatible with some form of global precedence. More generally, the emerging suggestion is that shifts in precedence depend on conflict between levels. This is consistent with Experiment 1, with the exception that in that experiment there was no orienting task. In light of the present findings, this suggests that level-specific advantage may not have been due to task per se but rather to conflict between levels, with the effect of task serving to modulate the availability of level-specific information, effectively prolonging (in the case of task-relevant global information) or expediting (in the case of task-relevant local information) the advantage at a given level.

#### **5.4 Discussion**

The present study examined whether the influence of competing symbolic stimuli at different levels of structure on attentional control depends on top-down selection processes. Certain aspects of the results suggest this was the case. In particular, there was positive evidence that attention can be allocated voluntarily to a specific level of a compound symbol. This was shown by a task-compatible, level-specific cueing effect: with inconsistent cues in which global and local arrows pointed in opposite directions, a local cueing effect was observed in the local orienting task (target detection was faster for targets appearing at the location indicated by the local arrows) whereas a global cueing effect was observed in the global orienting task (target detection was faster for targets

appearing at the location indicated by the global arrow). Thus, current task goals determined the level of structure to be selected, and the directional meaning of the arrow(s) at this level subsequently induced an unintentional shift of attention. These findings are comparable with previous work examining the influence of competing symbols at the same level of structure (Pratt & Hommel, 2003).

Though top-down control of attention via orienting task made it possible to select information at either level of structure depending on which level was task-relevant, other aspects of the present results suggest that this type of selection was insufficient for restricting selection to only arrows at the local level. In particular, we observed a local-neutral cueing effect (cueing effect due to the global level) not only in the global orienting task but also in the local orienting task, indicating that access to symbolic information at the global level was not prevented when attending to the location of a local rectangle. This finding is inconsistent with the predictions of a top-down control setting account, which suggests that because the global arrow's directional information was irrelevant to the local orienting task it should not be processed and, therefore, no cueing effect should have been observed (Folk et al., 1992). Instead, this finding is more in-line with a perceptual precedence account (Navon, 1977), which suggests that processing of information at the global level is obligatory whereas processing of information at the local level is optional. According to this account, the local-neutral cueing effect was observed regardless of orienting task because there was an arrow at the highest level of globality (i.e., the relative position of an item in hierarchical space). As processing of the

global level is obligatory, this level was therefore selected and the arrow at this level then induced an unintentional shift of attention.

Interestingly, a global-neutral cueing effect (cueing effect due to the local level) was observed in the local but not the global orienting task. On the one hand, this might indicate that access to symbolic information at the local level was prevented when attending to the orientation of a global rectangle, consistent with the predictions of a top-down control setting account. On the other hand, considering that this task-level compatibility effect was not observed with local-neutral cues (indicating that access to symbolic information at the global level could not be prevented when attending to the location of a local rectangle), the perceptual precedence account seems to provide a more complete account of the data for the two neutral cue types. Accordingly, the global-neutral cueing effect may reflect the assumption that processing of information at the local level is optional (Navon, 1977). That is, because the local level was not task-relevant in the global orienting task it was not processed and, as a result, no cueing effect was observed. Taken together, the pattern of spatial cueing effects for the two types of neutral cues suggest that cueing effects triggered by the global level may be more strongly reflexive than those triggered by the local level, insofar as the spatial orienting effect for local-neutral cues (cueing effect due to global level) could withstand violations to a nonspatial task-level attentional set whereas the spatial orienting effect for the global-neutral cue (cueing effect due to the local level) could not.

According to Navon's (1977, 2003) global precedence hypothesis, the availability of the global level is constant and does not attenuate even when focused on the local

level. Subsequent findings, however, suggest that this assumption may be too strong as there is evidence that the availability of different levels of structure of hierarchical patterns vary with time (Kimchi, 1998). An effect of processing duration (i.e., SOA) on global advantage (Experiment 1), therefore, does not support Navon's global precedence hypothesis; though, it is consistent with a weaker version in which the availability of the global level can be modulated over time (Navon, 1991). Therefore, it is speculated that an effect of SOA was not observed in Experiment 3 because the task-relevancy of a particular level modulated the availability of that level, effectively prolonging (in the case of task-relevant global information) or expediting (in the case of task-relevant local information) the availability and thus dominance of level-specific information. Only in the absence of direct task demands is there an obligatory global-to-local change in advantage (Experiment 1.2), and even then, only in the presence of conflict. The emerging picture here is that shifts in precedence depend on conflict between levels. Accordingly, it is concluded that the results support a version of global precedence in which task-set can either maintain the availability of the global level (evident by the absence of SOA effects on global cueing effects when the global level was task-relevant; Experiment 3) or attenuate the availability of the global level (evident by the absence of SOA effects on local cueing effects when the local level was task-relevant; Experiment 3).

In summary, the present experiment found that interactions between task demands and the structure of the input information selectively modulate the relative needs of visual information at different levels of stimulus structure. To select symbols at different levels



of structure, therefore, the present work suggests that at least two factors need to be considered: the observer's current task, which specifies the demands of visual information from the input, and the globality of this visual information across the percept, which specifies the availability of the percept for selection. Studies investigating determinants of selection efficiency typically draw on tasks requiring selective attention to centrally presented local information while ignoring irrelevant peripheral information, as in flanker tasks. Moreover, the stimuli used in these studies are generally perceptually simple, containing semantic information at only one level of stimulus structure, as in a single central arrow. Many structural differences exist between the stimuli presented in traditional studies of selectivity and the sort of stimuli found in the real-world (e.g., hierarchical levels of structure, depth planes). Considering that differences in stimulus structure are known to influence processing strategies (Garner, 1970, 1974), understanding the role of stimulus structure in information processing is crucial for understanding how various factors influence selective attention. Ignoring the nature of the stimulus, at worst, would lead to incorrect assessment of the nature of information processing, and, at best, an inadequate picture. A goal for future research, therefore, should be to understand how other dimensions of stimulus structure, such as a target's location in depth on a three-dimension plane, contribute to selectivity.

## **CHAPTER 6: ROLE OF BOTTOM-UP SALIENCE**

### **6.0 Chapter Overview**

Chapter 6 reports an experiment that examines the role of level salience on the selection priorities of global and local information. In particular, to assess whether the task-compatible, level-specific cueing effects in Experiment 3 can be attributed to differential salience between levels, the present experiment used the same cues as in the local orienting task in Experiment 3 (in which one of the local arrows was a color-singleton), however, there was no secondary matching task. Accordingly, if the results of Experiment 3 were attributable to the salience (as opposed to task-relevance) of the local level biasing a local processing mode, then making the local level salient should produce a local advantage even when the arrows at this level are task-irrelevant, as has been demonstrated in previous work (Han, He, Yund, & Woods, 2001; Hübner & Malinowski, 2002; Stoffer, 1993, 1994).

### **6.1 Introduction**

Although the two orienting tasks in Experiment 3 clearly required responses to either the global or the local level, the arrow cues differed between tasks, which raises the possibility that this difference may have had some influence on the results. This difference may be particularly problematic for the cues containing local arrows, because the local arrows, at the stimulus level and independent of the task, were more salient in the local orienting task (a single green arrow among red arrows) than in the global orienting task (all red arrows). By itself, this stimulus level difference—local arrows being more salient in the local versus global orienting task—could potentially explain the

finding with global-neutral cues, in which there was a significant cueing effect in the local orienting task (targets detected faster when appearing at the location the local arrows pointed) but not in the global orienting task. It is unclear, therefore, to what extent this finding with global-neutral cues can be attributed to the orienting task. Likewise, differential local salience between tasks could also explain the finding with inconsistent cues, in which there was a significant local cueing effect in the local orienting task (targets detected faster when appearing at the location the local arrows pointed) and a significant global cueing effect in the global orienting task (targets detected faster when appearing at the location the global arrow pointed). If local salience, independent of the orienting task, was responsible for the different pattern of cueing effects with inconsistent cues between tasks, then local salience should produce significant local cueing effects regardless of the relevancy of a particular level to a given task. Experiment 4 tests this possibility. In particular, Experiment 4 tests whether a local color singleton can draw attention to the local level and reverse the precedence effect.

## **6.2 Methods**

### **Participants**

Forty undergraduates from the University of Nebraska-Lincoln participated in exchange for course credit. All participants had normal or corrected-to-normal vision, were naïve to the purpose of the experiment, and were informed of their rights of participation according to the University of Nebraska-Lincoln institutional review board. None of the participants took part in any of the previous experiments.

### **Stimuli, procedure, and design**

The compound arrow cue stimuli were the same as in the local orienting task in Experiment 3 (see Figure 2.2). The procedure was also the same except that there was no secondary matching task, meaning that cue processing was now entirely incidental to the detection task. Thus, participants were informed that central arrows did not predict the location of a target and, therefore, were irrelevant to the detection task and should be ignored. The design was also the same as Experiment 3 except that there were more trials and that rather than there being just one block of consistent/inconsistent cues followed by one block of neutral cues, there were now four blocks of each, which were interleaved. This modification was made to determine whether it would eliminate the suspected practice effect (i.e., main effect of cue type) from Experiment 3. Thus, participants saw each cue (consistent, inconsistent, local-neutral, global-neutral) at each SOA (250, 500, 750) and validity state (for consistent and neutral cues, valid or invalid; for inconsistent cues, global-valid or local-valid). These 24 conditions were repeated 27 times for a total of 648 trials. Experimental sessions took place individually and lasted ~45 minutes.

### **6.3 Results**

Prior to all analyses, RTs less than 100 ms or greater than 2.5 *SDs* above conditional means were removed (5.7%). Data were analyzed via linear mixed modeling with subjects and display items specified as crossed random effects (Baayen et al., 2008; Hoffman, 2015) and by-subject random slopes for within-subject manipulations (Barr et al., 2013). There was a significant main effect of SOA,  $F(2, 92.3) = 67.19, p < .001$  (targets detected faster at longer SOAs). The main effect of cue type, which was significant in Experiment 3, was no longer significant,  $F(3, 63.9) = 1.62, p = .19$ , likely

due to the increased number of blocks and their interleaving. Regarding spatial cueing effects (Figure 6.1), a significant validity x SOA interaction emerged,  $F(2, 66.8) = 4.12, p = .02$ . Cueing effects were significant at the 250 ms SOA ( $M = -15.55, SE = 4.69, t = -3.32, p = .002$ ) and were significantly smaller at the 500 ms SOA by ( $M = -12.37, SE = 6.11, t = -2.02, p = .05$ ), as well as at the 750 ms SOA by ( $M = -17.09, SE = 6.17, t = -2.77, p = .007$ ). The -3.18 ms cueing effect at the 500 ms SOA (i.e., -15.55 minus -12.37) and the 1.54 ms cueing effect at the 750 ms SOA (i.e., -15.55 minus -17.09) were not significantly different from zero ( $ps > .51$ ) or from each other ( $t = -.76, SE = 6.18, p = .45$ ). Importantly, there was a significant cue type x validity interaction,  $F(3, 45.5) = 4.01, p = .013$ , indicating that the sizes of the cueing effects differed between cue types. Significant cueing effects occurred with consistent ( $M = -13.45, SE = 6.85, t = -1.96, p = .05$ ), local-neutral ( $M = -12.76, SE = 6.30, t = -2.03, p = .05$ ), and global-neutral ( $M = -12.49, SE = 6.19, t = -2.02, p = .05$ ) cues, none of which differed ( $ps > .92$ ). Each, however, was significantly different from the cueing effect with inconsistent cues ( $ts > 2.78, SEs \sim 9, ps < .01$ ). With inconsistent cues, the cueing effect at the 250 ms SOA was due to the global level ( $M = -10.82, SE = 6.31, t = -1.75, p = .078$ ), whereas the cueing effects at the 500 ( $M = 18.67, SE = 7.41, t = 2.52, p = .027$ ) and 750 ( $M = 14.95, SE = 7.63, t = 1.96, p = .050$ ) ms SOAs were due to the local level.

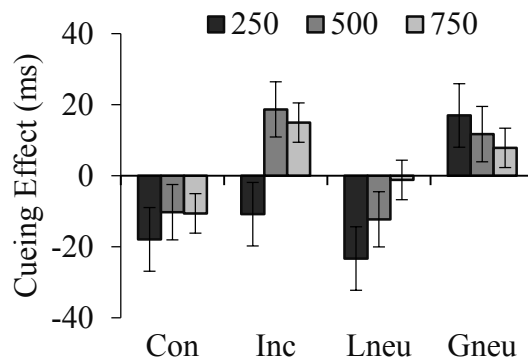


Figure 6.1. Mean spatial cueing effects (valid minus invalid or, for the inconsistent cue, global-valid minus local-valid) for each cue type and SOA in Experiment 4. For the inconsistent cue, negative values reflect a cueing effect due to the global level whereas positive values reflect a cueing effect due to the local level. Note that the global-neutral cueing effect was remapped (i.e., multiplied by -1) to reflect that this cueing effect was attributable to the local level. Error bars represent +/- 1 standard error.

#### 6.4 Discussion

If local salience accounted for the local cueing effects in the local orienting task in Experiment 3, then local salience should produce a local cueing effect independent of the status of the local level with respect to one's task. Moreover, just as in Experiment 3, the local cueing effect should not vary with SOA. The results of Experiment 4 did not support this possibility. With inconsistent cues—despite a local cueing effect at the 500 and 750 ms SOAs—neither a global nor local cueing effect was found at the 250 ms SOA (in fact, the trend was toward a global cueing effect), possibly suggesting that global processing passively interfered with local processing (e.g., Navon, 1977; Sanocki, 2001) or that local salience biased competition for selection between levels (Hommel et al., 2001; Hommel & Akyürek, 2009; Pratt & Hommel, 2003) by attenuating the availability of the global level and/or by enhancing the availability of the local level. In any case,

these results indicate that a local-level entry point for visual processing is not obligatory, even under conditions in which it might be expected. This indicates that a local color singleton was not sufficient to produce the early and temporally stable local cueing effect with inconsistent cues in the local orienting task in Experiment 3. Thus, with inconsistent cues, a color singleton at the local level did not produce early local cueing effects (Experiment 4) unless the local level was task-relevant (Experiment 3). Similarly, with global-neutral cues, whereas there was no cueing effect in the global orienting task in Experiment 3, there was now a significant and temporally stable cueing effect. This suggests that the former was not due to the absence of a color singleton at the local level. Thus, these findings suggest that the effects of orienting task on the size of the cueing effects with inconsistent and global-neutral cues in Experiment 3 were indeed due to orienting task, not salience. Accordingly, it is concluded that the results of these experiments support a version of global precedence in which task set can either maintain the availability of the global level (evident by the absence of SOA effects on global cueing effects when the global level was task-relevant; Experiment 3) or attenuate the availability of the global level (evident by the absence of SOA effects on local cueing effects when the local level was task-relevant; Experiment 3).

## CHAPTER 7: ROLE OF ATTENTIONAL FOCUSING AND ADJUSTMENTS

### 7.0 Chapter Overview

Eriksen and Rohrbaugh (1970) proposed that attention can be allocated selectively at a level of a hierarchical stimulus. The zoom-lens metaphor of spatial attention captures this idea (Eriksen & St. James, 1986; Eriksen & Webb, 1989; Eriksen & Yeh, 1985), where visual attention can be allocated to differently sized regions of the visual field. Changing the level attended, therefore, can be seen as a redistribution of resources over a region that is proportionally larger than the height of the level in the hierarchy (Castiello & Umiltà, 1990; Eriksen & St. James, 1986). Accordingly, it is possible that global-local response time differences reflect the time needed to refocus attention from the global to the local level. Support for this account is provided by studies showing that a tradeoff exists between the size of the visual field over which attention is distributed and its resolution (Eriksen & St. James, 1986; Eriksen & Yeh, 1985), and that the size of such attentional focusing plays an important role in attentional control (Theeuwes, 2004).

So far, experiments using the compound arrow cueing procedure have required only simple detection responses to a 1° target (Experiments 1-4). It is possible that such a simple (coarse) judgement might have permitted what Theeuwes (2004; see also Gibson & Peterson, 2001; Theeuwes, Kramer, & Belopolsky, 2004; Belopolsky et al., 2007) has referred to as a wide attentional window. These studies suggest that the size of the attentional window is an important factor in determining whether an irrelevant color singleton will capture attention. For example, Belopolsky et al. (2007) manipulated the size of the attentional window by requiring observers to detect either a global or a local



shape prior to performing a search task. They found that attention was captured more often when the attentional window was induced to be wide (global shape detection) than when it was induced to be narrow (local shape detection). Accordingly, if detection responses to a 1° target permitted a wide attentional window, then the spatial cueing task may have introduced a top-down bias towards global processing across all conditions. This bias presumably would have an additive effect with the orienting bias manipulated with the secondary matching task in Experiment 3 and, therefore, may be overpowered by conditions conspiring to produce a local advantage. Though speculative, this overall top-down bias toward processing the global level might have manifested itself in the finding that when the cue was a global arrow composed of local rectangles (local-neutral cue) a cueing effect was observed even in the local orienting task (Experiment 3, Figure 5.2).

Though attractive, there are also at least three pieces of evidence that cast doubt on this hypothesis. First, there was a (global) cueing effect with local-neutral cues in the local orienting task (Experiment 3, Figure 5.2). As previous work has shown that top-down attention to pop-out local items weakens global advantage (Han & He, 2003), it might be expected that a top-down bias towards global processing induced by a wide attentional window should be weakened in the local orienting task and, therefore, the local-neutral cueing effect to be smaller than in the global orienting task. However, no difference between tasks was found. Second, Lamb and Robertson (1988) found that responses to the local level of a central, hierarchical stimulus were longer when stimuli occurred randomly and were mixed with peripherally presented stimuli compared with a

condition in which all stimuli were always presented at central fixation. They suggested that with central presentation, a smaller focus of attention could be maintained, leading to enhanced local processing. As the present cues were presented at central fixation, it might be expected that no global advantage should result given that attention was consistently directed at a level (via task manipulation) within a block of trials. Finally, this possibility was considered in Experiment 1.3, where cue-target eccentricity was manipulated with the logic being that a wide attentional window would predict a cue-target proximity effect. None was found—eccentricity did not alter the pattern. Consequently, spatial uncertainty, presumably a condition of diffuse or wide attention, does not seem to affect the size of global advantage, at least not when cue processing is incidental and both levels are related to as objects.

To examine the possibility that global-local response time differences reflect the time needed to refocus attention, Experiment 5 manipulated attentional focus (Figure 2.3) along the lines of previous work (Belopolsky et al., 2007; Hernandez, Costa, & Humphreys, 2007). If it is assumed that global and local levels are equated on salience, then the focused attention condition should prime a local advantage (because the effective visual field is smaller, potentially omitting grouping cues). This would be evident by larger local cueing effects (with inconsistent and global-neutral cues) in the focused versus diffuse attention condition. In contrast, the diffuse attention condition should prime a global advantage (because the effective visual field is larger, encompassing all the items). Thus, in the diffuse attention condition there should be a bias toward global processing, which would be evident by a larger global cueing effect (with inconsistent

and local-neutral cues) relative to the focused attention condition. However, if the local level contains a salient color singleton, then the focused attention condition should prime a local advantage (because the effective visual field is smaller, as well as because attention is allocated automatically to the singleton), and the diffuse attention condition should prime a local advantage commensurate with the focused attention condition (because, though the effective visual field may encompass the whole cluster of items, attention is allocated automatically to the singleton).

## **7.1 Methods**

### **Participants**

Fifty-three undergraduates from the University of Nebraska-Lincoln participated in exchange for course credit. All participants had normal or corrected-to-normal vision, were naïve to the purpose of the experiment, and were informed of their rights of participation according to the University of Nebraska-Lincoln institutional review board. None of the participants took part in any of the previous experiments.

### **Stimuli, procedure, and design**

The compound arrow cue stimuli were the same as those in Experiment 4, except that now on 25% of trials the local color singleton or the global shape was oriented vertically (no-go trials). The task was to press the spacebar when a target appearing either left, right, above, or below central fixation was detected. Participants were instructed to respond to the target as quickly as possible only when a go signal (which was the same for both attention conditions) was present and that they should withhold response when a target was preceded by a no-go signal. Participants were also informed that the location

of the target was random. The trial sequence consisted of a fixation cross (500 ms), followed by a compound arrow cue (250, 500, or 750 ms SOA), and then the target (to response). The intertrial interval was 1,500 ms. Before the start of the experiment, participants received a sample block of 12 practice trials for each of the attention conditions.

The two attention conditions (focused and diffuse) were manipulated within subjects. The design was identical for each condition. Three types of cues were used (inconsistent, local-neutral, and global-neutral), which were presented with equal probability leftward ('<') or rightward ('>'). Four target locations were used (left, right, above, or below fixation). A left or right target was presented with equal probability on 90% of trials. In the focused attention condition, participants responded to the target when the local arrow/rectangle color singleton was horizontally oriented (go trials), and withheld their response when the local arrow/rectangle color singleton was vertically oriented (no-go trials). In the diffuse attention condition, participants responded to the target when the global arrow/rectangle was horizontally oriented (go trials), and withheld their response when the global arrow/rectangle was vertically oriented (no-go trials). No-go trials occurred on 25% of all trials. In both attention conditions, the same exact displays were used, but the no-go signal (up or down local arrow/rectangle color singleton for the focused attention condition, and up or down global arrow/rectangle for the diffuse attention condition; Figure 2.3) was chosen randomly. Attention conditions were blocked and the order counterbalanced across participants. For each condition, all types of trials were mixed. The location of the local shape color singleton was chosen

randomly for each trial. There were 384 trials in each attention condition, of which 288 were go trials and 72 were no-go trials, for a total of 768 trials.

## 7.2 Results

Prior to all analyses, RTs less than 100 ms or greater than 1.5\*interquartile range above conditional means were removed (< 1%). No-go trials (25%), trials with no-go errors (i.e., erroneously responding to the target on no-go trials; 2.5%), and trials with go errors (i.e., failing to respond to the target on go trials; < 1%) were excluded from the analysis. Data were analyzed via linear mixed modeling with subjects and display items specified as crossed random effects (Baayen et al., 2008; Hoffman, 2015) and by-subject random slopes for within-subject manipulations (Barr et al., 2013). There was a main effect of SOA for inconsistent ( $M = -101.71$ ,  $SE = 5.41$ ,  $t = -18.80$ ,  $p < .001$ ), local-neutral ( $M = -94.07$ ,  $SE = 4.66$ ,  $t = -20.20$ ,  $p < .001$ ), and global-neutral ( $M = -101.07$ ,  $SE = 4.86$ ,  $t = -20.81$ ,  $p < .001$ ) cue types, and which did not differ between cues  $F < 1$ . Regarding spatial cueing effects (Figure 7.1), there were significant main effects of validity for inconsistent ( $M = 12.28$ ,  $SE = 5.41$ ,  $t = -2.27$ ,  $p = .02$ ; the positive sign indicates that this cueing effect was due to the local level) and local-neutral ( $M = 9.16$ ,  $SE = 4.66$ ,  $t = -1.97$ ,  $p = .05$ ) cues, but not global-neutral cues ( $M = -2.60$ ,  $SE = 4.86$ ,  $t = -.54$ ,  $p = .59$ ). Moreover, these effects did not vary significantly with SOA, attention condition, or their interaction. These findings are difficult to interpret but at the very least point to some interaction of salience and attention given that a local singleton led to an early local cueing effect when the compound arrow cue was task-relevant (demonstrated

here by the effect of validity at the 250 ms SOA for inconsistent cues) but not when it was task-irrelevant (Experiment 2).

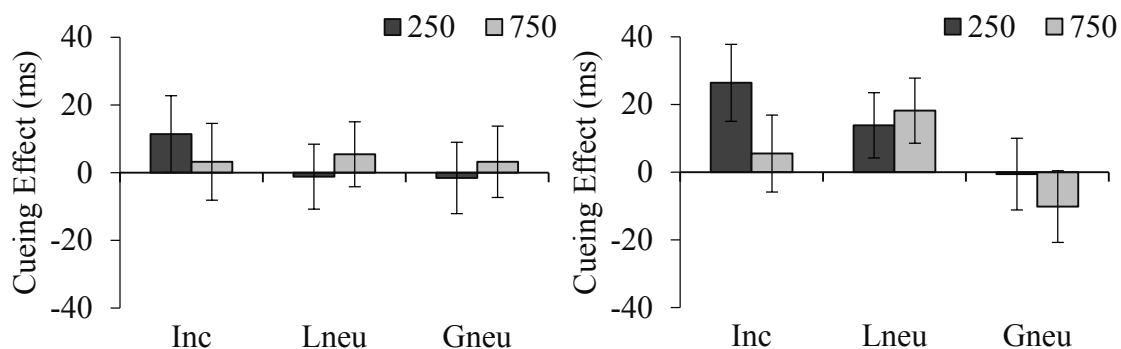


Figure 7.1. Mean spatial cueing effects (valid minus invalid or, for the inconsistent cue, global-valid minus local-valid) for each cue type and SOA in the focused (left) and diffuse (right) attention conditions in Experiment 5. For the inconsistent cue, negative values indicate a cueing effect due to the global level whereas positive values indicate a cueing effect due to the local level. Note that the global-neutral cueing effect was remapped (i.e., multiplied by -1) to reflect that this cueing effect was attributable to the local level. Error bars represent +/- 1 standard error.

Finally, there was a significant cue type x SOA x attention interaction,  $F(2, 52.1) = 2.01, p = .04$ . With inconsistent cues, the effect of attention was greater at the 750 versus 250 ms SOA, evident by a significant attention x SOA interaction ( $M = 19.98, SE = 9.82, t = 2.03, p = .05$ ). This effect was also significant for local-neutral cues ( $M = -16.40, SE = 8.31, t = -1.98, p = .05$ ), but differed significantly from that for inconsistent cues ( $t = -2.55, p = .01$ ) as it was in the opposite direction (Figure 7.2). As shown, whereas responses were speeded in the focused versus diffuse condition with inconsistent cues at only the 750 ms SOA, responses were speeded in the focused condition with local-neutral cues at only the 250 ms SOA. With global-neutral cues, the attention x SOA

interaction was smaller relative to inconsistent cues ( $t = -1.93, p = .052$ ) and not significant ( $M = -8.19, SE = 9.71, t = -.80, p = .40$ ). Thus, the effect of attention changed with SOA in opposite directions with inconsistent and local-neutral cues, and did not change with SOA with global-neutral cues. The finding with inconsistent cues is consistent with the idea that conflict pushes attention to more local levels. This possibility is tested directly next.

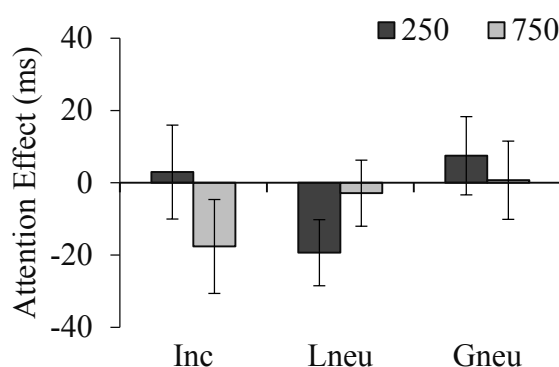


Figure 7.2. Mean attention effect (focused minus diffuse) for each cue type and SOA in Experiment 5. Positive values reflect speeded responses in the diffuse attention condition, whereas negative values reflect speeded responses in the focused attention condition.

Error bars represent +/- 1 standard error.

If conflict pushes priority to local processing, then the presence of conflict on trial N-1 might facilitate local processing on trial N in conflict (inconsistent) cues. If so, there should be larger local cueing effects on trial N conflict cues when trial N-1 was also a conflict cue (relative to a neutral cue). Furthermore, with inclusion of a local singleton, this conflict adaptation effect (i.e., enhanced conflict processing; Botvinick et al., 2001) might be enhanced by a manipulation that facilitates attention capture (i.e., diffuse attention condition), and thereby bias processing in favor of the local (arrow) level. If so,

the conflict adaptation effect should be larger in the diffuse versus focused attention condition. In line with these predictions, Figure 7.3 shows that when trial N-1 required resolution of conflict, trial N cueing effects with inconsistent (conflict) cues was larger (at the 250 ms SOA) than when trial N-1 did not require resolution of conflict. This conflict adaptation effect was enhanced in the diffuse relative to focused attention condition. Thus, there was greater impact of salience on trial N cueing effect when trial N-1 activated conflict resolution processes.

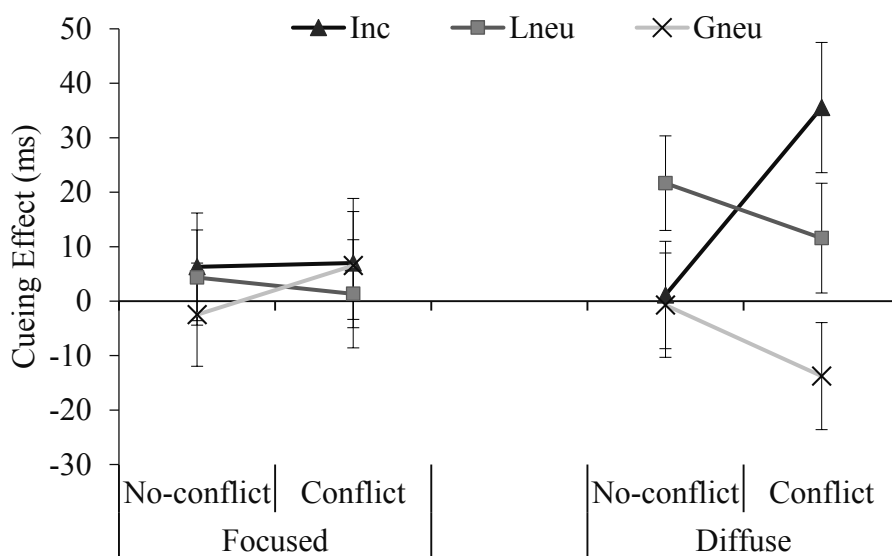


Figure 7.3. Mean spatial cueing effects (valid minus invalid or, for the inconsistent cue, global-valid minus local-valid) for each cue type and attention condition as a function of trial N-1 cue (either a neutral—no-conflict—cue, or an inconsistent—conflict—cue in Experiment 5. For the inconsistent cue, negative values indicate a cueing effect due to the global level whereas positive values indicate a cueing effect due to the local level. Note that the global-neutral cueing effect was remapped (i.e., multiplied by -1) to reflect that this cueing effect was attributable to the local level. Error bars represent +/- 1 standard error.



### **7.3 Discussion**

The present experiment investigated the role of attentional focusing on selection of a spatially uninformative arrow at either the global or the local level of hierarchical structure. The pattern of results was complex and cannot be mapped neatly onto the expectations of a perceptual global precedence account (there was no evidence of global advantage) or an attentional focusing account (cueing effects did not differ between attention conditions). Of course, the cueing effects were also inconsistent with the pattern observed in nearly all of the previous experiments reported here, which only adds to difficulty with their interpretation. This difficulty notwithstanding, an important sequential effect was observed which supported the notion that conflict between levels pushes attention to more local levels. The implications of this finding are elaborated on in Chapter 8.

## **CHAPTER 8: GENERAL DISCUSSION**

### **8.0 Chapter Overview**

Chapter 8 summarizes the main results of the experiments reported in the current thesis and relates these results to the primary research objectives presented in Section 2.1. In addition, a few methodological issues are mentioned and some recommendations for addressing these issues are offered. The chapter concludes with a discussion of how the present findings relate to the current state of knowledge in the field. A number of practical, theoretical, and methodological implications are also considered and directions for future research prescribed.

### **8.1 Summary of Experimental Results**

The essence of global precedence is the inevitability of global processing. According to Navon, global precedence occurs because identification of global information occurs first and constitutes an obligatory stage of perceptual processing. Despite this fact, little attention has been devoted to investigating whether global processing is in fact obligatory. Indeed, the standard global/local paradigm cannot even assess this issue given that participants are required to process the critical stimulus in a goal-directed manner via task and stimulus parameters that emphasize global or local characteristics. To determine whether a process is obligatory, however, requires equating each level in terms of its likelihood of processing. That is, the option to process either the global or local level in a given task is necessary but not sufficient. The option to process either level, in addition to the option to not process either level must also be equated. For instance, even if one finds evidence in a divided attention paradigm for obligatory global

processing, it may be that this evidence depended on the global level being task-relevant (not just task-relevant on a given trial, as any conclusion drawn is based on the whole task; Iglesias-Fuster et al., 2014).

The main goal of the current thesis, therefore, was to investigate global and local processing in situations that do not require an observer to process a hierarchical stimulus. The current thesis refers to this sort of processing as incidental. Operationally, incidental processing was defined as processing of a hierarchical stimulus when information at different levels of structure was uninformative (did not aid task performance) and task-irrelevant (did not need be processed to perform the task). Critically, as the hierarchical stimulus was irrelevant to the primary task and, therefore, could be ignored, the compound arrow cueing paradigm provides an opportunity to determine whether the global-to-local processing sequence is indeed obligatory, which, to this point, has been a difficult issue to address. The motivation for the paradigm is based on the argument that the most appropriate test of global precedence (specifically, its dispositional nature) requires that the critical compound stimulus be entirely task-irrelevant. A key manipulation was SOA, the rationale being that the priming potency of a level varies with SOA in correspondence with how early that level was processed or became available. The primary research question addressed in each of these experiments and their associated finding is summarized below and on Table P.2. In addition, a summary of the experimental conditions under which significant cueing effects were or were not observed is provided on Table 8.1.

Experiment 1 examined global and local processing in incidental perception of hierarchical structure. Results indicated that inconsistent cues induced a global cueing effect at short SOAs (target detection was faster when the global versus local level pointed toward the target), consistent with global advantage, whereas at long SOAs, a local cueing effect was observed (target detection was faster when the local versus global level pointed toward the target), indicative of a local advantage (Experiment 1.1). Importantly, global-neutral arrows (global rectangle comprised of local arrows) induced a local cueing effect even at short SOAs (Experiment 1.2), suggesting that the obligatory transition from early global advantage to late local advantage seen with inconsistent cues depended in some way on the presence of competitive interactions between global and local levels, competition that was absent in consistent and neutral cues given that responses available at global and local levels were compatible in consistent cues and did not conflict in neutral cues (because there was no response associated with the neutral level).

Experiment 2 was a replication of Experiment 1 except that SOA was manipulated along a broader time course. With inconsistent cues, a global cueing effect was observed for SOAs between 100 and 300 ms, whereas a local cueing effect was observed for SOAs between 400 and 900 ms. Thus, just as in Experiment 1, global advantage occurred early during processing and local advantage occurred later. This global-to-local temporal sequence observed for task-irrelevant compound arrows has since been independently replicated and extended to action planning (Chan, Gozli, & Pratt, 2014). Thus, taking Experiments 1 and 2 together, there seems to be fairly strong

evidence for the idea that different levels of hierarchical structure are processed with different latencies or are registered at different points during processing.

Experiment 3 examined whether the influence of competing symbolic stimuli (arrows) at different levels of structure on attentional control depends on top-down selection processes. The results showed a clear task-compatible, level-specific cueing effect when there was conflict between the two levels of structure (i.e., inconsistent cue), congruent with a control setting account. Yet, when there was no such conflict, the results were compatible with a global precedence account: when the cue was a global arrow composed of local rectangles (i.e., local-neutral cue), a global cueing effect was observed regardless of orienting task. Similarly, when the cue was a global rectangle composed of local arrows (i.e., global-neutral cue), a local cueing effect was observed in the local orienting task but not in the global orienting task, findings compatible with some form of global precedence. In addition, though differential local salience between tasks does not impact the primary conclusions related to global precedence given that local salience cannot account for the absence of a cueing effect with global-neutral cues in the global orienting task, it does impact the conclusion that the task-compatible, level-specific cueing effects with inconsistent and global-neutral cues in the local orienting task are compatible with a control setting account. This is because the salience of the local arrow in this task could explain these cueing effects equally as well as orienting task, a possibility that was tested in Experiment 4.

Experiment 4 examined the role of bottom-up salience in control of level-specific selection biases. Recent work has provided direct behavioral and neurophysiological

evidence that salient but irrelevant singletons can be actively suppressed when top-down guidance is deployed (Gaspelin, Leonard, & Luck, 2015). It is unlikely, therefore, that differential local salience between tasks was responsible for the differences between tasks and for the pattern of cueing effects in the local orienting task in Experiment 3.

Nonetheless, to be sure, Experiment 4 tested this possibility. This experiment was a replication of Experiment 1.2—in which there was no secondary task (i.e., processing of the compound cue was incidental to the detection task)—with the exception that one of the local arrows was a color singleton. If the local color singleton captured attention, then participants should be faster to respond to targets appearing at the location indicated by a local singleton arrow relative to targets appearing at the mirror location (i.e., a local cueing effect). In the same vein, there should not be a cueing effect with cues in which the local color singleton was a rectangle (i.e., local-neutral cues).

This prediction was not supported as there was, if anything, a global cueing effect with inconsistent cues at the 250 ms SOA (indicating that the local arrow color singleton did not capture attention and then shift attention to the local-valid location), as well as a significant cueing effect with local-neutral cues at short SOAs, indicating that the local rectangle color singleton did not capture attention and draw resources away from processing of the global arrow. However, a case for rapid-disengagement could be made, according to which spatial attention is initially captured by the singleton but rapidly disengages before the target appears (Theeuwes, 2010). In other words, this account suggests that top-down suppression occurs after an initial attentional shift to the local-valid (inconsistent cues) and valid (local-neutral cues) location. This account is plausible

given that the target did not appear until at least 250 ms after the onset of the arrow cue, thereby providing ample time to disengage from the local singleton. The effect of SOA on the cueing effect with inconsistent cues (reduced global cueing or, equivalently, enhanced local cueing effect at longer SOAs) and with local-neutral cues (reduced cueing effect at longer SOAs), however, would imply a weakening of top-down suppression with processing duration, which would not be expected of top-down control processes. As such, it appears that the early global cueing effect with inconsistent cues was due to influence from the global level. Thus, a color singleton at the local level did not produce a rapid local cueing effect (Experiment 4) unless the local level was task-relevant (Experiment 3), suggesting that the effects in question were due to task, not salience. Taken together, it is concluded that the results support a version of global precedence in which task set can either maintain the availability of the global level (evident by the absence of SOA effects on global cueing effects when the global level was relevant to the task) or attenuate the availability of the global level (evident by the absence of SOA effects on local cueing effects when the local level was relevant to the task).

Experiment 5 manipulated the scope of focal scope of attention (focused or diffuse), which led to a complex pattern of results. The redeeming quality of this cacophonous pattern is that a moment can be taken to reflect on the current limitations of the compound arrow cueing paradigm. Some of these limitations are weaknesses with cueing tasks themselves, such as the binary pairing of cue responses (orient left or right) with target locations (left or right), which lead to effects of polarity correspondence (i.e., effects driven by task structure; Proctor & Cho, 2006). Another unfortunate difficulty has

been determining a suitable method for designing experiments with a fully crossed factorial structure while maintaining a manageable number of trials. Finally, it is unclear what effect design-driven variables (e.g., blocked versus mixed cue types across trials, number of cue types, etc.), SOA-driven variables (e.g., fixed versus continuous SOAs, range and number of SOAs, etc.), and response-driven variables (e.g., number of target-locations) might have on the pattern of cueing effects within the compound arrow cueing paradigm.

Table 8.1. Summary of experimental conditions in which cueing effects were and were not observed. Significant effects are designated by \*\* ( $p < .05$ ) and \* ( $p < .10$ ), otherwise the effect was not significant (designated by —). Continuous SOA values (Experiment 2) are designated by a <sup>c</sup> superscript, otherwise SOAs were 250, 500, and 750 ms (except in Experiment 5 where only 250 and 750 ms SOAs were used).

Exp.	Cue Type	Valid Cue Level	Level Status w/ Respect to Task	Cueing Effect	SOA
1.1	Inconsistent	Global	Incidental	**	250
1.2	Inconsistent	Global	Incidental	**	250
1.3	Inconsistent	Global	Incidental	**	250
1.4	Inconsistent	Global	Incidental	*	250
2	Inconsistent	Global	Incidental	**	<sup>c</sup> 100-300
3	Inconsistent	Global	Relevant	**	250-750
3	Inconsistent	Global	Irrelevant	—	—
4	Inconsistent	Global	Incidental	*	250
5	Inconsistent	Global	Relevant	—	—
5	Inconsistent	Global	Irrelevant	—	—
1.1	Inconsistent	Local	Incidental	**	750
1.2	Inconsistent	Local	Incidental	**	750
1.3	Inconsistent	Local	Incidental	**	750
1.4	Inconsistent	Local	Incidental	**	750
2	Inconsistent	Local	Incidental	**	<sup>c</sup> 400-900
3	Inconsistent	Local	Relevant	**	250-750
3	Inconsistent	Local	Irrelevant	—	—



4	Inconsistent	Local	Incidental	**	500-750
5	Inconsistent	Local	Relevant	**	250, 750
5	Inconsistent	Local	Irrelevant	**	250, 750
1.1	Local-Neutral			n/a	n/a
1.2	Local-Neutral	Global	Incidental	**	250-750
1.3	Local-Neutral	Global	Incidental	**	250-500
1.4	Local-Neutral	Global	Incidental	**	250-750
2	Local-Neutral	Global	Incidental	**	<sup>c</sup> 400-550
3	Local-Neutral	Global	Relevant	**	250-750
3	Local-Neutral	Global	Irrelevant	**	250-750
4	Local-Neutral	Global	Incidental	**	250
5	Local-Neutral	Global	Relevant	**	250, 750
5	Local-Neutral	Global	Irrelevant	**	250, 750
1.1	Global-Neutral			n/a	n/a
1.2	Global-Neutral	Local	Incidental	**	250-750
1.3	Global-Neutral	Local	Incidental	**	250-500
1.4	Global-Neutral	Local	Incidental	**	250-750
2	Global-Neutral	Local	Incidental	—	<sup>c</sup> —
3	Global-Neutral	Local	Relevant	**	250-750
3	Global-Neutral	Local	Irrelevant	—	—
4	Global-Neutral	Local	Incidental	**	250
5	Global-Neutral	Local	Relevant	—	—
5	Global-Neutral	Local	Irrelevant	—	—
1.1	Consistent	Both	Incidental	**	250-750
1.2	Consistent	Both	Incidental	**	250-750
1.3	Consistent	Both	Incidental	**	250-500
1.4	Consistent	Both	Incidental	**	250-750
2	Consistent	Both	Incidental	**	<sup>c</sup> 100-900
3	Consistent	Both	Global-Relevant	**	250-750
3	Consistent	Both	Local-Relevant	**	250-750
4	Consistent	Both	Incidental	**	250
5	Consistent			n/a	n/a
5	Consistent			n/a	n/a

## 8.2 Thesis Objectives Revisited

The primary objectives of the current thesis were 1) to examine global and local processing in incidental perception of hierarchical structure, and 2) to examine control of

level-specific selection (see Section 2.1). The primary conclusion bearing on these objectives is as follows: 1) there is strong evidence that global precedence (or something akin to it) guides perceptual microgenesis (i.e., the time course of development in the percept) in incidental perception of hierarchical structure, and 2) interactions between task demands and the structure of the input information selectively modulate the relative needs of visual information at different levels of stimulus structure. Importantly, it seemed that a global-to-local shift in advantage was obligatory when there was conflict between levels and processing was incidental (Experiments 1-2), as well as that processing could be restricted to a task-relevant global level but not to a task-relevant local level (Experiment 3). These findings suggest that level-specific advantages may not have been due to top-down task set per se but rather to conflict between levels, with the effect of task set serving to modulate the availability of level-specific information, effectively prolonging (in the case of task-relevant global information) or expediting (in the case of task-relevant local information) the advantage at a given level. To select symbols at different levels of structure, therefore, the current thesis concludes that at least two factors need to be considered: the observer's current task, which specifies the demands of visual information from the input, and the globality of this visual information across the percept, which specifies the availability of the percept for selection.

### **8.3 Relation to Current State of Knowledge**

#### **8.3.1 Implications for global precedence in perception of hierarchical structure**

The present findings contribute to a greater understanding of visual perception by elucidating the source, nature, and time course of global/local processing under incidental

processing conditions. The present findings also establish important contextual conditions on how and when global- or local-level information is dominant, which has the potential to extend/constrain current knowledge to different kinds of people, stimuli, and task-contexts, in addition to extending current knowledge to more ecologically valid stimuli in which information is contained at multiple levels of stimulus structure, as described below.

**Availability of global features varies over time, suggesting queued precedence.** One of the main goals in Experiments 1-2 was to determine whether Navon's (1977) notion of stationary global precedence holds under incidental processing conditions. A stationary global precedence account predicts that global advantage should be observed and should remain constant across SOA given that, not only is global information available earlier (which accounts for the global advantage), but also that its availability does not decline over time, not even when local information is being processed (which accounts for the obligatory nature of global advantage and the preponderance of asymmetric, global-to-local interference patterns in global/local tasks). The present finding that global advantage interacted with processing duration (Experiments 1-2 and 4) indicates that the availability of directional information at the global level was somehow modulated during incidental perception of hierarchical structure, consistent with previous findings (Kimchi, 1998). Although this pattern does not support a stationary global precedence hypothesis (Navon, 1977, 1991), it is consistent with a weaker version of global precedence whereby the availability of global information may be modulated over time. Navon (1991) referred to this account as the queue

hypothesis. He speculated that such a shift in dominance may be indicative of a serial processor that operates on the local level after it operates on the global level and which stores in memory primarily information relevant to the current operation. The important point here is that global information is not lost but rather is somehow made less available.

Of course, the present findings do not entirely support the queue account of global precedence either, at least not a queue account in which the activity of a serial processor is envisioned as containing purely effortful operations. According to Navon's (1977) global precedence, global properties of hierarchical stimuli are more readily processed than local properties. In turn, greater effort in allocating attentional resources to local properties may be required. In support of this notion, Blasi et al. (2007) showed that relative to the global level, allocating attentional resources to the local level was associated with increased activity in dorsolateral prefrontal cortex and parietal cortices, regions commonly linked to top-down modulation of stimulus processing (Corbetta & Shulman, 2002; Desimone & Duncan, 1995; Miller & Cohen, 2001). The present finding of an obligatory local advantage during later processing (Experiments 1-2 and 4), however, is inconsistent with this view. Instead, it may be that the system is predisposed to process not only global information, as suggested by Navon (1977), but is also predisposed to shift priority to local information. Because stimulus features vary across stimuli, and because local information is relative (i.e., its identity potentially changes over time), it is probably not advantageous for a system to be predisposed to process local information. However, it probably is advantageous for a system to be predisposed to shift

processing from global to local information at some point in time, suggesting queued precedence (i.e., obligatory global precedence, followed by obligatory local precedence).

**Global-to-local shift in precedence requires cross-level conflict, suggesting contingent queued precedence.** Critically, an obligatory global-to-local shift occurred only for conflict cues (in which the spatial meaning of global and local items conflicted—i.e., the inconsistent cue type) and only in the absence of level-specific task demands. Accordingly, the current thesis hypothesizes that the obligatory shift in advantage during incidental perception of hierarchical structure depends on conflict between levels. Two strategies have been offered for the resolution of conflict by the cognitive control mechanism. One is to bias the task-relevant information (Botvinick et al., 2001; Notebaert & Verguts, 2008) and the other is to bias the task-irrelevant information (Stoffels, 1996; Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002). Accordingly, the queued precedence account suggests that level-specific advantage is not due to task per se (i.e., top-down selection of a particular level) but rather to conflict between levels, with the effect of task serving to modulate the availability of level-specific information, effectively prolonging the advantage at a given level. In other words, the current results are more consistent with the idea of contingent queued precedence. It suggests that all an orienting task can achieve is to bias already prepared control operations (i.e., faster transition to local dominance) but not to trigger a new, task-independent operation (i.e., early local precedence). Thus, this account suggests that the reason why the SOA effect disappeared in Experiment 3 was because the task-relevancy of a particular level maintained the dominance of that level—only in the absence of task demands was there

an obligatory global-to-local change in advantage (Experiments 1-2), and even then, only in the presence of conflict.

The contingent queued precedence account makes a straightforward and testable prediction regarding effects of selection history: if conflict pushes priority to local processing, then the presence of conflict on trial N-1 should facilitate local processing on trial N in conflict cues. If so, there should be a larger local cueing effect on trial N conflict cues when trial N-1 was also a conflict cue (relative to a neutral cue). Furthermore, with inclusion of a local singleton (Experiment 4), this conflict adaptation effect (i.e., enhanced conflict processing) might be enhanced by a manipulation that facilitates attention capture (i.e., Experiment 5, diffuse attention condition), and thereby bias processing in favor of the local level. If so, the conflict adaptation effect should be larger when attention is diffuse relative to when attention is focused. In other words, the prediction is that interactions between task demands and the structure of the input information will selectively modulate the relative needs of visual information at different levels of stimulus structure. These predictions were confirmed in Experiment 5. To select symbols at different levels of structure, therefore, the contingent queued precedence account suggests that at least two factors need to be considered: the observer's current task, which specifies the demands of visual information from the input, and the globality of this visual information across the percept, which specifies the availability of the percept for selection (see also, Morrison & Schyns, 2001, where an alternative factor—the representation of that visual information across scale space—was suggested in place of the globality factor).

**Gradual change in availability over time suggests obligatory content-to-level binding.** Recent work suggests that attentional selectivity in global/local processing improves discretely (Hübner, 2014). This is consistent with the predictions of Hübner and Volberg's (2005) content-to-level binding theory. According to this view, the contents of the different levels in a hierarchical structure are identified and represented independently of their respective level. Consequently, to obtain a complete object representation that can be used, for example, to resolve response conflicts, the contents must subsequently be actively linked or bound to their respective level. This account is supported by neuroscientific data demonstrating that the processing of information at early stages is affected by the output of processes at later stages. 'Actively' is the key word here—meaning via a second, presumably post-perceptual process. Given the considerations discussed above in reference to Figure 1.1, however, it is not clear that a secondary process is necessary providing that levels and their content (i.e., identity, message, etc.) can be bound in the microgenesis of the percept via early perceptual organization mechanisms (e.g., grouping by shared or common function). In support of this, Experiment 2 observed gradual (as opposed to discrete) change in the size of spatial cueing effects over time.

Reinforcing this single-process account, no evidence was found suggesting that level-specific information was necessarily integrated as neither congruency nor interference effects were observed (Experiment 1). In other words, symbolic information at different levels of structure was not necessarily integrated and had independent effects on behavior. This suggests that the purpose of a global-to-local processing scheme may

not be to facilitate recognition per se but rather to facilitate processes that constrain possible actions (where recognition is just one of the possible actions). For example, knowledge constrains identification of objects (e.g., knowing that blenders appear in kitchens means that the blender-like object in the bathroom probably is not a blender). Global-to-local processing might facilitate application of this knowledge (e.g., perception of a large room will enable access to a kitchen schema more readily than a bathroom schema given that kitchens tend to be larger than bathrooms). Similarly, symbolic cueing effects occur given knowledge that the direction of an arrow is usually indicative of important information in the real world. Global-to-local processing could facilitate application of this knowledge (e.g., perception of overall form may enable access to the appropriate behavior more readily because local forms may differ).

### **8.3.2 Implications for attentional control in general and symbolic control in particular: Spatial constraints on selection differ across object classes**

The conclusion that the global-to-local sequence observed in Experiments 1-2 was obligatory is at odds with the prevailing view in which the processing sequence is thought to be more flexible (e.g., Morrison & Schyns, 2001). Global/local processing is typically examined with displays that emphasize local processing (e.g., central presentation of the imperative compound stimulus, fixed target locations, etc.). In contrast to local processing, the function of global processing is to provide a representation of the spatial layout and a representation of locations for possible action (i.e., affordances). Thus, just because the processing of spatial layout is flexibly global-to-local, this does not mean that the processing of affordances is. Moreover, although Schyns and Oliva (1997; Schyns &



Oliva, 1999) showed that the processing of scene-relevant affordances is flexible, there is reason to believe that the processing of behaviorally- and socially- relevant cues may not be as flexible.

In particular, there are at least three reasons to suspect that temporal visual processing of symbolic stimuli may differ from other classes of objects. One reason is because there is evidence that temporal visual processing of objects and faces differs (e.g., Greene & Zaidel, 2012; Hill, Patel, Gu, Seyedali, Bachevalier, & Sereno, 2010; Zhao, Uono, Yoshimura, & Toichi, 2014). Similarly, there is evidence that gaze cues and arrow cues may differ (e.g., Frischen et al., 2007). A second reason is because there is evidence that expertise leads to automatic processing of subordinate level information, and people are arguably experts at processing arrows. Arrows, for example, might be categorized as simply a shape at a basic level. At a subordinate level, this might be categorized as a directional arrow. Accordingly, with expertise, global information is capable of activating subordinate level categorizations (Sigurdardottir, Michalak, & Sheinberg, 2014). Finally, orienting to behaviorally and biologically relevant cues, such as directional arrows and gaze, respectively, appears to be distinct from traditional conceptualizations of orienting as either exogenous or endogenous. In contrast to endogenous orienting (which occurs with intention and arises from deliberate resource allocation), and in contrast to exogenous orienting (which occurs without intention and arises from sensory stimulation), automated symbolic orienting occurs without intention but arises from the overlearning of the cue's contingency over time (Dodd & Wilson, 2009; Hasher & Zacks, 1979; Hommel et al., 2001; Ristic & Kingstone, 2012; Van der

Stigchel, Mills, & Dodd, 2010; but see Sigurdardottir et al., 2014), and learned processes are not as flexible as biological processes. For example, learned processes are constrained by context, whereas biological processes are more context-independent. Taken together, these considerations suggest that spatial constraints on selection differ between object classes. Although this has been demonstrated repeatedly with single-level cues, the present findings are the first show an equivalent distinction for cues with hierarchical structure.

### **8.3.3 Implications for theories of selectivity and target-distractor interactions**

To ensure efficient goal-directed behavior, the brain must not only focus visual processing on goal-relevant stimuli but also must exclude irrelevant, distracting information from processing. Distractor processing has important implications for daily functioning (e.g., educational achievement; driving safety; advertising strategies), and disproportionate distractor processing is associated with several psychopathologies (e.g., attention deficit hyperactivity disorder, schizophrenia). The question of how humans cope with distraction is therefore of central importance to psychological research. Navon's work has been significant in this regard. Since Navon's (1977) introduction of the compound stimulus paradigm for examining the nature of global and local processing in perception of hierarchical structure, global and local processing dynamics have been applied to a number of varied areas of research—including scene perception (Brockmole, Castelano, & Henderson, 2006; Greene & Oliva, 2009; Joubert, Rousselet, Fize, & Faber-Thorpe, 2007; Loftus & Harley, 2004), face processing (Martin & Macrae, 2010; Perfect, Weston, Dennis, & Snell, 2008), emotional processing (Baumann & Kuhl, 2005;

Gasper & Clore, 2002; Tan, Jones, & Watson, 2009), reading, among others—and in turn have enhanced our understanding of individual differences in performance across culture (Davidoff, Fonteneau, & Fagot, 2008), age (Scherf, Behrmann, Kimchi, & Luna, 2009; Staudinger, Fink, Mackay, & Lux, 2011), race (McKone, Davies, Fernando, Aalders, Leung, Wickramariyaratne, & Platow, 2010), gender, and a variety of cognitive disorders.

#### **8.4 Action Addressability Principle**

The natural world continuously presents us with various opportunities for action. Because one cannot perform all possible actions at the same time, there must be mechanisms in place to reduce the number of options available to us at any given point in time. Such decisions are generally thought to be based on sensory information and constrained by effector systems (used to determine whether to look, reach or grasp). Constraints on visual acuity imposed by the optical limits of the eyes imply that the resolution of most stimuli in the visual field is low by default. Intuitively, it would seem that limited acuity of visual sensory mechanisms cause a deficiency in data quality that needs to be overcome. In fact, many researchers cite the need to overcome this deficiency as the primary function of saccadic eye movements (i.e., to re-orient the region of the eyes where acuity is highest—the fovea—to regions of the visual field where resolution is poor). Though the dependence of higher-order cognition on high-resolution visual input is incontrovertible (Henderson, 2003), it does not follow that low-resolution input is a problem to be overcome. Saccadic eye movements may indeed function primarily to enhance resolution in support of high-level cognitive processes (though, this assumption

is far from uncontested; e.g., Najemnik & Giesler, 2005, 2008); however, enhancing resolution does not amount to overcoming deficient resolution. For instance, enhanced resolution may simply lead to a more durable representation, as opposed to a higher-quality one (e.g., flashbulb memory).

A widespread idea is that visual processing is temporally structured—proceeding global-to-local—either because a) global information is more important early on, whereas local information is more important later, b) global processing constrains and therefore facilitates recognition, or c) global information is available to direct attention earlier than local information. The central idea put forward here is that perceptual processes are temporally organized in order to facilitate flexible, goal-directed action. More specifically, the current thesis argues that the function of the obligatory global-to-local processing sequence observed with conflict cues under conditions of incidental processing (Experiments 1-2) is to reduce the computational workload, though, not for perception but for action. In other words, the purpose of perception is to enable goal-directed action. In this view, to the extent that perception brings one closer to realizing the goal of the system (think of the game 20 questions), then there would be no need for a method aimed at reducing the computational demands involved in processing scenes to a high-level to the limits of visual acuity because action does not always require high-level understanding.

In light of the findings in Experiments 1-2 (i.e., default global-to-local temporal sequence in incidental perception of directionally relevant compound symbolic structure), the current thesis suggests that one reason why the entry point of visual processing

defaults to the global level for this class of stimuli may be to facilitate goal-directed action. Given that meaningful visual information can be extracted from global features (Beaucousin et al., 2011; Poirel, Pineau, & Mellet, 2008) and that the function of symbols is to convey meaningful information that is not inherent to its individual features, then a system that starts processing at the global level is immediately able to respond to relevant symbolic information and to ignore irrelevant perceptual information. Moreover, supposing information at the global level does not afford goal completion, then a system that starts processing at the global level is able to then immediately guide attention toward relevant local regions. For example, using a contextual cueing paradigm, Brockmole, Castelhano, and Henderson (2006) found that local contexts near the target were used to guide attention only when global information was non-predictive, suggesting that observers were biased to associate target locations with global contexts. Symbols are capable of producing automatic shifts of attention, a property acquired presumably through experience (Ristic & Kingstone, 2012). Given that symbolic material is, by definition, a psychological feature with no perceptual counterpart, symbolic representation must be abstract. According to the encoding specificity principle (Tulving, 1972, 1983; Tulving & Thomson, 1973), performance is best when the type of processing performed during practice matches the type of processing performed during retrieval. Accordingly, if the communicative value of symbols is acquired and represented in memory in abstract format, then symbolic processing should be most efficient when processing is directed toward the more abstract, global properties of the environment. In support of this view, previous work has shown that memory for specific scene details is

better when the type of processing performed at study matches the type of processing performed at test (Reingold, 2002). Furthermore, face processing is more efficient with- than with-out global processing (Richler, Mack, Palmeri, & Gauthier, 2011; Sekuler, Gaspar, Gold, & Bennett, 2004).

In conclusion, it is argued that the temporal order of processing generally proceeds from global-to-local levels of structure in fixed fashion so as to ‘pick-up’ behaviorally relevant symbols capable of effortlessly guiding where processing should be directed (e.g., arrow and gaze cues). The idea is that global processing ensues until the perception of form matches an action scheme (if x, then move eyes to y). If no action scheme is found or if the action scheme did not bring about desirable consequences, then processing moves to progressively more local levels of stimulus structure for more elaborate processing. For example, imagine the fire alarm goes off and you have to locate a stairwell to leave the building. If unfamiliar with the building, you are probably searching for an EXIT sign that designates the stairwell (e.g., Figure 1.1). The question posed in the current thesis basically amounts to whether you are searching for the word ‘EXIT’ or for a sign with red letters hanging over a doorway. It is hypothesized that you are searching for the latter. That is, the current thesis suggests that global processing precedes local processing in perception of behaviorally relevant hierarchical structure. This is because the level of encoding determines the level of retrieval (cf. encoding specificity principle; Tulving, 1972, 1983; Tulving & Thomson, 1973). If the global property is encoded, then global properties can be used to retrieve. If the local property is encoded, then the local properties can be used to retrieve. However, because local

properties can be retrieved via inference (e.g., stairwell is underneath the EXIT sign) of global properties (e.g., red blob above discrete segment of corridor), a stimulus is more efficiently dissected for use by processing global properties.

### **8.5 Implications of Current Thesis**

As touched on in the preceding sections, the experimental findings reported in the current thesis have important theoretical and practical implications. In terms of intellectual merit, the use of an incidental processing procedure to measure precedence is important in that this procedure closely reflects the manner in which a great deal of information is processed in the real world (i.e., most items in the visual field are irrelevant and uninformative to one's current task). Though attention, perception, and action can be strongly influenced by goals and intentions, processing of stimuli routinely occurs in a passive manner given the overwhelming number of inputs available at any given time. The current thesis may also establish important boundary conditions on how and when globality determines selection efficiency. Finally, the present thesis developed a method that combines two widely-used paradigms (spatial cueing and compound stimulus tasks) for implicitly probing observers' perceptual representations in order to address fundamental issues of broad theoretical interest (selection of competing symbols at different levels of stimulus structure; entry point of visual perception and its flexibility). The results of this work make an important empirical and methodological contribution to the study of attentional control in general and symbolic control in particular, as well as global/local processing. For instance, the logic of the paradigm can be extended to versions in which all measurable dimensions (i.e., dimensions that

influence identification of features necessary for representing the form of an arrow, such as eccentricity and visual angle) and all task dimensions are independent, and thus, processing of measurable dimensions can still be incidental while processing of other dimensions is task-relevant. For example, if one's task were singleton-search for a color, processing of form would be incidental (as in Experiment 3). As such, the current thesis enhances our understanding of perception and attention and, therefore, should be of broad theoretical interest given that the relation between levels of objects and selective attention is often of central interest beyond vision science, and may play a role in theorizing about other cognitive processes.

In terms of broader impact, the current thesis has potential to benefit society and contribute to desirable social outcomes. Research investigating the processing of hierarchical structure has had a tremendous impact on educational and business-related practices, as well as on characterizing various psychopathologies. In education, canonical effects associated with global and local processing are often taken as an index of trait-related processing style, which can be optimized by constructing learning environments and materials tailored toward a particular processing style. In business, such effects are often used to evaluate the fit between person and job. And in psychopathology, such effects are often used as diagnostic criteria, for instance, of Dyslexia and Dyscalculia (Rubinstein & Henik, 2006), Obsessive Compulsive Disorder (Yovel, Reville, & Mineka, 2005), and Autism (Frith, 1989; Gross, 2005; Happé & Frith, 2006; Hayward et al., 2012; Plaisted, Swettenham, & Rees, 1999). Thus, theories of hierarchical processing inform practices in some of the largest and most important institutions in society. The



current work, therefore, has the potential to lead to empirically-based practices for tailoring fit between person and environment in order to maximize performance. It also has the potential to reveal distinctions between ‘deficits’ and ‘biases’, which will be important to generation of effective treatment plans.

## **8.6 Future Directions**

The objectives of the current thesis relate to longer-term goals in three ways. First is the question of whether and how global precedence in the focal percept influences eye movements during scene viewing? Global/local research is rooted in a single paradigm far removed from natural viewing behavior, focusing almost exclusively on discrete processing episodes. The current experiments extend this behavioral work to more natural viewing conditions (i.e., incidental processing conditions). Future work will generalize the current work to continuous processing tasks (eye movement kinematics), as well as investigate neural correlates of continuous, global/local viewing behavior.

A second relation between the objectives of the current thesis and longer-term goals is the question of how task-relevant information changes processing. It has been argued in the current thesis that the most appropriate test of global precedence requires that the critical compound stimulus be entirely task-irrelevant. Under such conditions, the current experiments obtained evidence supporting Navon’s (1977) perceptual account of global advantage, in which processing proceeds from global structuring to local detail. Considering that many studies have found evidence suggestive of a post-perceptual locus (e.g., Miller, 1981a; Oliva & Schyns, 1997), the present findings suggest that task-relevant processing may substantively change the nature of processing relative to task-

irrelevant processing. An important question, therefore, is what properties characterize task-relevant and task-irrelevant processing, and how do differences in these properties promote and/or cancel dispositional biases in perception?

Third, studies investigating determinants of selection efficiency have identified several factors that may be crucial in determining whether selection is more or less efficient. Typically, such studies draw on tasks requiring selective attention to centrally presented local information while ignoring irrelevant peripheral information. Moreover, the stimuli used in these studies are generally perceptually simple, containing semantic information at only one level of stimulus structure (e.g., letters). Many structural differences exist between the stimuli presented in traditional studies of selectivity and the sort of stimuli found in the real-world. Considering that differences in stimulus structure are known to influence processing strategies (e.g., Garner, 1970, 1974), understanding the role of stimulus structure in information processing is crucial for understanding how various factors influence selective attention. Ignoring the nature of the stimulus, at worst, would lead to incorrect assessment of the nature of information processing, and, at best, an inadequate picture (Garner, 1970). A long-term goal of this research, therefore, is to develop an understanding of how other stimulus structures, such as a target's location in depth on a three-dimension plane, contributes to selectivity.

### **8.7 Concluding Remarks**

In conclusion, the experiments reported in the current thesis suggest that information at the global level is dominant in incidental perception of hierarchical structure, though, not necessarily always available (Experiments 1-2) as task set appears

able to modulate its availability. One way is through selective attention, implemented as control settings that allow relevant features to filter through to working memory (Experiment 3). Another way is through focusing of attention, implemented as a zoom-lens that trades scope for detail (Experiment 5). More speculatively, this might suggest that flexible use of levels is achieved through processes that control where in the hierarchy an observer needs to be and how efficiently they get there. Task set seems a likely candidate for specifying where in the hierarchy processing needs to be (or the level of organization required to perform a task; e.g., Forester & Lavie, 2009), and stimulus-stimulus and stimulus-response compatibility seem likely as candidates for governing how easily one traverses the hierarchy. It is important to note that the present use of an incidental processing paradigm is important in that it closely reflects the manner in which a great deal of information is processed in the real world. Though attention, perception, and action can be strongly influenced by goals and intentions, processing of stimuli routinely occurs in a passive manner given the overwhelming number of inputs available at any given time. The present results suggest that under such conditions the perceptual system is more prepared to process global versus local information.

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**APPENDIX A: MODEL PARAMETERS FOR EACH EXPERIMENT**

Table A1. Parameter estimates, standard errors, and *p*-values for Experiment 1.1. SOA was centered at 750 and validity was effect coded (-.5 = valid or global-valid, and .5 = invalid or local-valid).

Model Parameter	Consistent			Inconsistent		
	<i>Est</i>	<i>SE</i>	<i>p</i>	<i>Est</i>	<i>SE</i>	<i>p</i>
<u>Fixed Effects</u>						
Intercept	299.61	5.96	.00	295.97	6.06	.00
S250	50.29	3.08	.00	54.00	3.45	.00
S500	7.01	3.07	.02	14.28	3.44	.00
Vald	13.92	3.53	.00	-10.00	3.55	.00
Vald*S250	2.59	4.92	.60	25.74	4.98	.00
Vald*S500	-1.76	4.91	.72	7.21	4.97	.15
<u>Random Effects</u>						
Subject Intercept	1506.34	323.81	.00	1505.33	327.68	.00
SOA Slope	83.22	33.35	.01	138.87	41.77	.00
Vald Slope	7.02	41.27	.43	5.26	72.96	.47
Residual	5579.06	107.56	.00	5712.39	109.63	.00

Table A2. Parameter estimates, standard errors, and *p*-values for Experiment 1.2. SOA was centered at 750 and validity was effect coded (-.5 = valid or global-valid, and .5 = invalid or local-valid).

Model Parameter	Consistent			Inconsistent			Local-Neutral			Global-Neutral		
	<i>Est</i>	<i>SE</i>	<i>p</i>	<i>Est</i>	<i>SE</i>	<i>p</i>	<i>Est</i>	<i>SE</i>	<i>p</i>	<i>Est</i>	<i>SE</i>	<i>p</i>
<u>Fixed Effects</u>												
Intercept	327.4	10.0	.00	324.4	8.8	.00	325.2	9.4	.00	320.5	9.6	.00
S250	41.5	4.1	.00	46.3	3.6	.00	48.1	3.7	.00	51.8	3.9	.00
S500	11.1	4.0	.01	9.5	3.6	.01	8.5	3.7	.02	13.2	3.9	.00
Vald	18.9	4.3	.00	-10.1	4.3	.02	6.9	4.5	.13	16.8	4.3	.00
Vald*S250	-4.3	6.0	.47	28.1	5.9	.00	2.0	6.1	.74	2.6	5.9	.66
Vald*S500	-1.3	5.9	.83	9.1	5.8	.12	4.8	6.0	.42	-2.3	5.8	.70
<u>Random Effects</u>												
Subject Intercept	4035	898	.00	3149	703	.00	3718	824	.00	3780	841	.00
SOA Slope	165	56	.00	96	44	.01	97	45	.02	150	53	.00
Vald Slope				35	63	.29	64	73	.19	28	61	.32
Residual	7403	150	.00	7187	145	.00	7682	155	.00	7212	146	.00

Table A3. Parameter estimates, standard errors, and *p*-values for Experiment 1.3. SOA was centered at 750, validity was effect coded (-.5 = valid or global-valid, and .5 = invalid or local-valid), and proximity was effect coded (-.5 = outside, .5 = inside).

Model Parameter	Consistent			Inconsistent			Local-Neutral			Global-Neutral		
	<i>Est</i>	<i>SE</i>	<i>p</i>	<i>Est</i>	<i>SE</i>	<i>p</i>	<i>Est</i>	<i>SE</i>	<i>p</i>	<i>Est</i>	<i>SE</i>	<i>p</i>
<u>Fixed Effects</u>												
Intercept	299.0	6.02	.00	301.1	6.1	.00	294.6	6.2	.00	296.9	5.9	.00
S250	47.8	3.43	.00	45.8	3.1	.00	53.8	3.2	.00	45.8	3.3	.00
S500	11.4	3.4	.00	11.9	3.0	.00	13.6	3.2	.00	5.0	3.3	.13
Vald	.3	3.8	.93	-8.8	3.6	.01	4.0	4.2	.35	.9	3.6	.81
Vald*S250	7.7	5.2	.14	17.1	5.2	.00	8.6	5.2	.10	11.7	5.1	.02
Vald*S500	11.7	5.2	.03	6.1	5.1	.23	.6	5.2	.91	3.7	5.1	.47
Prox	1.2	4.6	.79	7.7	3.7	.04	8.5	3.9	.03	.3	3.6	.94
Prox*S250	-9.0	5.2	.08	-11.9	5.2	.02	-18.2	5.2	.00	1.0	5.1	.85
Prox*S500	5.9	5.2	.25	-6.9	5.1	.17	-8.7	5.2	.10	-4.7	5.1	.36
Prox*Vald	3.2	7.4	.67	9.7	7.2	.18	2.8	7.4	.71	-1.4	7.2	.85
Prox*Vald*S250	-8.5	10.5	.41	-.3	10.3	.98	8.7	10.5	.41	12.1	10.2	.24
Prox*Vald*S500	-.2	10.4	.99	-8.8	10.2	.39	-9.6	10.5	.36	-1.4	10.2	.89
<u>Random Effects</u>												
Subject Intercept	1062	274	.00	1128	286	.00	1171	298	.00	1026	264	.00
SOA Slope	86	35	.01	46	27	.05	55	30	.03	75	32	.01
Vald Slope	26	45	.28				148	74	.02			
Prox Slope	256	100	.01	9	39	.41	60	53	.13			
Residual	5523	113	.00	5312	109	.00	5672	115	.00	5329	108	.00

Table A4. Parameter estimates, standard errors, and *p*-values for Experiment 3. SOA was centered at 750, validity was effect coded (-.5 = valid or global-valid, and .5 = invalid or local-valid), and task was effect coded (-.5 = local orienting task, .5 = global orienting task).

Model Parameter	Consistent			Inconsistent			Local-Neutral			Global-Neutral		
	<i>Est</i>	<i>SE</i>	<i>p</i>	<i>Est</i>	<i>SE</i>	<i>p</i>	<i>Est</i>	<i>SE</i>	<i>p</i>	<i>Est</i>	<i>SE</i>	<i>p</i>
<u>Fixed Effects</u>												
Intercept	406.6	12.8	.00	413.3	14.1	.00	358.7	10.4	.00	358.8	10.5	.00
S250	46.3	2.5	.00	53.1	2.5	.00	48.5	2.8	.00	50.9	2.7	.00
S500	-17.6	2.6	.00	-19.4	2.5	.00	-16.6	2.8	.00	-21.2	2.7	.00
Vald	15.3	3.6	.00	3.2	3.6	.37	11.9	3.9	.00	7.4	3.8	.05
Vald*S250	.0	5.1	.99	-7.2	4.9	.15	5.4	5.5	.33	-4.2	5.3	.43
Vald*S500	2.7	5.2	.60	-1.6	5.1	.75	1.0	5.6	.86	4.3	5.4	.43
Task	-8.8	3.6	.02	-15.3	3.6	.00	-7.0	3.9	.08	-.2	3.8	.97
Task*S250	-8.9	5.1	.08	-15.6	4.9	.00	-7.4	5.5	.18	-.9	5.3	.86
Task*S500	-4.7	5.2	.36	.3	5.1	.95	1.4	5.6	.81	-4.1	5.4	.45
Task*Vald	8.9	7.3	.22	26.5	7.1	.00	-7.2	7.9	.36	-9.6	7.7	.21
Task*Vald*S250	-8.0	10.1	.43	-6.2	9.9	.53	-4.0	11.0	.72	10.4	10.6	.33
Task*Vald*S500	-10.2	10.3	.32	2.9	10.1	.78	5.4	11.2	.63	-6.2	10.8	.57
<u>Random Effects</u>												
Subject Intercept	5955	1436	.00	7214	1731	.00	2915	828	.00	2979	843	.00
Residual	16967	335	.00	16383	324	.00	10665	291	.00	9811	269	.00



Table A5. Parameter estimates, standard errors, and *p*-values for Experiment 4. SOA was centered at 750 and validity was effect coded (-.5 = valid or global-valid, and .5 = invalid or local-valid).

Model Parameter	Consistent			Inconsistent			Local-Neutral			Global-Neutral		
	<i>Est</i>	<i>SE</i>	<i>p</i>	<i>Est</i>	<i>SE</i>	<i>p</i>	<i>Est</i>	<i>SE</i>	<i>p</i>	<i>Est</i>	<i>SE</i>	<i>p</i>
<u>Fixed Effects</u>												
Intercept	328.4	11.1	.00	331.5	12.7	.00	331.1	13.0	.00	331.9	11.6	.00
S250	60.5	5.9	.00	47.3	7.2	.00	73.9	7.4	.00	62.0	5.6	.00
S500	7.4	6.0	.22	12.5	7.1	.08	13.9	7.3	.06	13.8	5.7	.02
Vald	10.2	7.9	.20	-13.1	8.9	.14	2.1	9.4	.82	6.1	7.0	.39
Vald*S250	9.2	10.3	.37	24.4	12.5	.05	27.5	12.8	.03	9.9	9.8	.31
Vald*S500	.6	10.5	.95	-6.4	12.3	.60	11.0	12.6	.38	6.1	9.9	.54
<u>Random Effects</u>												
Subject Intercept	4194	1004	.00	5448	1314	.00	5683	1368	.00	4760	1127	.00
SOA Slope	167	112	.07	260	164	.06	272	172	.06	153	101	.07
Vald Slope	323	238	.09	70	251	.39	241	294	.21			
Residual	28364	509	.00	40337	722	.00	42036	752	.00	25470	456	.00

Table A6. Parameter estimates, standard errors, and *p*-values for Experiment 5. Effect coding was used for the SOA (-.5 = 250, .5 = 750), validity (-.5 = valid or global-valid, .5 = invalid or local-valid), and attention condition (-.5 = focused, .5 = diffuse) factors.

Model Parameter	Inconsistent			Local-Neutral			Global-Neutral		
	<i>Est</i>	<i>SE</i>	<i>p</i>	<i>Est</i>	<i>SE</i>	<i>p</i>	<i>Est</i>	<i>SE</i>	<i>p</i>
<u>Fixed Effects</u>									
Intercept	412.7	20.9	.00	393.3	16.0	.00	394.1	16.5	.00
SOA	-102.6	13.2	.00	-93.9	9.1	.00	-100.3	9.2	.00
Vald	-11.6	5.8	.05	-9.1	5.4	.10	-2.3	5.5	.68
Vald*SOA	14.5	12.7	.26	-5.5	9.2	.55	-2.4	9.5	.80
Attent	7.3	11.9	.54	11.1	7.8	.16	4.1	9.7	.68
Attent*SOA	20.6	10.5	.05	-16.5	9.6	.09	-6.8	9.5	.48
Attent*Vald	-8.7	10.5	.41	-13.9	9.3	.14	-6.2	12.1	.61
Attent*Vald*SOA	12.7	20.9	.54	2.3	18.3	.90	-14.4	19.0	.45
<u>Random Effects</u>									
Subject Intercept	22886	4560	.00	13357	2675	.00	14180	2840	.00
SOA Slope	7710	1798	.00	3309	870	.00	3254	874	.00
Vald Slope	347	355	.16	404	299	.09	406	315	.10
Attent Slope	6036	1471	.00	2089	630	.00	3801	981	.00
Vald*SOA Slope	2659	1666	.06						
Attent*Vald Slope				161	917	.43	2914	1513	.03
Attent*SOA Slope				400	958	.34			
Residual	69539	991	.00	53091	759	.00	57245	815	.00

