PARSING ARROW AUTOMATICITY: GLOBAL PRECEDENCE AND INTERFERENCE IN HIERARCHICAL STIMULI

by

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Human visual perception adeptly processes information at both global, holistic levels and local, detailed levels, a phenomenon often studied using hierarchical stimuli. Concurrently, symbolic cues like arrows are known to trigger automatic attentional orienting. Prior research on hierarchical arrows has suggested a global-to-local temporal dynamic in their cueing effects. This study aimed to investigate whether the automaticity associated with arrows operates predominantly at the global or local level within hierarchical stimuli and to compare these effects with those elicited by neutral C-shape hierarchical stimuli, thereby examining potential alterations to typical global/local processing patterns. Twenty-eight university students participated in an experiment employing hierarchical arrow and C-shape stimuli. They performed tasks requiring identification of direction at either the global or local level, with trials being congruent, incongruent, or neutral. Reaction time (RT) served as the primary dependent variable. The results replicated the Global Precedence Effect (GPE) where participants respond faster to global control trials than local control trials. The GPE was found to be significant for both arrow and C-shape stimuli; however, this effect was significantly larger for C-shapes. We also looked at the Global Interference Effect (GIE), defined as the difference in incongruency effects between local and global tasks: (Local Incongruent – Local Congruent) – (Global Incongruent – Global Congruent). This Global Interference Effect measures whether conflicting information at

the global level impedes performance more (or less) than conflicting information at the local level. A Global Interference Effect was not observed for either stimulus type. Interestingly, arrow stimuli elicited significantly amplified congruency effects (RT Incongruent – RT Congruent) compared to C-shape stimuli, and this amplification was evident regardless of whether attention was directed to the global or local level. While classic spatial attentional automaticity of arrows, as typically measured by GIE or specific cueing paradigms, was not clearly demonstrated, the substantially amplified congruency effects suggest a potent and automatic processing of the arrow's inherent directional meaning. This likely manifests as enhanced response facilitation in congruent conditions and increased response competition in incongruent conditions, indicating that the semantic content of arrows is compellingly processed even when part of an unattended stimulus level. The comparison with C-shapes was fundamental in isolating these symbolic effects from general shape processing.

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Introduction

Global vs. Local Visual Processing

Human perception can operate at both a broad, holistic level and a fine-grained, detailed level. For example, one can look at a whole forest, or focus on individual trees. A classic demonstration of this dichotomy in experimental settings comes from hierarchical stimuli, in which a large, "global" shape is composed of smaller, "local" elements. This can look like a large H shape outlined by many smaller H's. In early studies, it was found that people tend to recognize the global form faster than the local details, a phenomenon termed the global precedence effect (Navon, 1977). Additionally, researchers observed an asymmetry in interference known as the global interference effect: when the global shape and local elements conveyed conflicting information, the global information disrupted local judgments more than vice versa. This means an incongruent global shape can slow down identification of local features, whereas incongruent local details have relatively little impact on global recognition. These findings support the idea that the visual system prioritizes an initial gestalt of the scene (processing the overall configuration prior to finer components). Over subsequent decades, many reaction-time studies have confirmed faster responses to global-level targets (Van der Hallen et al., 2015), along with greater interference caused by global distractors than by local distractors. This robust pattern suggests a default bias toward global processing in hierarchical stimuli.

Importantly, global dominance is not absolute. It can be moderated by stimulus and task conditions. Factors such as the spacing, size, or salience of the local elements (Mevorach et al., 2006) can alter the balance between global and local processing. For instance, making the local features more visually salient or distinct tends to reduce or even reverse the global advantage. Some researchers have demonstrated that when local elements are extremely salient, attention can be biased toward those details, leading to comparatively faster local processing or greater local-to-global interference. Conversely, brief exposure durations or masking tend to favor global information (Kimchi & Palmer, 1982), since coarse global outlines are extracted quickly while local details require more time or focal attention. Thus, the “default” global precedence effect can be disrupted under certain conditions, indicating that global vs. local processing is somewhat flexible rather than rigidly fixed. Nevertheless, under typical viewing conditions with moderate element spacing and salience, a global-first processing strategy is often observed. This bias toward the whole is in line with Gestalt principles emphasizing our tendency to perceive unified forms (Wagemans, 2015); indeed, holistic processing is considered a fundamental aspect of perceptual organization. The present work takes this classic paradigm and asks what happens when the stimuli themselves carry inherent directional meaning, specifically, arrow shapes, which could potentially perturb or enhance these baseline global/local dynamics.

Special Populations and Global/Local Processing

The dynamics of global versus local visual processing can vary across different populations, such as individuals with autism spectrum disorder (ASD) or those with heightened anxiety. Research has demonstrated that individuals with ASD often show a detail-focused cognitive style, sometimes manifesting as a weaker global precedence effect compared to neurotypical individuals (Happé & Frith, 2006; Van der Hallen et al., 2015). This “weak central coherence” suggests that hierarchical stimuli might be processed differently, with less automatic integration of global forms. Similarly, anxiety has been shown to modulate attentional biases and influence processing styles (Shilton et al., 2019). For example, anxious individuals may exhibit reduced attentional disengagement from salient or threatening stimuli (Moriya & Tanno, 2009). Considering that arrows are highly salient and symbolically charged stimuli, it is important to explore how these populations might process arrow automaticity within hierarchical contexts. Including these considerations in the current investigation can help bridge basic perceptual research with individual differences in cognitive processing.

Automatic Orienting by Arrow Cues

Beyond basic shape processing, another relevant line of research concerns attentional orienting triggered by symbolic cues. Arrows are an example: a simple arrow can draw our gaze or attention in the direction indicated, even without conscious deliberation. In spatial cueing experiments, centrally presented arrows have been shown to produce reflexive shifts of attention to a target location in the indicated direction, despite being irrelevant or non-predictive of the target. For instance, when participants fixated centrally and a peripheral target could appear randomly left or right, a non-informative arrow presented at fixation still sped up responses to targets on the side it pointed toward and slowed responses on the opposite side. This occurred even though participants knew the arrow's direction had no relation to where the target would actually appear (Tipples, 2002). Such results suggest that arrow cues trigger an automatic orienting of attention, akin to the involuntary capture caused by sudden peripheral flashes. Our attentional system interprets it as a guide, reflexively biasing us toward that direction.

Notably, this effect is not unique to arrows; it parallels the well-documented phenomenon of gaze-induced orienting. Research has shown that an image of eyes gazing in a particular direction causes a similar reflexive attention shift in observers, even when gaze direction is non-predictive. Arrows, though merely symbolic, appear to tap into a comparable attentional mechanism as biologically salient cues like eye gaze (Ristic et al., 2002). In fact, central arrows and gaze cues produce very similar behavioral cueing effects under most conditions, although some evidence indicates that gaze cues may have a slight edge in automaticity. For example, arrow-induced cueing can be modulated by context or color cues (Johnson et al., 2010), whereas gaze-induced orienting is more resistant to such top-down influences. Nonetheless, the consensus is that arrows are highly overlearned directional symbols (Eimer, 1997) that our brains process rapidly and somewhat involuntarily. Decades of exposure to arrows in everyday life—on signs, screens, and elsewhere—likely ingrain an association between the arrow shape and the act of shifting attention or movement in that direction. Consistent with this, neurocognitive studies have found that arrow cues elicit activation (Carrasco, 2011) in attention networks similar to those engaged by peripheral onsets and gaze cues, underscoring that the orienting they induce has a reflexive, stimulus-driven character. This powerful automatic orienting by arrows is well-established in simple cueing paradigms and forms the basis for asking how such directional cues might interact with hierarchical (global/local) stimuli.

Global or Local Level Arrow Automaticity?

Given the phenomena above, it is intriguing to consider the level of processing through which an arrow exerts its attentional pull. Does an arrow's orienting effect depend on perceiving the global shape of an arrow, or can the effect be driven by local arrow components? In other words, when a hierarchical stimulus contains arrow shapes, is attention automatically drawn to the arrow's overall direction, or to the directions of the individual arrow elements, or both? This question bridges the global/local processing literature with the arrow cueing literature. On one hand, the global precedence principle suggests that observers might initially register the overall arrow configuration and thus orient in the direction of the whole arrow. On the other hand, if the local elements are themselves small arrows, perhaps those could individually trigger micro-orienting effects that add up or compete. There has been some prior research directly examining hierarchical arrow stimuli to address this issue.

Researchers introduced compound “Navon arrows” (a large arrow composed of smaller arrows) to investigate how attention is allocated to global vs. local levels when both carry directional meaning (Mills & Dodd, 2014). Their findings revealed a temporal dynamic in arrow cueing: at a short cue-to-target interval, observers’ attention was pulled in the direction of the global arrow, whereas at a longer interval, the orienting effect shifted to reflect the direction of the local arrows. In trials where the large arrow pointed one way and the constituent arrows pointed the opposite way, the initial facilitation favored the global direction at early timepoints, but later on, responses showed influence of the local arrows’ direction. This pattern suggests that arrow automaticity may operate first at a global level, with the integrated shape directing attention, and subsequently at the local level as the smaller arrows are analyzed. Follow-up studies examined this effect by varying task demands at each level (Mills & Dodd, 2016); they confirmed that when one level of the compound arrow is made task-relevant, it can modulate the attentional cueing hierarchy, but the general finding of an initial global-oriented cueing effect followed by a later local-oriented effect still held. In essence, these studies support a global-to-local time course in processing arrow cues, consistent with the broader global precedence framework.

Complementary evidence comes from studies using hierarchical arrows in other contexts. Even when a compound arrow stimulus was rendered invisible through masking techniques (Laycock et al., 2017), it could still produce orientation biases in attention at both global and local levels. In that study, observers were unconsciously cued by the global or local direction of a non-conscious arrow figure, a striking demonstration that arrow-induced orienting does not require explicit awareness. Moreover, individual differences in that paradigm hinted at variability in whether the global or local arrow information dominated orienting. Overall, the literature to date suggests that arrow cues within hierarchical stimuli have the capacity to influence attention at both the global and local scale. However, the relative strength and timing of these effects can depend on factors like exposure duration and task context.

Building on this background, the present paper investigates whether arrow automaticity operates predominantly at the global or local level of a hierarchical stimulus, and how it might alter the typical global/local processing pattern. We approached this question by directly comparing hierarchical stimuli that carry cues that are thought to be automatically associated with direction (hierarchical arrows) to those that do not (hierarchical C's), in both global and local processing tasks. A key aspect of our design involved controlling the spatial distribution of global and local information in both stimulus types. In previous experiments exploring global and local processing, our lab used a hierarchical C (a large C made of small C's) as the stimulus. This stimulus ensured that both the global and local elements of the stimulus were equidistant from the participant's fixation point. However, since hierarchical arrows cannot have a rounded shape similar to the letter C, some of the local elements of a hierarchical arrow will necessarily be closer to fixation than others. For this reason, we used filled versions of both the arrow and C-shaped versions of the stimuli, which caused both to have local elements at varying distances from fixation (Figure 1). Importantly, both stimulus types were aligned at fixation (with the central local element precisely centered on the fixation point), so that the global shape's outline and the local pieces occupied roughly the same retinal locations for arrows and C-shapes. This removes any confound of the arrow's global form simply being more peripheral.

Using these stimuli, participants were asked to judge the direction indicated at either the global or local level—for example, determining to which side the large shape pointed, or which direction the small arrows or C's were oriented. On some trials the two levels were congruent, and on others they were incongruent. There were also control trials, where there was no competing information with a left/right directional component (on the non-task level). This design allowed us to measure not only the baseline global precedence effect but also the size of any interference between levels. The central question was whether arrow stimuli would alter these patterns relative to the neutral C-shape stimuli. If arrow automaticity operates mainly at the global level, we would expect the global arrow shape to strongly capture attention, perhaps enhancing the global precedence and interference. If instead arrow cues act principally at the local level, the small arrow elements might seize attention early, potentially diminishing the global advantage. A third possibility is that arrows engage attention at both levels, amplifying interference overall, since both global and local arrow information would be compelling. By comparing performance with arrow vs. C-shape stimuli, we can assess how the arrows' inherent directional cueing affects global/local processing dynamics.

Methods

Participants

Undergraduate students at University of Oregon (N = 28 students) participated for course credit. All reported normal or corrected-to-normal vision, no history of neurological disorders, and were naïve to the study's purpose. Handedness was not controlled for. Informed consent was obtained, and the procedure was approved by the university's ethics board.

Stimuli and Apparatus

Stimuli were hierarchical figures presented on a 24-inch monitor at 1920x1080 resolution. Participants were seated approximately 75 cm from the display. The global form on each trial was either a large arrow or a filled in C-shape (a filled circle with a triangular wedge removed), each subtending 6.5° of visual angle. The large shape was constructed from many smaller elements of the same type (each local arrow or local C-shape subtending 0.8° of visual angle). For arrow stimuli, small arrows were arranged to form the outline of the big arrow. For C-shape stimuli, small C shapes were arranged to form the outline of a larger filled in C-shape shape. All stimuli were drawn in black on a gray background (see Figure 1).

Each trial's stimulus could be congruent, incongruent, or control/neutral. In congruent trials, all the local elements pointed in the same direction as the global figure. In incongruent trials, the local elements pointed in the opposite direction of the global figure. In neutral (control) trials, one level was nondirectional: for arrow stimuli, neutral trials used a non-directional shape at the distracting level (a small "o" or circle at the local level, or a diamond/star shape at the global level, instead of an arrow); for C-shape stimuli, neutral trials used a small "o" shape at the local level or a complete circle at the global level. These neutral elements contained no left/right directional information, and therefore served as control conditions with no directional conflict.

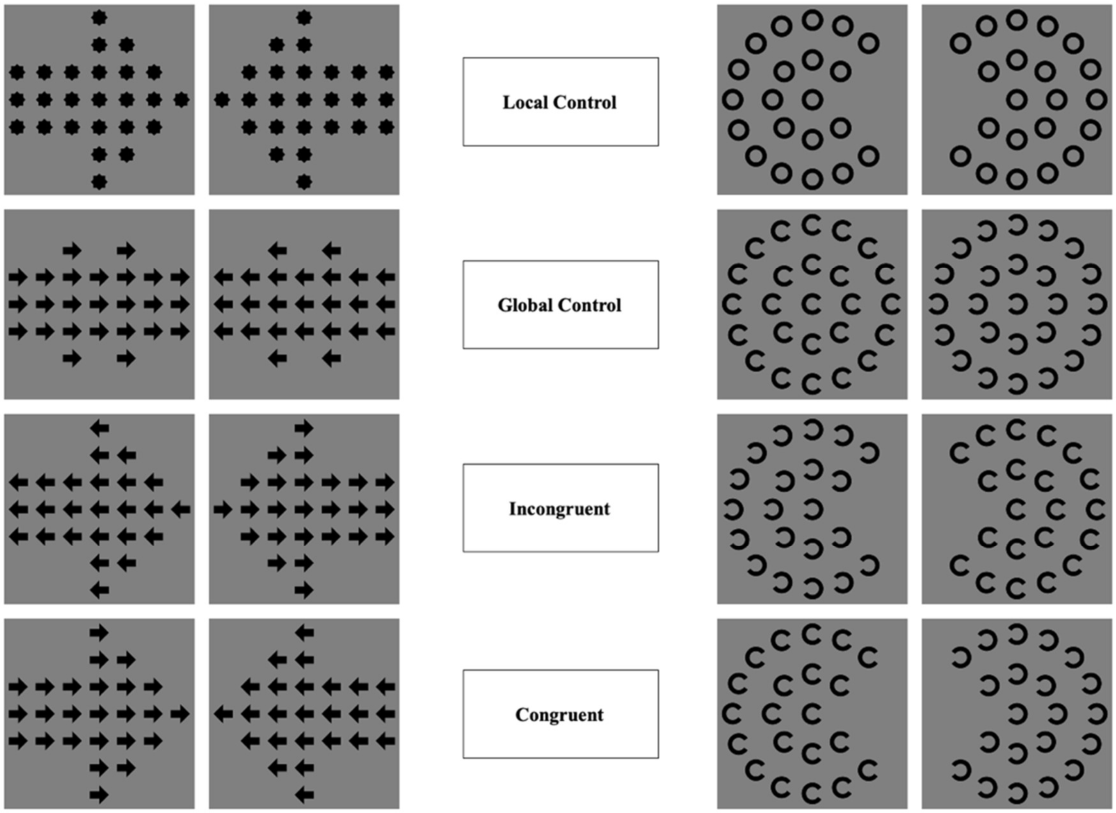

Figure 1: Hierarchical stimuli used in this experiment.

Arrows on the left, C's on the right.

Stimulus presentation and data collection were controlled by PsychoPy (version v2024.2.4) on a HP PC. Responses were collected via a standard keyboard: participants pressed the "F" key (left index finger) to indicate a left-pointing target and the "J" key (right index finger) for a right-pointing target. A fixation circle was presented at the start of each trial, followed by the hierarchical stimulus, which remained on-screen until the participant responded or until a 2 second response deadline had elapsed. Auditory feedback (a brief beep) was provided on error or timeout trials.

Task and Procedure

The experiment used a 2 × 2 × 3 within-subjects design. The factors were Stimulus Type (Arrow vs. C-shape), Task (Global-level response vs. Local-level response), and Trial Type (Congruent vs. Incongruent vs. Neutral). Participants performed two alternating tasks in separate blocks: in "global" blocks, they identified the direction of the large (global) figure (the direction the global arrow was pointing, or the orientation of the global C's opening) while ignoring local details; in "local" blocks, they reported the common direction of the small local elements while ignoring the global shape. Blocks were grouped by stimulus type: there were 8 blocks total (4 arrow blocks and 4 C-shape blocks). Block order was counterbalanced across participants (half of the participants began with an arrow block, half with a C shape block). The experiment was divided into 4 blocks of 150 trials each (25 for each of 6 conditions [congruent, control, incongruent]x[left, right]), and the task instruction switched between global and local at each block (e.g. 150 trials of the global task, then 150 trials of the local task, etc.). An on-screen cue remained on the bottom two corners of the screen (either "LARGE" for global task or "SMALL" for local task) to remind participants of the current task. The task that started each block (global or local first) was randomized for each block and counterbalanced across participants.

Each trial began with a central fixation dot (duration 550-800 ms), which was replaced by the compound stimulus presented at fixation until response or until the maximum RT elapsed. Participants were instructed to respond as quickly and accurately as possible. After the response, a short tone provided feedback only if incorrect. An inter-trial interval of 100 ms separated trials. Short rest breaks were offered between blocks to minimize fatigue. Trial order within each block was randomized. Each block contained an equal number of congruent, incongruent, and neutral trials in random sequence, and left/right target directions were equally represented. The global and local elements were always from the same stimulus set on a given trial (e.g. an arrow made of smaller arrows, or a filled in C made of smaller C's), so any directional conflict arose only from incongruent orientations, not from mixing stimulus identities.

The design controlled for potential spatial biases noted in previous studies. By using identical central fixation for both global and local elements, we eliminated peripheral presentation differences that could otherwise give a global advantage. Stimulus identity (arrow vs. C-shape) was the only major visual difference between conditions. The two stimulus types were matched in overall size. Trials were arranged so that no systematic ordering (e.g., no streak of multiple incongruent trials or task switches) could confound the results; counterbalancing ensured that any carryover or practice effects were distributed evenly.

Data Analysis

The dependent variable was reaction time (RT) on correct trials. Accuracy was also analyzed for completeness, but since errors were infrequent, we focus on RT. Trials with incorrect responses or excessive delays were excluded from RT analysis. RT values were submitted to within-subjects analyses. We conducted paired-samples t-tests and repeated-measures ANOVAs. All hypothesis tests were two-tailed with $\alpha = 0.05$.

For clarity, we operationalized the Global Precedence Effect as the RT difference between local control and global control conditions (i.e. RT for Local Control – RT for Global Control), such that a positive value indicates faster performance on global trials (a global advantage). Likewise, we define the Global Interference Effect as the difference in incongruency effects between local and global tasks: (Local Incongruent – Local Congruent) – (Global Incongruent – Global Congruent).

This Global Interference Effect measures whether conflicting information at the global level impedes performance more (or less) than conflicting information at the local level.

Results and Discussion

Descriptive Statistics of Reaction Times

Mean correct reaction times (RTs), standard deviations (SD), and standard errors of the mean (SE) for each condition are presented in Table 1. These data provide an overview of performance across the 2 (Task: Global, Local) × 2 (Stimulus Type: Arrow, C-shape) × 3 (Trial Type: Congruent, Control, Incongruent) within-subjects design.

Visual inspection of these means, depicted in Figure 2, generally shows that responses to incongruent trials were slower than to congruent or control trials. Furthermore, responses in the local task tended to be slower than in the global task. This pattern aligns with established findings in cognitive psychology, suggesting the experimental manipulations effectively modulated cognitive load and conflict as intended. For instance, global arrow congruent trials (Mean RT = 0.520 s) were faster than local arrow congruent trials (Mean RT = 0.561 s), and global arrow congruent trials were faster than global arrow incongruent trials (Mean RT = 0.573 s).

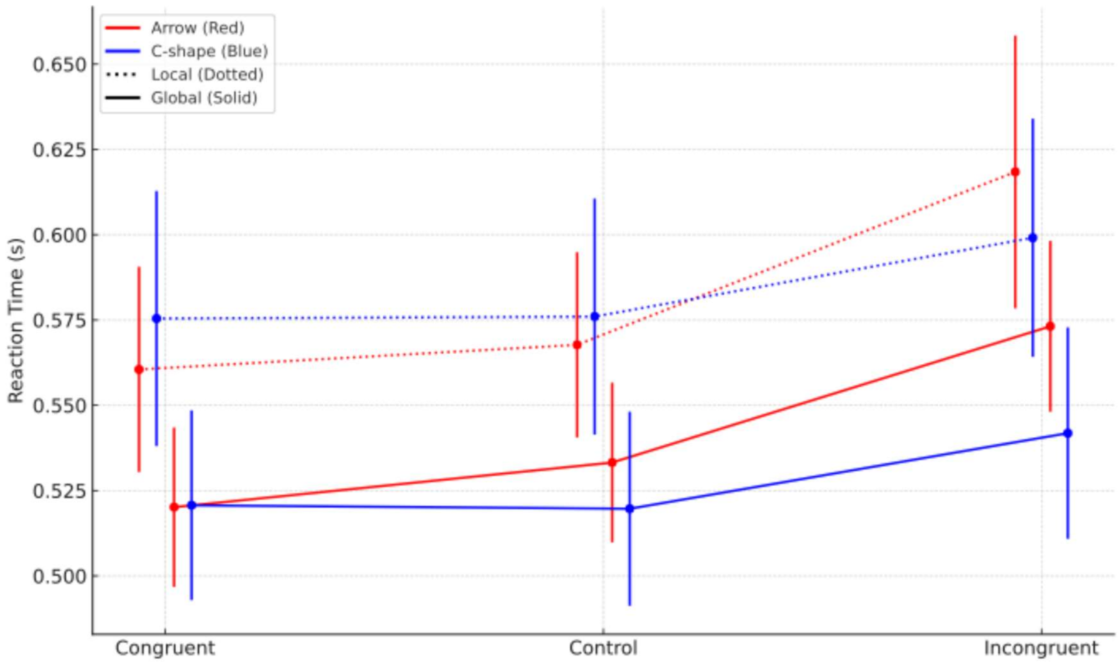

Figure 2: RTs for all experimental conditions.

Points are at the mean value. Error bars show a 95% confidence interval.

Arrow stimuli and C-shape stimuli show broadly similar RTs in control conditions (e.g., Global Arrow Control M=0.533 s vs. Global C-shape Control M=0.520 s). However, they appear to diverge more in congruent and particularly in incongruent conditions, especially for local tasks. For example, the RT difference between local incongruent and local congruent trials for Arrow stimuli (0.618 s – 0.561 s = 0.057 s) appears larger than for C-shape stimuli (0.599 s – 0.575 s = 0.024 s). This preliminary observation offers an initial indication that arrows might induce stronger conflict or facilitation.

Task	**Trial Type**	**Stimulus Type**	**Mean RT (s)**	**N**	**SD (s)**	**SE (s)**
Global	Congruent	Arrow	0.520	28	0.0631	0.0119
Global	Congruent	C-shape	0.521	27	0.0737	0.0142
Global	Control	Arrow	0.533	28	0.0632	0.0119
Global	Control	C-shape	0.520	27	0.0754	0.0145

Global	Incongruent	Arrow	0.573	28	0.0676	0.0128
Global	Incongruent	C-shape	0.542	27	0.0821	0.0158
Local	Congruent	Arrow	0.561	28	0.0813	0.0154
Local	Congruent	C-shape	0.575	27	0.0991	0.0191
Local	Control	Arrow	0.568	28	0.0733	0.0139
Local	Control	C-shape	0.576	27	0.0917	0.0177
Local	Incongruent	Arrow	0.618	28	0.1079	0.0204
Local	Incongruent	C-shape	0.599	27	0.0926	0.0178

Table 1: Mean Reaction Times (s), Standard Deviations (SD), and Standard Errors (SE) for all Experimental Conditions.

Analysis of Reaction Times: ANOVA Findings

To examine the effects of Task (Global vs. Local) and Trial Type (Congruent, Control, Incongruent) on RTs, separate 2×3 repeated-measures Analyses of Variance (ANOVAs) were conducted for Arrow stimuli and C-shape stimuli. Greenhouse-Geisser corrections were applied where the assumption of sphericity was violated. The alpha level was set at $p<.05$ for all analyses. Results are summarized in Table 2.

Arrow Stimuli ANOVA

The ANOVA for Arrow stimuli revealed a significant main effect of Task ($F(1,27)=17.13$, $p<.001$, $\eta g2=.064$), indicating that RTs differed significantly between global and local tasks. Inspection of means in Table 1 confirms that responses were slower for local tasks (e.g., Local Control Arrow M=0.568 s) compared to global tasks (e.g., Global Control Arrow M=0.533 s).

There was also a significant main effect of Trial Type ($F(1.27,34.37)=104.43$, $p<.001$, $\eta g2=.091$). This indicates substantial RT differences based on the congruency between global and local levels. As seen in Table 1, incongruent trials (M=0.573 s for Global, M=0.618 s for

Local) were generally the slowest, followed by control trials (M=0.533 s for Global, M=0.568 s for Local), and then congruent trials (M=0.520 s for Global, M=0.561 s for Local). The Task × Trial Type interaction was not statistically significant ($F(1.58,42.56)=0.52$, $p=.521$, $\eta g2=.00083$).

C-shape Stimuli ANOVA

For C-shape stimuli, a significant main effect of Task was also observed ($F(1,26)=27.49$, $p<.001$, $\eta g2=.099$). Similar to arrow stimuli, participants were slower to respond in local tasks (e.g., Local Control C-shape M=0.576 s) than in global tasks (e.g., Global Control C-shape M=0.520 s). The main effect of Trial Type was also significant ($F(1.53,39.87)=30.95$, $p<.001$, $\eta g2=.015$), indicating that trial congruency influenced RTs for C-shape stimuli as well. The pattern generally followed that of arrows, with incongruent trials being slowest. The Task × Trial Type interaction for C-shape stimuli was not significant ($F(1.61,41.79)=0.08$, $p=.875$, $\eta g2 =.000038$).

The significant main effects of both Task and Trial Type for both Arrow and C-shape stimuli underscore the robustness of these fundamental processing characteristics in visual attention tasks. Responding to local features is generally more demanding than global features, and incongruent information consistently slows responses compared to congruent or neutral information, irrespective of whether the stimulus is an arrow or a C-shape. This consistency across stimulus types for these main effects establishes a baseline of common processing mechanisms.

The absence of a significant Task × Trial Type interaction for both Arrow and C-shape stimuli is a critical finding. It suggests that the impact of trial congruency (i.e., the RT difference between congruent, control, and incongruent trials) is similar regardless of whether participants are attending to the global or local level. This implies an additive relationship: the cognitive cost or benefit associated with trial congruency appears to be a relatively fixed amount that sums with the RT determined by the task level (global or local), rather than congruency effects being disproportionately larger or smaller at one level compared to the other.

While the main effect of Trial Type is significant for both stimuli, the magnitude of this effect, as indicated by the generalized eta-squared ($\eta g2$), appears substantially larger for Arrow stimuli ($\eta g2$=.091) compared to C-shape stimuli ($\eta g2$=.015). This difference in effect size suggests that the manipulation of congruency had a more pronounced impact on RTs when the stimuli were arrows than when they were C-shapes. This observation hints that the inherent meaning of arrows might engage attentional or response mechanisms more profoundly, leading to larger RT variations across trial types, a point further explored in the analysis of congruency effects.

Stimulus Type	**Source**	**df**	**F-value**	**p-value (GG-corr)**	**ηg2**
Arrow	Task	1, 27	17.13	<.001	.064
	Trial Type	1.27, 34.37	104.43	<.001	.091
	Task × Trial Type	1.58, 42.56	0.52	.521	.00083
C-shape	Task	1, 26	27.49	<.001	.099
	Trial Type	1.53, 39.87	30.95	<.001	.015
	Task × Trial Type	1.61, 41.79	0.08	.875	.000038

Table 2: Summary of 2 (Task) × 3 (Trial Type) ANOVA Results on RTs for Arrow and C-shape Stimuli.

p-values are Greenhouse-Geisser corrected where appropriate. $\eta g2$ = generalized eta-squared.

Global Precedence and Interference Effects

To assess the classic global precedence and potential interference effects, specific planned comparisons were conducted using traditional measures of these effects. The Global

Precedence Effect (GPE) was operationalized as the RT difference between local control and global control conditions (RT Local Control – RT Global Control), such that a positive value indicates faster performance on global trials. The Global Interference Effect was assessed by comparing the difference in the interference effects caused by the irrelevant stimuli in the local and global tasks, using a difference of differences ((RT Local Incongruent – RT Local Congruent) – (RT Global Incongruent – RT Global Congruent)). A positive value in this measure would indicate that the impact of irrelevant global information on the local task is greater than that of irrelevant local information on a global task (the typical result in studies of global and local processing). Results are presented in Table 3 and visualized in Figure 3.

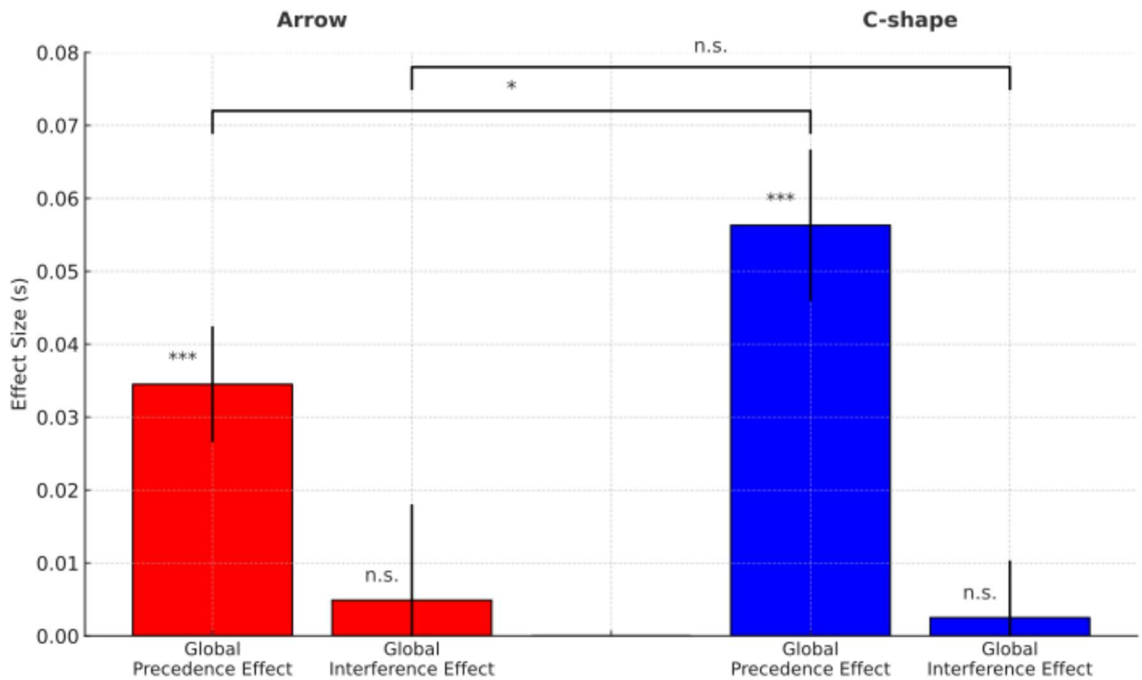

Figure 3: Global Precedence Effects and Global Interference Effects shown for different stimulus types.

Effect size (y-axis) takes into account the relevant calculations for global precedence and interference effects. Asterisks signify significance, both from zero and between global precedence and interference calculations. Error bars show a 95% confidence interval. Asterisks indicate statistical significance (*** = $p < .001$, ** = $p < .01$, * = $p < .05$, n.s. = not significant ($p > .05$).

A significant Global Precedence Effect was observed for Arrow stimuli (Mean Effect = 34.5 ms, SE = 0.0078 s, $t(27)=4.44$, $p<.001$), indicating that participants were significantly faster to respond to global control arrows than to local control arrows. Similarly, a significant GPE was found for C-shape stimuli (Mean Effect = 56.3 ms, SE = 0.0101 s, $t(26)=5.57$, $p<.001$), demonstrating faster responses to global control C-shapes compared to local control C-shapes. The replication of the Global Precedence Effect for both stimulus types confirms that global information was generally processed with priority over local information in this paradigm, consistent with classic Navon (1977) findings. In a direct comparison, the magnitude of the Global Precedence Effect was found to be significantly larger for the C-shape stimuli compared to the arrow stimuli (Mean Effect = -22.7 ms, SE = 0.0084 s, t(26)=-2.71, p=.012). This might suggest subtle differences in the baseline processing of global versus local features for these two stimulus types.

The Global Interference Effect, comparing the relative impact of the irrelevant global cues in a local task versus that of the irrelevant local cues in a global task, was not significant for Arrow stimuli (Mean Effect = 4.9 ms, SE = 0.0129 s, t(27)=0.38, p=.706). Likewise, this effect was not significant for C-shape stimuli (Mean Effect = 2.5 ms, SE = 0.75 s, t(26)=0.33, p=.743). In addition, the magnitude of the Global Interference Effect measures did not significantly differ between the Arrow and C-shape stimuli (Mean Effect = -0.4 ms, SE = 0.015 s, t(26)=-0.026, p=.979). Thus for both stimulus types, the interference caused by the irrelevant processing level was equal in the global and local task, which differs from the typical finding of a greater impact of the irrelevant global stimulus in a local task. However, this should not be taken to mean that there was an absence of interference from the irrelevant cues, but rather that the magnitude of the interference did not differ between the global and local tasks. This should be considered in conjunction with the overall congruency effects (comparing incongruent to congruent trials directly) discussed subsequently.

Effect Type	**Stimulus Type**	**Mean Effect (ms)**	**SE (ms)**	**t-statistic**	**df**	**p-value**
Global Precedence Effect	Arrow	34.5	7.8	4.44	27	<.001
	C-shape	56.3	10.1	5.57	26	<.001
	Between Arrow C-shape	-22.7	0.8	-2.71	26	.012
Global Interference Effect	Arrow	4.9	12.9	0.38	27	.706
	C-shape	2.5	7.5	0.33	26	.743

	Between Arrow C-shape	-0.4	15.0	-0.027	26	.979

Table 3: Global Precedence and Global Interference Effects for Arrow and C-shape Stimuli.

Global Precedence Effect = RT Local Control – RT Global Control. Global Interference Effect = [RT Local Incongruent – RT Local Congruent]-[RT Global Incongruent – RT Global Congruent].

Congruency Effects

As discussed above, the lack of significant Global Interference Effects does not imply that the irrelevant cues cause no interference, only that the interference effects were equal in the global and local tasks. To assess the impact of conflicting versus consistent directional information at relevant and irrelevant levels, we separately measured the Congruency effects, calculated as the difference in mean RT between incongruent and congruent trials (RT Incongruent – RT Congruent). These effects were examined for both global and local tasks and for Arrow versus C-shape stimuli. Positive values indicate a cost (slower RTs) for incongruent trials compared to congruent trials. Results are presented in Table 4 and visualized in Figure 4.

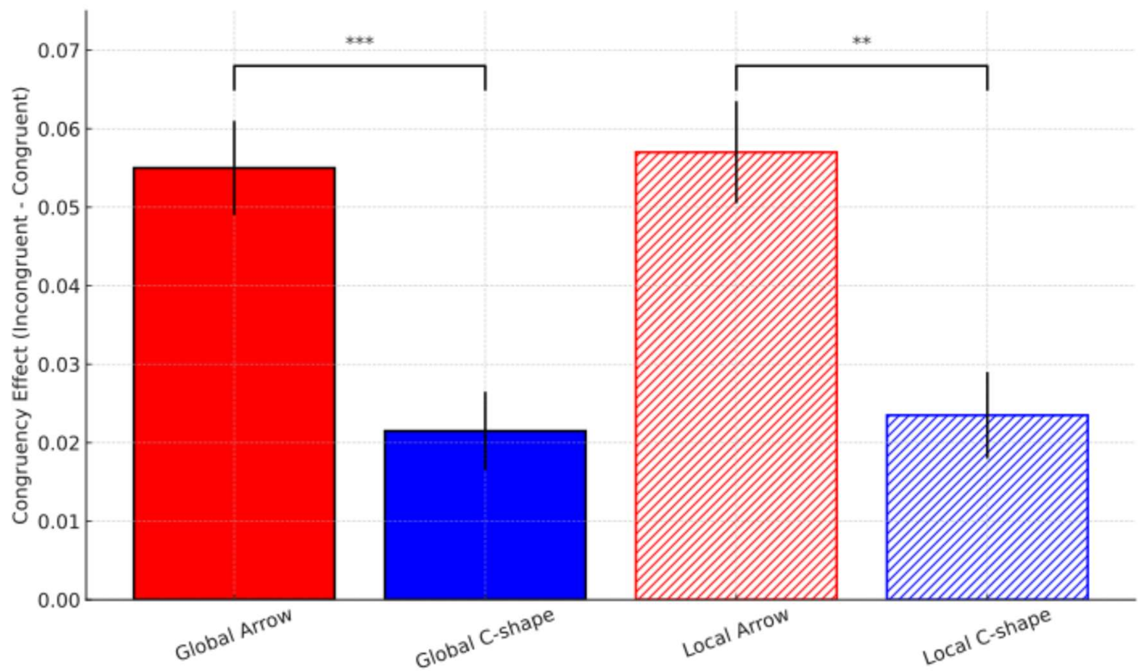

Figure 4: Congruency Effect for different experimental conditions.

Error bars show a 95% confidence interval. Asterisks signify significance between stimulus,within task. Asterisks indicate statistical significance (*** = $p < .001$, ** = $p < .01$, * = $p < .05$, n.s. = not significant ($p > .05$).

The mean congruency effects were:

- Global Arrow: 55.0 ms (SE = 9.9 ms)
- Global C-shape: 21.5 ms (SE = 6.6 ms)
- Local Arrow: 57.0 ms (SE = 10.2 ms)
- Local C-shape: 23.5 ms (SE = 9.3 ms).

Paired t-tests were conducted to compare the magnitude of these congruency effects between Arrow and C-shape stimuli. In the global task, the congruency effect of the irrelevant local cue for Arrow stimuli was significantly larger than that for C-shape stimuli (Arrow: 55.0 ms vs. C-shape: 21.5 ms; $t(26)=3.92$, $p=.00057$). This indicates that when participants attended to the global level, the conflict or facilitation arising from the relationship between global and local directions was substantially greater for arrow stimuli than for C-shape stimuli.

A similar pattern was observed in the local task. The congruency effect of the irrelevant global cue for Arrow stimuli was also significantly larger than for C-shape stimuli (Arrow: 57.0 ms vs. C-shape: 23.5 ms; $t(26)=3.13$, $p=.00427$). This suggests that even when attention was focused on the local level, the directional meaning of the irrelevant global Arrow created more interference (or the relevant local arrow benefited more from a congruent global arrow) compared to the C-shape stimuli.

These findings robustly demonstrate that arrow stimuli produce significantly amplified congruency effects compared to C-shape stimuli, regardless of whether attention is directed globally or locally. This amplification may be a reflection of the potent, automatic processing of the directional meaning inherent in arrows, leading to greater interference in incongruent trials and/or enhanced facilitation in congruent trials relative to the more neutral C-shapes. The consistency of this amplification across both global and local attentional tasks speaks to the pervasive nature of arrow-induced attentional capture or response competition; the semantic content of the arrow appears to be processed compellingly, even when it forms part of the unattended level of the stimulus.

This stimulus-specific amplification of congruency effects provides an important nuance to the non-significant Task × Trial Type interactions observed in the overall ANOVAs. While the general pattern of congruency (e.g., incongruent trials being slower than congruent ones) did not differentially scale with task level (global/local) for a given stimulus type, the absolute magnitude of this congruency effect is consistently and significantly inflated by the semantic content of the arrow stimulus itself. This suggests that while the underlying mechanisms responding to congruency might operate similarly at global and local levels, arrow stimuli provide a stronger input to these mechanisms due to their inherent directional meaning. The increased difficulty in resolving conflict for arrow stimuli, as evidenced by the larger congruency costs, points towards arrows being potent cues that automatically orient attention or prime responses, making it more challenging to disregard their direction when it mismatches the target direction.

Task Level	**Stimulus Type**	**Mean Congruency Effect (ms)**	**SE (ms)**	**Comparison**	**t-statistic**	**df**	**p-value**
Global	Arrow	55.0	9.9	Global Arrow vs. Global C-shape	3.92	26	.00057
	C-shape	21.5	6.6				
Local	Arrow	57.0	10.2	Local Arrow vs. Local C-shape	3.13	26	.00427
	C-shape	23.5	9.3				

Table 4: Mean Congruency Effects (ms) (RT Incongruent – RT Congruent) and Standard Errors (SE) for Global and Local Tasks with Arrow and C-shape Stimuli, and t-test Comparisons of Congruency Effects between Stimulus Types.

General Discussion

The primary objective of this study was to investigate whether the automaticity associated with arrow cues operates predominantly at the global or local level of hierarchical stimuli and how these symbolic stimuli might alter typical global/local processing patterns when compared to non-symbolic C-shapes. The findings revealed a Global Precedence Effect (GPE) for both stimulus types, albeit larger for C-shapes, and an absence of the Global Interference Effect (GIE). Additionally, arrow stimuli produced significantly amplified congruency effects compared to C-shapes at both global and local task levels. These results provide a nuanced perspective on the nature of arrow automaticity in the context of hierarchical visual processing.

Interpreting the Absence of "Classic" Arrow Automaticity in the Current Task

Past research has characterized arrow automaticity as an involuntary, reflexive shift of spatial attention in the direction indicated by an arrow, even when the arrow is non-predictive of a target's location. This orienting is typically evidenced by faster responses to targets appearing in the cued direction and slower responses to targets in uncued directions (Tipples, 2002). The current findings, particularly the absence of a classic GIE that might reflect dominant attentional capture by a global arrow, do not straightforwardly demonstrate this type of spatial orienting automaticity.

An alternative interpretation, as suggested by the initial framing of the research questions, is that the arrow in this study primarily functioned as a cue for the keyboard response rather than a cue to shift spatial attention. Arrows are highly overlearned symbols for direction, and this deep association could lead to a direct priming or activation of the corresponding motor response (e.g., a left-pointing arrow primes the "F" key press associated with a left response). Such direct stimulus-response (S-R) compatibility effects are well-documented and significantly influence reaction times. The specific structure of the task employed—identifying the direction of a stimulus element and pressing a spatially corresponding key—may have preferentially engaged this S-R mapping system. The arrow's direction offers a direct conceptual overlap with the required response parameter (key direction), potentially making its semantic content immediately relevant for response selection. This contrasts with paradigms where an arrow cues a spatial location of a subsequent, distinct target, thereby emphasizing an attentional shift. If an arrow automatically activates its associated response tendency, this could overshadow or bypass a more purely visuospatial attentional shift. The C-shape, while directional, likely possesses a weaker, less overlearned S-R association, leading to less potent response priming. This points mainly to the conclusion that arrow automaticity is nuanced, and may vary when the arrow signifies a direct stimulus response, in contrast to cueing attention.

This S-R priming interpretation gains further traction when considering the hierarchical nature of the stimuli. In incongruent hierarchical arrow trials (e.g., global arrow points left, local arrows point right, and the task is to respond to the local direction), participants face two competing response activations. The unattended global arrow might prime a leftward response, while the attended local arrows prime a rightward response. This dual response competition could be a significant factor contributing to the substantially larger congruency effects observed for arrow stimuli compared to C-shape stimuli. For C-shapes, the directional meaning of the unattended level might be less automatically translated into a motor command, resulting in weaker response competition.

Reconciling Discrepancies with Previous Literature

The current results do not replicate previous studies that found clear evidence for arrow-induced attentional shifts in cueing paradigms or specific global-to-local temporal dynamics in attentional orienting with compound arrow cues. Several factors could contribute to these discrepancies.

Firstly, task demands differ significantly. The current study required participants to identify the direction of a component within the hierarchical stimulus itself, making the arrow (or C-shape) element the direct target of judgment. This contrasts with many classic cueing paradigms where the arrow serves to orient attention to a separate target location for subsequent detection or discrimination. When the arrow's directional information is the very feature to be extracted for response, the cognitive system might prioritize its semantic decoding and translation into a response code over a pre-emptive spatial shift of attention.

Secondly, stimulus characteristics, such as the "filled" versions of arrows and C-shapes used here, might interact with processing in ways different from line-drawn or outline shapes. While controlled for by comparison with C-shapes, these specific visual properties could influence the relative salience of global and local levels or the ease of extracting directional information.

Thirdly, temporal factors are important. Mills and Dodd (2014, 2016) highlighted the role of cue-to-target intervals (SOAs) in revealing temporal dynamics of global versus local arrow processing. The present study presented stimuli until a response was made, which allows for different processing stages to unfold and potentially interact, compared to studies using fixed, often short, SOAs designed to isolate early automatic effects.

Finally, "automaticity" itself may not be a unitary concept. As has already been discussed, the current study might be tapping into a different facet of automatic processing, such as automatic S-R activation or semantic priming, than studies focusing on reflexive spatial attention. The potent influence of arrows observed here, manifesting as amplified congruency effects, is undeniably "automatic" in the sense of being rapid and difficult to suppress, but its mechanism appears distinct from pure visuospatial orienting.

Implications of Amplified Congruency Effects for Arrow Stimuli

A central finding of this study is the significantly larger congruency effects for arrow stimuli compared to C-shape stimuli, observed when attention was directed to either the global or local level (Global task: arrows 55.0 ms vs. C-shapes 21.5 ms; Local task: arrows 57.0 ms vs. C-shapes 23.5 ms). This amplification could be interpreted as a reflection of the potent, automatic processing of the directional meaning inherent in arrows, leading to greater interference in incongruent trials and/or enhanced facilitation in congruent trials relative to the more neutral C-shapes. The strength of this effect persists even when the conflicting or congruent arrow information comes from the unattended level of the stimulus, underscoring the difficulty in voluntarily suppressing the arrow's directional meaning.

This compelling processing of the arrow's semantic content likely translates into an automatic activation of associated responses, leading to larger RT costs when this primed response conflicts with the required response to the target level, and larger RT benefits when it aligns. The pervasiveness of this amplified congruency effect—occurring whether the global or local level was the target—suggests that the directional meaning of arrows is processed almost obligatorily from both levels of the hierarchy. It implies that the cognitive system cannot easily "gate off" the meaning of an arrow at an unattended level; its directional information "leaks" through and influences the processing of the attended level to a greater extent than for the less symbolically charged C-shapes. This points to a deeply ingrained and pervasive processing of arrow symbolism.

Discussion of Global Precedence and Global Interference Effects in the Context of Stimulus Type

The study replicated the classic Global Precedence Effect (GPE), with faster responses to global targets than local targets for both arrow (34.5 ms) and C-shape (56.3 ms) control stimuli. However, the GPE was significantly smaller for arrow stimuli than for C-shape stimuli. One possible interpretation for this reduced global advantage with arrows is that the local arrow elements themselves are more salient or individually meaningful than the local C-elements. The inherent directional meaning of each small arrow could make these local elements "compete" more effectively with the global arrow for initial processing resources. This increased "pull" from local arrows might diminish the typical speed advantage of the global form, resulting in a smaller RT difference between local and global control conditions for arrows compared to C-shapes.

The typical Global Interference Effect (GIE)—where irrelevant global information causes more interference on local tasks than irrelevant local information does on global tasks—was not found for either stimulus type in this study. Instead, interference was symmetrical; the magnitude of interference from an incongruent distractor was comparable regardless of whether it was a global distractor in a local task or a local distractor in a global task. For arrow stimuli, this symmetry could arise from the strong semantic content present at both hierarchical levels. If local arrows are themselves potent directional cues (as suggested by their contribution to amplified congruency effects), they may be "strong enough" to interfere with global processing to a similar extent that the global arrow interferes with local processing. This contrasts with situations where local elements are less meaningful and thus exert less "upward" interference on global judgments. For C-shapes, the reason for symmetrical interference is less clear but might relate to the specific stimulus construction (e.g., filled shapes, central fixation of elements) ensuring comparable visual salience or informational load at both levels, or it may also reflect the specific task demands of directional identification.

Implications for Special Populations

The current findings also open avenues for investigating how arrow automaticity might manifest in special populations. For individuals with ASD, the heightened detail-focused cognitive style could potentially amplify local-level interference, especially when arrows are present at the local level. This might further modulate the global precedence or congruency effects observed with arrow stimuli (Chouinard et al., 2007; Ristic et al., 2005). Likewise, individuals with elevated anxiety might exhibit altered attentional dynamics that interact with arrow cueing, given that anxiety can influence the allocation of attentional resources and the disengagement from salient stimuli (Moriya & Tanno, 2009; Shilton et al., 2019). Future studies should investigate whether the amplified congruency effects found with arrows here would be equally or more pronounced in these populations, contributing to our understanding of how symbolic cues like arrows interact with underlying cognitive and affective traits.

Limitations of the Study

Several limitations should be acknowledged. The participant sample consisted of undergraduate students (N=28), and thus findings may not generalize to other populations with different cognitive profiles or levels of experience with symbolic cues. The stimuli used were specific "filled" arrow and C-shape configurations; the observed patterns of effects might be, to some extent, specific to these visual forms. The task involved direct directional judgment and a corresponding keyboard response, and the nature of automaticity (or its particular manifestation) could be contingent on these specific task requirements. Furthermore, stimuli were presented until a response was made. Exploring fixed and varied SOAs could reveal different temporal aspects of processing, potentially aligning more closely with findings from previous studies (Mills and Dodd 2016). Finally, the absence of eye-tracking means that small, uninstructed eye movements cannot be definitively ruled out, although central fixation was emphasized. Eye-tracking could provide more direct evidence regarding overt or covert attentional shifts.

Future Research Directions: Unpacking Arrow Automaticity

The current findings underscore that more research is needed to delineate precisely what aspects of arrow processing are automatic and under what conditions different forms of automaticity manifest. Future studies could aim to disentangle attentional orienting from response priming effects more directly. For instance, one could compare tasks requiring detection of a non-directional peripheral target cued by a central hierarchical arrow (emphasizing spatial orienting) with tasks requiring identification of the arrow's direction itself (emphasizing S-R mapping or semantic processing).

Parametric manipulation of stimulus and task variables would also be beneficial. Varying the SOA between cue and target (in designs that separate them) or manipulating the presentation duration of hierarchical stimuli could illuminate the time course of global versus local arrow processing. Systematically altering the salience or perceptual load of global versus local arrow elements could further clarify their respective contributions. Investigating whether different types of arrows (e.g., simple line drawings vs. filled shapes, chevrons vs. traditional arrows) modulate these effects could also yield insights into the critical features driving arrow automaticity.

Another avenue to analyze the temporal aspects of global and local processing would be to alter the response modality. In the current keyboard response, only reaction time can be measured, but this blunt measure obscures many of the details of the separate sensory, decision and motor responses involved. Alternatively, it would be possible to require participants to indicate the direction of the stimulus by dragging their finger to the left or right across a touch screen. In a scenario where the stimulus is presented to the participant when the finger tracking movement is already in flight (directed to, for example, a default target at the top of the screen), it might be possible to observe sensory and decision processes unfolding over time (for examples using different paradigms, see Dotan et al., 2019). This finger tracking modality would allow for enhanced analysis of timing and more precision when analyzing global/local interference effects.

Exploring individual differences presents another fruitful avenue. Factors such as working memory capacity, cognitive style (e.g., global/local bias, as noted in studies on autistic traits; Laycock et al., 2017), or even affective states like anxiety might modulate how hierarchical arrows are processed and the extent to which their "automatic" influences are expressed. Finally, neuroimaging techniques like fMRI could help identify the neural networks engaged by hierarchical arrows when they function primarily as response cues versus spatial attention cues, further elucidating the distinct mechanisms potentially underlying their influence.

An additional consideration for future research is the developmental trajectory of arrow automaticity. The processing of directional cues likely emerges gradually as children gain experience with symbolic representations, such as arrows on signs, screens, and in educational materials. Developmental research has shown that global precedence itself is not fully mature in early childhood and continues to develop through adolescence (Kimchi et al., 2005). The automaticity of arrow cues may similarly depend on the extent of exposure and experience with directional symbols. Younger children may exhibit weaker or more variable automatic processing of arrow direction compared to adults, potentially showing different time courses of global and local arrow cueing (Mills & Dodd, 2016). Investigating arrow automaticity across developmental stages, using both reaction time measures and more dynamic tracking approaches such as finger tracking (Dotan et al., 2019), would clarify how the influence of symbolic cues on attention and response selection evolves over time (Kail, 1991).

Conclusions

These results suggest that while classic spatial attentional automaticity (i.e., an involuntary shift of spatial attention) was not clearly demonstrated in the expected manner within this specific hierarchical task, arrows nonetheless exerted a powerful and automatic influence on performance. This influence likely stemmed from the potent processing of their inherent directional meaning, manifesting as enhanced response facilitation in congruent conditions and increased response competition in incongruent conditions. The semantic content of arrows appears to be processed compellingly and is difficult to ignore, even when part of an unattended stimulus level.

This research contributes to a more nuanced understanding of "arrow automaticity," suggesting that its manifestation can be highly task dependent. In contexts like the one studied here, where the arrow's direction is integral to the response, its automaticity may primarily take the form of response priming or S-R compatibility effects rather than pure spatial orienting. The practical implication is that the design of informational displays incorporating arrows should consider not only their potential to guide attention but also their capacity to automatically prime responses, which could be either beneficial or detrimental depending on the specific task goals and response requirements. The directional meaning of arrows is processed with a high degree of automaticity that profoundly influences response selection, even if this does not always manifest as a classic shift of spatial attention in complex hierarchical displays. Future research should continue to explore the multifaceted nature of arrow automaticity and the specific conditions that dictate its varied expressions.

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