In presenting this thesis in partial fulfilment of the requirements for an advanced degree at the University of British Columbia, I agree that the Library shall make it freely available for reference and study. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by the head of my department or by his or her representatives. It is understood that copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Department of Psychology
The University of British Columbia
Vancouver, Canada

Date Aug 26th, 2003.
ABSTRACT

Traditionally, volitional attention has been studied in the Posner cuing paradigm by using central spatially predictive arrows as attentional cues. The important assumption underlying this methodology has been that arrows (and other central attentional cues) orient attention spatially only if they predict where the target is likely to appear. Recent studies, however, indicate that this fundamental assumption underlying the classic methodology is mistaken. Several studies now report that a range of central directional cues, including arrows, can trigger reflexive orienting effects in both young children and adults when they do not predict where the target is likely to appear.

This fact raises the question of whether past studies, using predictive central arrows as attentional cues, were measuring (1) volitional attention because the arrows were predictive, (2) reflexive attention because the arrows were directional, or (3) some combination of volitional and reflexive attention.

This issue was investigated in two studies. The first study is presented in Chapter 1. This investigation tested adults with (1) predictive arrow cues (2) nonpredictive arrow cues, to get a pure measure of reflexive orienting, and (3) predictive nondirectional cues, to get a pure measure of volitional orienting.

The results of this first study showed that the magnitude of orienting observed with predictive arrow cues was always larger than the sum of pure reflexive and voluntary orienting, suggesting that the traditional measure reflects an interaction between reflexive and volitional attention.

The second study, presented in Chapter 2, tested children between the ages of 3 and 6 in a conditions comparable to those in the first study with adults. The results showed that pure reflexive orienting was adult-like, but volitional orienting was not. Young children, unlike adults, could sustain volitional attention for only a brief period
of time. Moreover, and also unlike adults, reflexive and volitional orienting appeared to be additive rather than interactive.

It is suggested that collectively these findings are consistent with the fields' current understanding of the maturation of brain regions thought to mediate reflexive and volitional orienting.
TABLE OF CONTENTS

Abstract ........................................................................................................................... ii
Table of Contents ......................................................................................................... iv
List of Tables ................................................................................................................ vi
List of Figures .............................................................................................................. vii
Acknowledgements ..................................................................................................... viii
Dedication ..................................................................................................................... ix

CHAPTER 1 ................................................................................................................... 1
Introduction .................................................................................................................. 2
Experiment 1 ................................................................................................................ 7
Method ........................................................................................................................... 7
  Participants .................................................................................................................. 7
  Apparatus and Stimuli ............................................................................................... 7
  Design ........................................................................................................................ 9
    Arrow Cues .............................................................................................................. 10
    Number Cues ......................................................................................................... 10
  Procedure .................................................................................................................. 11
Results ............................................................................................................................ 12
Discussion ..................................................................................................................... 17
Experiment 2 ................................................................................................................ 17
Method ........................................................................................................................... 18
  Participants ................................................................................................................ 18
  Apparatus, Stimuli, Design, and Procedure ............................................................... 18
Results ............................................................................................................................ 19
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discussion</td>
<td>22</td>
</tr>
<tr>
<td>General Discussion</td>
<td>22</td>
</tr>
<tr>
<td>References</td>
<td>25</td>
</tr>
<tr>
<td>CHAPTER 2</td>
<td>28</td>
</tr>
<tr>
<td>Introduction</td>
<td>29</td>
</tr>
<tr>
<td>Experiment 1</td>
<td>31</td>
</tr>
<tr>
<td>Method</td>
<td>32</td>
</tr>
<tr>
<td>Participants</td>
<td>32</td>
</tr>
<tr>
<td>Apparatus and Stimuli</td>
<td>33</td>
</tr>
<tr>
<td>Design</td>
<td>34</td>
</tr>
<tr>
<td>Procedure</td>
<td>35</td>
</tr>
<tr>
<td>Results</td>
<td>37</td>
</tr>
<tr>
<td>Discussion</td>
<td>42</td>
</tr>
<tr>
<td>References</td>
<td>45</td>
</tr>
</tbody>
</table>
CHAPTER 1

Table 1. Mean response times, standard deviations, and error rates for Experiment 1 ................................................................. 13

Table 2. Mean response times, standard deviations, and error rates for Experiment 2 ................................................................. 19

CHAPTER 2

Table 1. Mean response times and standard deviations for adults ................................................................. 37

Table 2. Mean response times and standard deviations for children ................................................................. 38

Table 3. Overall error and eye movement rates ................................................................. 38
LIST OF FIGURES

CHAPTER 1

Figure 1. Sample Sequence of Events.................................................................9

Figure 2. Experiment 1 Results............................................................................14

Figure 3. Experiment 2 Results............................................................................20

CHAPTER 2

Figure 1. Sample Sequence of Events.................................................................34

Figure 2. Experiment 1 Results............................................................................39
ACKNOWLEDGEMENTS

I would like to express sincere gratitude to my supervisor Alan Kingstone for the exceptional support he provided me with, both on a scientific and personal level. Next, many thanks to Jatinder (Bobby) Sidhu for all the daycare trips; Bobby’s friendship and personal sacrifice truly made the research conducted with young children (reported in Chapter 2) effortless and enjoyable.

The research reported here was supported by graduate fellowships from the Natural Sciences and Engineering Research Council of Canada (NSERC), the Michael Smith Foundation for Health Research (MSFHR), and a University of British Columbia graduate award. Additional support came from grants awarded to Alan Kingstone from the Human Frontiers Science Program (HFSP), NSERC, and MSFHR.
to my parents Sonja and Pavle
CHAPTER 1
Introduction

Behavioral studies of covert spatial attention to date indicate that two qualitatively different forms of attentional orienting occur in response to two different attentional cues (e.g., Posner, 1980; Jonides, 1981; Müller & Rabbitt, 1989). Reflexive orienting occurs in response to salient events in the environment. Volitional orienting, on the other hand, is generated in accordance with an observer's goals and expectations. Traditionally, behavioral markers of reflexive orienting were experimentally examined using abrupt unexpected peripheral events whereas the behavioral index of volitional attention was examined by manipulating central spatially informative symbolic cues.

In the peripheral cuing task participants are typically presented with brief luminance transients, serving as attentional cues, appearing randomly (p=.5) in one of the two possible target locations. The observers' task is to press a key when the target appears on the screen at one of these two locations. In order to profile temporal characteristic of the target response, the time between the cue onset and the target onset is typically varied (Stimulus Onset Asynchrony or SOA) between 0 and 1000 ms. The results of such a task generally indicate that targets appearing at the location where the cue was presented within 0-300 ms are detected faster than targets appearing at the noncued location. However, when the cue-target time delay exceeds 300ms, the opposite effect is seen: targets appearing at the uncued location now produce faster response times (RTs) than the targets appearing at the previously cued location. This reversal of the attentional effect has been labeled "Inhibition of Return" (IOR), denoting the idea that attention was initially allocated to the cued location (hence the shorter RTs early on) and is now being inhibited in returning to the cued location at longer SOA intervals (e.g., Posner, 1980; Posner & Cohen, 1984). This biphasic RT pattern at the cued location marked by early RT facilitation followed by IOR at longer cue-target delays has
traditionally been thought to reflect the behavioral signature of automatic attentional orienting (e.g., Rafal, Calabresi, Brennan & Sciolto, 1989; Posner & Cohen, 1984).

In contrast, volitional orienting is thought to reflect controlled rather than automatic processing in that it requires the development of an expectancy set that is based on the information provided by the cue (Müller & Rabbitt, 1989; Jonides, 1981). As such, attentional cues typically used to elicit volitional orienting manipulate internal expectations about a target's occurrence by using meaningful symbolic stimuli for directing attention (e.g., Jonides, 1981). In this task, participants are asked to fixate a central arrow cue that has predictive value about a target's occurrence. That is, the target appears at the location indicated by arrow direction on 80% of all the trials. The task is to detect the target appearing either at the cued or likely location (p=.8) or at the uncued or unlikely location (p=.2). The results show that targets appearing at the likely location are always detected faster than targets appearing at an unexpected location with the effect increasing and reaching an asymptote at approximately 500ms SOA (Müller & Rabbitt, 1989; Jonides, 1981).

The differences in the behavioral index of reflexive and volitional attention movements have suggested that this dichotomy may not reflect differences in allocation of resources within a single attentional mechanism (Posner, 1980; Jonides, 1981). As such, it was suggested that reflexive and volitional attention operate in an additive fashion with automatic (reflexive) and controlled (volitional) attentional being differentially susceptible to manipulations of cognitive load and expectancy information (e.g., Müller & Findlay, 1988). Reflexive orienting was found to be highly resistant to information provided by the cue; it could not be prevented given the proper triggering stimulus. At the same time, voluntary attention was found to be susceptible to the effects of a secondary task as well as to the automatic effects produced by the sensory properties of the cue (e.g., Müller & Rabbitt, 1989). This difference between
reflexive and volitional attention has been reinforced by a wealth of neuroimaging studies reporting that reflexive and volitional orienting, as defined by the classic behavioral paradigms, engage distinct neural circuits (e.g., Posner & Petersen, 1990; Posner, 1992; Corbetta, Miezin, Shulman & Petersen, 1993; Hopfinger, Buonocore & Mangun, 2000; Corbetta & Shulman, 2002). Converging evidence indicates that posterior parietal lobe and frontal cortex (more specifically frontal eye field region) are involved in controlling the direction of covert volitional attention as well as the maintenance of an expectancy set. In contrast, the circuit that involves ventral frontal cortex and temporoparietal junction shows sustained activation, as measured by fMRI, for detection of abrupt stimuli. Because of the differing maturational rates of frontal and parietal cortices (e.g., Johnson, 1997), marked developmental differences of reflexive and volitional attention have been observed such that fully-functioning reflexive orienting is present shortly after birth (Johnson, Posner & Rothbart, 1991) while volitional orienting reaches adult-like functioning much later, possibly at around 8 years of age (e.g., Brodeur & Enns, 1997).

The key theoretical assumption underlying classic behavioral paradigms of spatial attention is that central arrow cues engaged volitional orienting mechanism only because they predict spatially where the target will appear (Müller & Rabbitt, 1989; Rafal et al, 1989; Jonides, 1981). In other words, without predictive information about the target, arrows were regarded as ineffective in eliciting any orienting response, and could not, by virtue of the stimulus characteristics, trigger a shift in attention. This view stems largely from a classic study by Jonides (1981, Experiment 2) that required subjects to search a briefly presented array of letters for the target letter (L or R). Before the array appeared, a central arrow cue, randomly pointing to one of the target locations, was flashed momentarily at fixation. Results indicated that if subjects were told to ignore the arrow, orienting to the cued location was absent compared to the condition where
arrowhead was flashed at a peripheral location, suggesting that a nonpredictive central arrow cue does not trigger reflexive attention. Several recent studies, however, indicate that this acceptance of a null result was mistaken. Ristic, Friesen, and Kingstone (2002) asked participants to detect targets appearing to the left or right of a central arrow cue. Importantly, the arrow was uninformative of the target location such that it was randomly pointing to either of the two possible target locations. Contrary to the traditional result, participants were always faster to detect targets appearing at the cued compared to uncued locations even though they understood that arrow direction had no predictive meaning. Ristic et al (2002) observed faster RTs for cued targets at a range of cue-target intervals (195, 600, and 1000 ms), demonstrating that uninformative central arrow cues triggered a reflexive shift in spatial attention. Interestingly, and contrary to the traditional framework, the attentional orienting index was marked by a prolonged facilitation for cued targets without being accompanied by inhibition at longer SOA intervals. It is important to note that this is not an isolated instance reporting reflexive orienting in response to centrally presented directional uninformative cues. Similar findings using central arrow stimuli were obtained in two other studies (Hommel, Pratt, Colzato & Godjin, 2001; Tipples, 2002) as well as in other investigations employing other central directional cues such as eye gaze direction of both schematic faces (e.g., Friesen and Kingstone, 1998) and images of real faces (e.g., Driver et al, 1999; Langton & Bruce, 1999), head orientation (Driver et al, 1999; Langton, 2000), and finger pointing (Langton & Bruce, 2000). Taken together, these recent results demonstrate that a range of nonpredictive but directional attention cues presented at central fixation, including arrows, reliably trigger a reflexive shift of spatial attention, with the effect markedly different effect from the traditional reflexive effect, i.e., reflexive orienting in is long-lived and it is not accompanied by IOR.
Since the introduction of the cuing paradigm in early 1980s, the possibility of a central attentional cue triggering reflexive attention was abandoned, and, as a consequence never seriously entertained, a premise that was largely based on findings reported by Jonides in 1981 (see Kingstone, Smilek, Ristic, Friesen & Eastwood, in press for a review). The recent studies, however, showing that spatially nonpredictive but directional stimuli produce shifts in reflexive attention, raise the possibility that reflexive attention may have been contributing to the effects observed in the past with spatially predictive directional stimuli. In light of this possibility, the most important question now becomes whether the classic behavioral paradigms utilizing spatially informative arrow stimuli were estimating the contribution of volitional attention alone, as originally thought (because the arrow is predictive), reflexive attention (because arrow is directional), or perhaps some unique combination of reflexive and volitional responses that result from an interaction generated by cue directionality and its information. This test represents a crucial examination of the validity of both the classic experimental paradigm and the accumulated results that were, over the past years, generated by it.

In two experiments reported here we investigated this fundamental question whereby orienting responses for spatially predictive and nonpredictive directional (arrow) and nondirectional (digit) attentional cues were dissociated. If the classic line of thought is correct, than we should observe little or no difference between the volitional orienting effects generated in response to spatially predictive directional cues compared to spatially predictive nondirectional central cues. If, in contrast, the traditional paradigm was not measuring volitional orienting alone, one would predict marked differences in the attentional effect produced by arrow and digit cues.
Experiment 1

Experiment 1 was designed to measure attentional orienting in response to spatially predictive and nonpredictive central cues. Spatial predictiveness was varied across two different cues types: directional arrow cues and nondirectional digit cues. As noted, recent studies demonstrate that central arrow cues trigger reflexive shift of attention even when arrow direction does not reliably predict the target location (e.g., Ristic et al, 2002). The aim here was to employ a central cue that would not have inherent directionality and thus would not engage reflexive attention. However, when this cue was given predictive value, it would provide a pure measure of volitional orienting. The critical comparison here is whether volitional orienting triggered by such nondirectional cues matches the volitional orienting effect produced by the classic spatially predictive arrow cues.

Method

Participants

Forty eight (48) undergraduate students participated in the experiment in exchange for monetary compensation (24 participated in each of the two cue type conditions). All observers were naïve to the purpose of the experiment and reported normal or corrected-to-normal vision.\footnote{Seven participants were excluded from the initial sample comprised of 55 participants. Because the task was a simple detection task, we adopted a stringent criterion based on which all observers who made more than 5% errors across both cue conditions were excluded from the analysis.}

Apparatus and Stimuli

Stimulus presentation and timing was controlled by VScope 1.2.7 software (Rensink, 1995) running on the 6100/66 Power Macintosh computer. Stimuli were presented on a 15-inch Apple color monitor set to black and white, operating at 65Hz screen refresh rate.
The stimuli and sample timing sequence are illustrated in Figure 1. All stimuli were black line drawings presented on white background. Arrow cues were created by combining a straight line (2.1° long) with an arrowhead and an arrowtail (with each 45-degree oriented line measuring 1° in length) attached to both ends of the line (e.g., <-<). The whole arrow measured 3.3° of visual angle in length as measured from the tip of the arrowhead to the end of the arrowtail. Digit cues (3, 6, and 9) were 3.3° in height and 2° in width with the exception of number 1 which was created using a capital letter I (3.2° long and 0.5° wide). The number cues were created using the Geneva font of 100 points in size. Both arrow and number cues were positioned such that the center of the arrow and the center of the digit was always aligned with the center of the screen. At the start of each trial, a central fixation point subtending 1°, comprised of two perpendicular intersecting lines (each 1° in length), appeared at the center of the screen. The target was always a black asterisk (measuring .9°) that appeared with eccentricity of 6.5° as measured from the center of the cue to the center of the target. The center of the target was aligned with the center of both arrow and number cues along the horizontal and vertical axes.
Figure 1 illustrates the stimuli and timing sequences for directional (arrow) and nondirectional (digit) cue conditions. Identical stimuli and presentation sequence were used in both Experiment 1 and Experiment 2. A straight line or a fixation point appeared on the screen for 675 ms. Then, an arrow pointing left, right, up or down, or a central number cue (1, 3, 6, 9) appeared on the screen. The target appeared either to the left, right, up or down after 100, 300, 600 or 900 ms. Both the cue and the target remained on the screen until response was made or for 2700ms, whichever came first. Intertrial interval was 525 ms. Note that the stimuli are not drawn to scale.

Design

Cue type (arrow or number) was varied between subjects so that each group responded to a single central cue (either arrow or number). Both central cues were varied as either spatially predictive (probability of the target occurring at the cued location = .8) or spatially nonpredictive (probability of the target occurring at the cued location p= .25) of the target location. Cue predictiveness was varied within subjects such that each participant responded to both predictiveness conditions. Cue predictiveness order was counterbalanced across participants such that half the
participants in each group (N=12) received spatially predictive cues first and the other half (N=12) received spatially nonpredictive cues first.

**Arrow Cues.** On every trial, a central cue could be directed to the left, right, up, or down constituting four possible target locations (left, right, up, down). In the nonpredictive condition, the target appeared with equal probability at all four locations (p=. 25). All possible cue directions and target locations were distributed equally throughout the experiment. In the predictive condition however, the target appeared at the location to where the arrow was pointing in 80% of all trials. In remaining 20% of trials targets appeared equally often among three remaining locations (6.67% for each of the three locations). Trials in which the target appeared at the location to where the arrow was pointing are labeled as cued target trials and the trials in which the target appeared at any of three other possible locations are labeled as uncued target trials.

**Number Cues.** For the number cues one of the four possible digits (1, 3, 6, 9) appeared at the center of the screen at the beginning of each trial. When number cues were uninformative of the target location, the targets appeared with equal probability (p=. 25) at all four possible locations (left, right, up, down) regardless of which central digit appeared on the screen. However, when the number cue was predictive of the target location, the experiment was set up so that number 3 predicted the target occurring on the right, number 9 the target occurring on the left, number 1 the target occurring up, and number 6 the target occurring down. All four cues were presented equally often throughout the experiment. Mirroring the setup employed for arrow cues, spatially predictive digit cues correctly indicated target location on 80% of all trials. In the remaining 20% of the trials the target appeared randomly at one of the three remaining locations (6.67% per location).

For all cue types (arrows and numbers) and cue predictiveness (nonpredictive or predictive) conditions, four cue-target onset delays (100, 300, 600 and 900 ms) were
varied equally among all possible trials. In all conditions participants were asked to perform a speeded target detection response by pressing the spacebar key on the keyboard with the index finger of their preferred hand. Additionally, in approximately 6% of all trials within each of the four conditions the target was not presented on the screen. These catch trials were dispersed randomly across all possible cue directions and were included to ensure that participants responded to target onset and not its anticipated appearance.

Procedure

The start of every trial was signaled by a 675ms presentation of a fixation cross in the center of the computer screen. Then, a central cue (either arrow pointing left, right, up, or down, or one of the four number cues) appeared on the screen. The target demanding a simple detection response appeared at one of the four target locations after 100, 300, 600, or 900 ms. The trial terminated on response or after 2700ms, whichever came first. The intertrial interval was set at 525 ms. Reaction Time (RT) was measured from target onset and it was based on execution of the keyboard responses. Each cue type x cue predictiveness condition (arrow nonpredictive; arrow predictive; number nonpredictive; and number predictive) was comprised of 480 experimental trials distributed over 8 blocks of 60 trials. Thus, each participant completed a total of 960 trials, 480 in response to each cue predictiveness condition.

Participants were seated in a dimly lit room centered with respect to the computer screen and the keyboard at approximate distance of 57 cm. Before the commencement of the experiment, observers were shown a picture of a typical experimental trial. They were informed about the type of the central cue, its possible directions (or values), and possible target locations. Depending on the cue predictiveness condition, observers were informed that the cues were either nonpredictive or predictive of the target locations. They were explicitly told, and
understood, the probabilities of the target occurrence for either arrow or number central cues. Ten practice trials were run before the first testing block, and the experimenter offered to answer any questions after the practice run was completed. Participants were instructed how to initiate testing blocks and were informed about the duration of the experiment and their total time commitment. All participants were asked to respond as fast and as accurately as they could and to maintain central fixation throughout the experiment.

Results

Incorrect key presses, anticipations (RT<100 ms), timed-out responses (RT>1000 ms), and false alarms (responding with a keypress when the target was not present) were classified as errors and were excluded from the analysis. For the arrow central cues, anticipations accounted for 0.47% of all trials while timed-out responses accounted for 0.26% of all target-present trials across both predictiveness conditions. Overall false alarm rate was 0.62%. For digit central cues, anticipations accounted for 0.53%, timed out trials for 0.26%, and key press errors for 0.004% of all target present trials. False alarm rate was 1.02%. As each type of error accounted for less than 2% of all trials, errors were not analyzed further. Mean error rates for each of the SOA by validity condition are presented in Table 1.
<table>
<thead>
<tr>
<th>Condition</th>
<th>Arrow</th>
<th></th>
<th>Number</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>nonpredictive</td>
<td>predictive</td>
<td>nonpredictive</td>
<td>predictive</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>%E</td>
<td>M</td>
</tr>
<tr>
<td>100 ms SOA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cued</td>
<td>342.7</td>
<td>52.6</td>
<td>0</td>
<td>349</td>
</tr>
<tr>
<td>Uncued</td>
<td>348.7</td>
<td>50.5</td>
<td>.002</td>
<td>369</td>
</tr>
<tr>
<td>300 ms SOA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cued</td>
<td>324.1</td>
<td>51.7</td>
<td>.009</td>
<td>316.8</td>
</tr>
<tr>
<td>Uncued</td>
<td>334.5</td>
<td>52.4</td>
<td>.018</td>
<td>358.8</td>
</tr>
<tr>
<td>600 ms SOA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cued</td>
<td>305.1</td>
<td>43.9</td>
<td>.004</td>
<td>304.8</td>
</tr>
<tr>
<td>Uncued</td>
<td>321.5</td>
<td>47.1</td>
<td>.006</td>
<td>350.6</td>
</tr>
<tr>
<td>900 ms SOA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cued</td>
<td>321.3</td>
<td>50.1</td>
<td>.007</td>
<td>317.0</td>
</tr>
<tr>
<td>Uncued</td>
<td>330.7</td>
<td>47.6</td>
<td>.005</td>
<td>354.9</td>
</tr>
</tbody>
</table>

Table 1. Mean response times (RTs), standard deviations, and error rates for Experiment 1.

The correct RT means are illustrated in Figures 1a and 1b for the arrow and digit central cues as a function of SOA and cue validity. Arrow cues were effective in triggering orienting both as nonpredictive and predictive of a target position. Replicating previous results (e.g., Jonides, 1981; Ristic et al, 2002), on average, participants responded faster to targets at cued compared to noncued locations. Number cues, on the other hand, were effective only when they predicted target locations.
Although both types of predictive cues (arrow and digit) produced significant orienting effects, the cuing effect (uncued RT minus cued RT) was much larger for the predictive arrow cue. Figure 2c illustrates the cuing effects for all types of cues.

Figure 2 shows results from Experiment 1. Figure 2a shows mean response times (RTs) plotted as a function of SOA and validity for nonpredictive and predictive directional arrow cues. Figure 2b shows mean RTs for nonpredictive and predictive central digit cues. Figure 2c plots the difference between uncued and cued RTs from all four conditions presented in Figures 2a and 2b.
These observations were first confirmed by 2 separate within-subjects ANOVAs with cue predictiveness, SOA, and validity, conducted on each of the cue type separately. Significant main effects of both SOA and validity were observed for both arrow \( [F (3, 69)= 42.6, p< .0001; F (1, 23)= 101.47, p< .0001] \) and number center cues \( [F (3, 69)= 39.42, p< .0001; F (1, 23)= 16.43, p< .0001 \) respectively\] indicating a preparatory set for increasing SOA intervals, and overall faster RTs for cued compared to uncued targets, respectively. The cue predictiveness x validity \[\text{all Fs}> 4.0, ps< .05\] interaction was significant in both analyses, as well as a three-way interaction between cue predictiveness, SOA, and validity \[\text{arrow: } F (3, 69)= 2.82, p< .05; \text{digit: } F (3, 69)= 4.21, p< .01]. Thus, the validity effect differed with respect to SOA and two predictiveness conditions for each cue type as illustrated in Figure 2c.

Next, in order to examine potential differences between the two cues, cue type (arrow, number) was included as a between-subject variable in a separate four-way between-within ANOVA. Significant main effects of validity \[F (1, 46)= 99.29, p<. 0001\], SOA \[F (3, 138)= 80.19, p< .0001\], and cue predictiveness \[F (1, 46)= 6.83, p< .05\] were observed. The highest order interaction that reached significance was a three-way interaction between cue predictiveness, SOA, and validity \[F (3, 138)= 6.4, p< .001\] indicating that orienting effect varied differently across SOA for spatially predictive and spatially nonpredictive cues. Two two-way interactions between cue predictiveness and

---

2 Although the order of cue predictiveness presentation was counterbalanced across subjects for both cue types, we included it as a between-subject variable in a preliminary analyses conducted on each of the cue type separately. No order effects interacting with validity were observed. For the arrow cues a four-way between (order)-within (cue predictiveness, SOA, and validity) omnibus ANOVA conducted on mean RT with returned a significant interaction between cue predictiveness and order \[F (1, 22)= 12.46, p< .01\] reflecting the issue that both predictive and nonpredictive cues were overall responded to faster when received second with the effect being bigger for the predictive cues. No other effects or interactions involving presentation order were significant \[\text{all Fs}< 2.6, \text{all ps}>.06\]. The same analysis was performed on digit central cues. The only significant effect involving order was again an interaction with cue predictiveness \[F (1, 22)= 7.69, p< .05\] reflecting that again cue predictiveness condition received second was overall responded to faster. Importantly, an interaction involving validity and order was not present \[\text{all Fs}<1\].
validity [F (1, 46)= 110.05, p<.0001] and SOA and validity [F (3, 138)= 11.8, p<.0001] demonstrating the similar trend were also significant. However, the interaction between cue predictiveness, validity, and cue type was nonsignificant [p>.2] indicating that, overall, the pattern of orienting in response to noninformative and informative cues was not statistically different between directional and nondirectional attentional cues.

When nondirectional number cues were varied independently of the target position, no differences in RTs were observed for cued compared to uncued targets. In contrast, when number cues were made predictive of the target location, a significant cuing effect at longer SOA intervals was observed, demonstrating a result consistent with behavioral index of volitional orienting (e.g., Müller & Rabbitt, 1989). A recent study (Fisher, Castel, Dodd & Pratt, 2003) reported that numerically low centrally presented number cues (1 and 2) trigger an automatic shift of attention to targets appearing in the left visual field whereas numerically high numbers (8 and 9) induce a shift of spatial attention towards the right visual field. To examine whether this effect was operating in the present data, we analyzed mean RTs in response to spatially nonpredictive digit cues (1, 3, 6, 9) as a function of SOA (100, 300, 600, and 900 ms) and target position (left, right, up, or down). No significant interaction involving cue type and target position was observed [F (9, 207) = 1.79, p > .05] indicating that indeed this spatial bias was not operating in our data and as such did not influence the magnitude of volitional orienting when digit cues were manipulated as spatially predictive.

Overall, the results from Experiment 1 indicate that when varied as spatially predictive of the target position, both arrow and number cues produced significant cuing effects for targets appearing at the predicted locations. In contrast to number cues, only directional arrow triggered a reflexive shift of attention when it was uninformative of the target position, and when it was made spatially predictive the size of orienting effect surpassed that of symbolic informative digit cues.
Discussion

When cue directionality and cue predictiveness are experimentally dissociated, marked differences in magnitude of volitional orienting in response to directional and nondirectional attentional cues emerge: Predictive arrow cues produced larger orienting effects than predictive nondirectional digit cues. However, when orienting in response to the two cues was compared in a between-subject analysis no significant interaction between cue type, cue validity, and predictiveness was observed. This result raises two possible explanations. First, it is indeed possible that orienting in response to nondirectional and directional predictive cues does not differ, a finding that would validate traditional cuing studies. However, this does not agree with our observations as illustrated in Figure 2c. An alternative explanation is that the cue type was included as a between-subject factor and the present experiment lacked the necessary power to detect a significant difference between the magnitudes of orienting to predictive directional and predictive nondirectional cues. Experiment 2 was conducted in order to address this alternative.

Experiment 2

The results from Experiment 1 demonstrated that the magnitude of orienting effect triggered by predictive arrow cues always exceeded orienting effects elicited by an uncontaminated measure of volitional orienting produced by symbolic digit cues. However, this magnitude difference was not reliable. Although the data from Experiment 1 are convincing, the fact remains that the results did not show statistical difference between the two cues when tested in an omnibus ANOVA. In addition, even if a reliable difference in orienting magnitude between the predictive arrow and digit cues had been observed, the fact remains that cue type was manipulated between subjects. As such there is a real possibility that any potential differences in orienting might have reflected group differences rather than differences in attentional orienting.
To address both these issues, we examined whether reliable difference would be observed when the effects are measured entirely within the same group of participants.

Method

Participants

The data from additional forty eight (48) undergraduate students from the University of British Columbia were included in the analysis. All participants were blind to the purpose of the experiment and none had participated in any previous conditions. Testing was divided over two sessions in duration of less than one hour each that were conducted on separate days.

Apparatus, Stimuli, Design, and Procedure

Experimental parameters were kept identical to those of Experiment 1 unless explicitly stated. All participants completed all four cue type x cue predictiveness conditions. Cue type (arrow or number) was counterbalanced within subjects across sessions such that half the participants received (N=24) arrow cues first and the other half received number cues first (N=24). Order of cue predictiveness (nonpredictive; predictive) presentation was counterbalanced both between and within subjects such that half of all observers (N=24) received predictive cues followed by nonpredictive cues in the first session and the other half (N=24) received the opposite order in their first session. Counterbalancing of cue type and cue predictiveness was completely crossed such that each group of 12 participants received a distinct combination of arrow and number cues between sessions as well as two cue predictiveness orders within sessions. Cue type was kept constant within a single session in order to match experimental manipulation with that used in Experiment 1.

Each participant completed a total of 1920 experimental trials, 480 in response to each cue type x cue predictiveness condition.
Results

As in Experiment 1, anticipations (RT<100), timed-out responses (RT>1000 ms), and false alarms were excluded from the analysis. Errors occurred on less than 1% of all target trials while false alarms occurred on less than 2.1% no target trials in each of the cue predictiveness conditions. Errors were not analyzed further. Mean correct RTs for all cue predictiveness conditions are shown in Table 2 and illustrated in Figure 3a for arrow cues and Figure 3b for number cues.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Arrow</th>
<th></th>
<th>Number</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>nonpredictive</td>
<td>predictive</td>
<td>nonpredictive</td>
<td>predictive</td>
</tr>
<tr>
<td>100 ms SOA</td>
<td>343.2</td>
<td>64.2 .007</td>
<td>342.3</td>
<td>56.7 .004</td>
</tr>
<tr>
<td>Cued</td>
<td>352.1</td>
<td>61.8 .009</td>
<td>366.7</td>
<td>72 .006</td>
</tr>
<tr>
<td>Uncued</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>300 ms SOA</td>
<td>323.2</td>
<td>59.6 .027</td>
<td>311.5</td>
<td>49.7 .027</td>
</tr>
<tr>
<td>Cued</td>
<td>322</td>
<td>57.8 .027</td>
<td>354.6</td>
<td>55.3 .029</td>
</tr>
<tr>
<td>Uncued</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>600 ms SOA</td>
<td>306.8</td>
<td>46 .008</td>
<td>299.3</td>
<td>41.5 .011</td>
</tr>
<tr>
<td>Cued</td>
<td>318.5</td>
<td>48 .01</td>
<td>337.7</td>
<td>44 .007</td>
</tr>
<tr>
<td>Uncued</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>900 ms SOA</td>
<td>313</td>
<td>48.5 .004</td>
<td>308.2</td>
<td>40.1 .007</td>
</tr>
<tr>
<td>Cued</td>
<td>325.1</td>
<td>44.2 .012</td>
<td>339.4</td>
<td>48.3 .01</td>
</tr>
</tbody>
</table>

Table 2. Mean response times (RTs), standard deviations, and error rates for Experiment 2.
Figure 3 shows results from Experiment 2. Figure 3a shows mean response times (RTs) plotted as a function of SOA and validity for nonpredictive and predictive directional arrow cues. Figure 3b shows mean RTs for nonpredictive and predictive central digit cues. Figure 3c plots the difference between uncued and cued RTs from all four conditions presented in Figures 3a and 3b.

As illustrated in Figures 3a and 3b the results mirrored those obtained in Experiment 1. These observations were examined using a four-way within-subjects ANOVA with cue type (arrow, number), cue predictiveness (nonpredictive, predictive),
SOA (100, 300, 600, and 900 ms), and validity (cued, uncued) included as factors. The results indicated that, on average, observers were faster to detect targets appearing after longer cue-target delays \(F(3, 141) = 59.4, p < .0001\) as well as that overall cued targets were detected faster than uncued targets \(F(1, 47) = 167.78, p < .0001\). Two two-way interactions between cue type and validity \(F(1, 47) = 89.67, p < .0001\) and cue predictiveness and validity \(F(1, 47) = 97.08, p < .0001\) were highly significant. A three-way interaction between cue predictiveness, SOA, and validity \(F(3, 141) = 4.62, p < .01\) reflecting that the cuing effect differed across SOA intervals but only when attentional cues were made spatially predictive of the target. Importantly, so was the three-way interaction between cue type, cue predictiveness, and validity \(F(1, 27) = 19.23, p < .0001\) indicating that spatially predictive arrow cues produced significantly larger orienting effects than the predictive number cues.

As in Experiment 1, order of cue presentation and cue predictiveness was included as a between-subject variable in a preliminary analysis. First, to assess any possible effects of cue type presentation order, mean correct RT scores were subjected to a between (cue order: arrow, number) within (cue type, cue predictiveness, SOA, validity) ANOVA. The analysis returned no significant main effect of order \(F < 1\) and significant interactions of cue order x cue type \(F(1, 46) = 9.1, p < .01\) and cue type, cue validity, and cue order \(F(1, 46) = 5.66, p < .05\) indicating that again both cue types were responded to faster when they were received second and that larger effect were observed for arrow cues regardless of whether they were received first or second. Next, to examine whether validity effects varied with order of cue predictiveness, it (nonpredictive, predictive) was entered as between-subject variable in three-way between within ANOVA conducted on each of the two cues types separately including cue predictiveness, SOA, and validity as within-subject factors. Again, for both arrow and number cues, no main effects of cue predictiveness order were observed [both Fs < 1]. The only significant interaction was observed in arrow condition between cue validity and order \(F(1, 46) = 4.7, p < .05\) reflecting the fact that overall invalid trials were overall slower when predictive cues were received second. No other interactions involving cue predictiveness and order of the presentation were significant [all Fs < 2.3, all ps > .085].

---

3 As in Experiment 1, order of cue presentation and cue predictiveness was included as a between-subject variable in a preliminary analysis. First, to assess any possible effects of cue type presentation order, mean correct RT scores were subjected to a between (cue order: arrow, number) within (cue type, cue predictiveness, SOA, validity) ANOVA. The analysis returned no significant main effect of order \(F < 1\) and significant interactions of cue order x cue type \(F(1, 46) = 9.1, p < .01\) and cue type, cue validity, and cue order \(F(1, 46) = 5.66, p < .05\) indicating that again both cue types were responded to faster when they were received second and that larger effect were observed for arrow cues regardless of whether they were received first or second. Next, to examine whether validity effects varied with order of cue predictiveness, it (nonpredictive, predictive) was entered as between-subject variable in three-way between within ANOVA conducted on each of the two cues types separately including cue predictiveness, SOA, and validity as within-subject factors. Again, for both arrow and number cues, no main effects of cue predictiveness order were observed [both Fs < 1]. The only significant interaction was observed in arrow condition between cue validity and order \(F(1, 46) = 4.7, p < .05\) reflecting the fact that overall invalid trials were overall slower when predictive cues were received second. No other interactions involving cue predictiveness and order of the presentation were significant [all Fs < 2.3, all ps > .085].
significant \[ F(9, 423) = 1.4, p > .15 \] demonstrating that any spatial bias induced by perception of numerically low and high numbers was not present in our data. As such, once again, we are confident that orienting effects observed in response to spatially predictive digit cues accurately reflects the contribution of endogenous orienting alone.

The results obtained in Experiment 2 replicate those from Experiment 1. Spatially nonpredictive directional arrow cues were once again effective in eliciting reflexive orienting while spatially nonpredictive digit cues were not. In addition both predictive arrow and number cues were effective in eliciting volitional orienting. Spatially predictive arrow cues produced the largest orienting effects as illustrated in Figure 3c.

**Discussion**

Experiment 2 manipulated cue type and cue directionality within the same group of observers. This manipulation allowed for a direct comparison of the magnitudes of the orienting effects generated by our four conditions (arrow nonpredictive; arrow predictive; number nonpredictive; number predictive). Thus, any differences between the orienting magnitudes were now independent of group differences because Experiment 2 was carried out within-subjects. The results mirrored those of Experiment 1, and indicated that a spatially predictive arrow cue, that was traditionally used in a range of behavioral and neuroimaging studies of human volitional attention, triggers a shift of spatial attention that is reliably larger than the unconfounded measure of voluntary orienting measured by spatially informative symbolic digit cues.

**General Discussion**

As outlined in the introduction, for over twenty years, the Posner paradigm has been widely used in research investigations and predictive arrow cues have almost exclusively been used to elicit voluntary orienting responses. However, several recent findings (e.g., Hommel et al, 2001; Tipples, 2002; Ristic et al, 2002) demonstrate that central arrow cues, by a virtue of their inherent directionality, trigger a reflexive shift of
spatial attention. Two experiments reported here examined the differences between the behavioral index of volitional attention when triggered by spatially predictive central directional cues, such as arrows, and when triggered by purely symbolic nondirectional informative cues, that on their own do not produce a shift in attention automatically. In Experiment 1 we dissociated orienting in response to spatially predictive directional and nondirectional attentional cues. The data demonstrated differences between the magnitudes of volitional orienting when triggered by the cue that, by the virtue of its stimulus characteristics, does not trigger a reflexive attentional shift and the orienting effect triggered by the predictive arrow cues. Experiment 2 replicated this initial result, and also demonstrated that a difference in magnitude of attentional orienting in response to directional arrow and nondirectional digit cues was significant.

To address the initial question pertaining to the validity of the classic paradigms, the data from the two experiments indicate that the orienting in response to spatially informative arrow cues does not equal either the reflexive or pure voluntary effect. Instead, the large orienting effect elicited by spatially predictive arrow cues appears to be unique such that the magnitude of this orienting effect surpasses both reflexive and volitional effects. In other words, its magnitude could not be accounted for simply by the addition of the reflexive and voluntary orienting effects (see Figures 2c and 3c). Although this interpretation represents a plausible account for the data, it is still unclear whether this large orienting effect arises as a result of a unique interaction between reflexive and volitional orienting systems or whether it represents an isolated effect seen only with spatially informative directional cues, such as arrows. If the effect is largely due to the interaction between the two orienting mechanisms, one would predict that the similar results would emerge when other attentional cues that trigger reflexive orienting when spatially uninformative and voluntary orienting when presented as informative of the target are employed (e.g., abrupt peripheral onsets).
Additionally, since we measured orienting response to two specific stimuli only, it is unknown whether the similar superadditive behavioral result could be observed for other informative directional cues presented at central fixation, such as eye gaze direction or head orientation. These questions are left for future studies.

Perhaps the most important implication of findings reported here concerns the validity of past experimental results reported in the attentional literature over the past two decades. Our results demonstrate two very important points. First, we replicate previous results indicating that reflexive attentional shifts occur when central nonpredictive cues are presented. As such these findings raise concerns about the original distinction between reflexive and voluntary attentional systems; a theoretical framework that was grounded in distinct behavioral paradigms employing peripheral onsets and informative central stimuli as attentional cues. Second, our data demonstrate that past investigations of volitional attention that used predictive central arrow stimuli were in fact not assessing the contribution of volitional attention alone, but rather a specific orienting response elicited by a predictive directional cue (i.e., arrow). More generally, these data cast doubt on the validity of the classic Posner paradigm, which routinely used predictive arrow cues, and, consequently, the accumulated knowledge about the properties of controlled attentional processes much of which has been grounded in this traditional experimental procedure. For example, the classical paradigms have been over the years typically adopted as an experimental default for neuropsychological (e.g., Rafal & Robertson, 1995), neuroimaging (Mangun & Hillyard, 1990; Corbetta et al, 1993; Hopfinger, Buonocore & Mangun, 2000; Corbetta & Shulman, 2002), and developmental (e.g., Brodeur & Enns, 1997; Goldberg, Maurer & Lewis, 2001) investigations, and as such have been the foundation on which much of the current knowledge about human attentional processes and the resulting scientific theories of attentional operations have been built.
References


CHAPTER 2
Introduction

Development of attentional processes plays a large role in early organization of behavior such that it influences early control of arousal levels, distress management, self-regulation as well as the organization of early social interactions (e.g., Rothbart, Posner & Rosicky, 1994; Posner & Rothbart, 2000). Behavioral investigations of human attention indicate that while attention generally moves in conjunction with eye movements (overt attention), it can also be allocated to an object or a position in space independently of a shift in gaze position (covert attention) (e.g., Klein, Kingstone, Pontefract, 1992; Klein & Shore, 2000). Both covert and overt attention can be triggered either externally by stimulus properties (e.g., transient abrupt-onset events) or by internal goals and expectations of an observer (Müller & Rabbitt, 1989; Posner, 1980; Jonides, 1981). Developmental studies conducted to date indicate that these two attentional systems (i.e., exogenous and endogenous, respectively) exhibit differential maturational rates, and as such play a large role in the development of relevant emergent behaviors (e.g., Hood, Atkinson & Braddik, 1998).

Development of reflexive or exogenous attention has typically been investigated in the experimental paradigms manipulating abrupt peripheral onsets, mirroring those employed with adults (e.g., Posner, 1980). When reflexive orienting is examined using manual response time (RT) measures in a cross-sectional sample of children, between ages of 5 and 18, the results indicate that reflexive orienting responses exhibit little or no comparative change over the lifespan (e.g., Brodeur, Trick & Enns, 1997). In contrast, studies of volitional or endogenous attention indicate the presence of marked developmental differences in the control of attention. Investigations of covert voluntary attention suggest that adult-like control of attentional allocation is observed only at about 8 years of age (e.g., Brodeur, Trick & Enns, 1997). These marked behavioral differences in allocation of covert reflexive and volitional attention have largely been
attributed to different maturational rates of the underlying brain mechanisms where
reflexive attention is thought to be controlled by earlier developing subcortical (e.g.,
superior colliculus) and cortical (parietal lobe) structures whereas the control of
volitional attention is accomplished by later developing frontal cortical areas (e.g.,
Johnson, 1997).

Recently, Ristic, Friesen & Kingstone (2002) reported that children as young as 4
years of age will shift their attention reflexively to where a spatially nonpredictive
arrow is directed. A group of children (mean age 4.5 years) and a comparison group of
adults detected peripheral targets appearing to the left or right of a central spatially
nonpredictive arrow cue. Attentional orienting was sampled at temporal intervals of
195, 600, and 1000 ms. The results revealed that, overall, both groups responded faster
to cued compared to uncued targets. This effect appeared less than 200 ms after the
arrow cue was presented and it persisted, and grew in magnitude, as the cue-target
SOA was extended to approximately 1000 ms.

This finding contrasts with the only other investigation that has studied the effect
of central arrow cues on attentional orienting in such young children. Brodeur and Enns
(1997, Experiment 1) asked three groups of children (mean ages of 6, 8, and 10 years) to
identify a target (X or O) that appeared either near to, or far from, a central arrow cue.
This arrow cue correctly indicated the target hemifield on 80% of the trials (i.e., it was
spatially predictive). Orienting effects were examined at SOAs of 133, 250 and 450 ms.
While adults showed significant orienting effects (Uncued-Cued RT) for all cue-target
intervals, children showed significant orienting effects for 133 ms SOA only. In contrast
to the Ristic et al. (2002) study, the cuing effect for the youngest group of children
declined as the SOA increased, disappearing altogether by the 500 ms SOA. Based on
these data, the authors argued that children 6 years of age were able to orient attention
volitionally in response to the predictive nature of a central arrow cue, but only for a
short period of time. Subsequent studies showed that after age 8, like adults, children are able to sustain volitional orienting for longer durations (Goldberg, Maurer & Lewis, 2001).

Insofar as these two studies can be attributed to reflexive and volitional attention respectively, the implication is that for young children reflexive orienting is rapid and long-lasting and volitional orienting is rapid and short-lived (the latter interpretation being favored by Brodeur & Enns). However, as we have shown in Chapter 1, there are very good reasons to question the interpretation of studies that have employed predictive arrow cues, as it was used by Brodeur & Enns (1997). The attention effect they observed with a predictive arrow cue could reflect reflexive attention, volitional attention, or some combination of the two.

Nevertheless, the fact remains that the Brodeur & Enns (1997) study suggests that predictive arrow cues produce a very different pattern of results than what was observed for adults in Chapter 1. Specifically, where the attention effect for predictive arrows grew for adults as the cue-target interval extended across time, the effect declined for children in the Brodeur and Enns' (1997) investigation. Whether this effect should be attributed to short-lived volitional attention, or a combination of reflexive and volitional attention that is very different from what was observed for adults, is very much an open question. In Chapter 2 we addressed this issue directly by employing the logic used successfully in Chapter 1, whereby we dissociated orienting responses of young children to spatially predictive and nonpredictive directional (arrow) and nondirectional (shape) central attentional cues.

**Experiment 1**

In order to examine this issue, first we presented a group of young children and a group of adults with a cuing task in which central directional arrow cues served as fixation stimuli. Further, to assess whether the orienting triggered by spatially
predictive arrow cues indeed reflected voluntary orienting, in a subsequent manipulation we compared orienting in young children and adults in response to central geometric shape cues. Instead of using digit cues as employed in Chapter 1, here we utilized central geometric shape (circle or square) as a symbolic target location predictor in order to equate familiarity with the cue between young children and adults. This nondirectional cue manipulation represents a crucial test of whether the attentional orienting in response to predictive arrow cues in children is indicative of voluntary orienting or not.

Both directional (arrow) and nondirectional (shape) cues were presented as either nonpredictive (p=.5) or predictive (p=.8) of the target location. All manipulations were carried out between subjects such that each cue type by cue predictiveness condition was carried out on a separate group of participants in each age group. In order to ensure that we were in fact examining covert orienting responses eye movements were monitored in all experimental conditions.

Method

Participants

A total of 60 children and 60 undergraduate students participated in the present study. Fifteen children and 15 adults were assigned to each of the cue type x cue predictiveness conditions (arrow nonpredictive; arrow predictive; shape nonpredictive; shape predictive). The ages for the children in each of the four conditions were: (1) nonpredictive arrow condition (9 males) 3 years, 5 months to 6 years, 2 months (mean age 4 years, 5 months); (2) predictive arrow condition (8 males) 4 years, 11 months to 5 years, 11 months of age (mean age 5 years, 3 months); (3) nonpredictive shape condition (7 males) 3 years, 5 months to 5 years, 4 months (mean age 4 years, 3 months); (4) predictive shape condition (9 males) 3 years, 4 months to 4 years, 9 months (mean age 4 years, 4 months). All children were recruited from local Vancouver Daycare Centers
with the informed consent of the parents and the daycare centers. Undergraduate students were recruited from UBC Psychology Subject Pool, and all observers completed the experiment in exchange for course credit.

**Apparatus and Stimuli**

The stimuli were presented on a Macintosh Powerbook 3200c laptop computer connected to an external keyboard. The stimuli were presented on a 12-inch LCD color screen set to black and white. VScope 1.2.7 software (Rensink, 1995) was used to control stimulus presentation and record response latencies and accuracies. Participants responded by pressing the spacebar key on the external keyboard, positioned in front of the computer, which was marked with red tape to remind children of correct response key. Eye movements were monitored on-line by the experimenter using an external mirror positioned above the computer screen.

The stimuli and sequence of events are presented in Figure 1. All stimuli were black line drawings presented on a white background. The arrow stimulus was created by attaching an arrowhead and an arrowtail (each 45-degree oriented line measured 0.6°) to the both ends of a horizontal line measuring 1.3° in length. The arrow stimulus was 2.5° long as measured from the tip of the arrowhead to the end of the arrowtail, and it was always positioned at the center of the screen. In a nondirectional cue condition, one of two geometrical shape cues, line drawings of a circle and a square, served as central fixation stimuli. The circle and square both measured 1.9° in length and height. A small central cross (subtending 1° visual angle), served as a fixation point in the nondirectional cue conditions. The response target was a black asterisk subtending 0.7°. The target always appeared 5° to the left or right of center as measured from the center of the cue to center of the target.
Figure 1 illustrates stimuli and timing sequence for directional (arrow and nondirectional (geometric shape) cue conditions. A straight line or a fixation point appeared on the screen for 675 ms. Then, an arrow pointing left or right, or central circle or square appeared on the screen. The target appeared centered across horizontal meridian, either on the left or right side of the cue after 100 or 900 ms. Both the cue and the target remained on the screen until response was made or for 2300 ms, whichever came first. Intertrial interval was 516 ms. Note that the stimuli are not drawn to scale.

Design

For the nonpredictive cue condition, the target location was unrelated to the cue. For instance, in the arrow cue condition, the left or right direction of the arrow was randomly determined as was the left or right location of the target. Thus, the target could appear at the cued location (location pointed at by the arrow) or at the uncued location (location not pointed at by the arrow) with a probability equal to chance (p=.5). Similarly, for nondirectional shape cue, the cue was either a circle or a square, and the location of the target was unrelated to the type of shape cue. For the predictive arrow cue condition, the arrow direction was again chosen at random, but now the target
appeared at the location cued by the arrow most of the time (p=. 8) and occasionally at the uncued location (p=. 2). Similarly, for the shape cue condition, one shape indicated that the target was likely to appear on the left (p=. 8) and the other shape indicated that the target was likely to appear on the right (p=. 8). The order of which shape indicated which side was counterbalanced across participants.

The timecourse of attentional allocation was examined by sampling the performance at two cue-target stimulus onset asynchronies (SOAs): 100 and 900 ms. The two delay intervals were distributed equally throughout the experiment. In addition, in approximately 6% of all trials the target was not presented. These catch trials were randomly seeded throughout the experiment.

Each participant, except the two children who completed only one block in response to nonpredictive shape, completed a total of 100 experimental trials that were divided in two blocks of 50 trials each. All participants, except one child, completed the two blocks of trials in succession. A practice block of about 10 trials was run at the beginning of the experimental session. A failure to emphasize response speed (mean detection RT greater than 500 ms for adults and 900 ms for children) resulted in 1 adult and 2 children being replaced.

Procedure

All trials began with the presentation of a straight line or a fixation cross for 675 ms. Then, in the arrow condition, an arrowhead and an arrowtail appeared at both ends of the line to create an arrow pointing left or right. In the nondirectional cue condition, center shape, either a circle or a square, appeared at the center of the screen. After 100 or 900 ms the target appeared on either left or right side of the screen. Each trial terminated on response, or after 2300 ms whichever came first. The intertrial interval was 516 ms.
All children were tested at a daycare facility. Two experimenters were present with the children at all times. One experimenter sat beside the child and ensured that each participant was responding with the proper key. The other experimenter was positioned behind the participant and recorded eye movements by observing participants' eyes in the mirror and the experimental sequence on the screen. On every trial, the experimenter judged whether an eye movement had occurred and if it did the experimenter recorded the trial number on which the saccade was made. Eye movements that were made either in anticipation of the target position or saccades that were made to the target when it appeared on the screen were recorded.

After agreeing to take part in the study, the children sat in front of the computer and were centered with respect to the screen and keyboard (viewing distance approximately 57 centimeters). The children were then told how the study was going to proceed. In all conditions children were asked to “catch the snowflake” as fast as they could when it appeared on the screen by pressing the red key on the keyboard. They were told that they would see either an arrow or circle or square presented at the center of the screen before the snowflake appeared. In the nonpredictive cue conditions, the children were informed that arrow direction (or shape) did not indicate where the snowflake would appear. In the predictive cue conditions, the children were informed that arrow direction would inform them about snowflake’s location most of the time. Similarly, for the predictive shape cue condition children were informed about the predictive relationship between the cue and the likely target location. The experimenter ensured that all children understood instructions fully before commencing the experiment.

Undergraduate students were tested in the laboratory. Experimental procedure and instructions paralleled those employed with children, with one exception that only one experimenter was present in the testing room at all times.
Results

Median RT was calculated for each participant. The interparticipant mean RTs for both age groups are illustrated in Figure 2 and presented in Table 1 for adults and Table 2 for children. Incorrect key presses, timed-out responses, and false alarms counted as errors and were removed from the analysis. Table 3 presents overall error rates as well as saccadic eye movement rate.

<table>
<thead>
<tr>
<th>Condition*</th>
<th>Arrow</th>
<th>Shape</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>nonpredictive</td>
<td>predictive</td>
</tr>
<tr>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>100 ms SOA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cued</td>
<td>385.5</td>
<td>67.3</td>
</tr>
<tr>
<td>Uncued</td>
<td>389.9</td>
<td>53.6</td>
</tr>
<tr>
<td>900 ms SOA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cued</td>
<td>337.9</td>
<td>47.7</td>
</tr>
<tr>
<td>Uncued</td>
<td>351.1</td>
<td>54.4</td>
</tr>
</tbody>
</table>

Table 1. Mean RTs and standard deviations for adults. *Since there was no true “cued” and “uncued” target conditions in nonpredictive shape condition, corresponding numbers represent mean RTs for targets appearing on the left and right side location for the two SOA intervals.

1 In order to ensure that we were measuring covert attention, number of recorded eye movements made either to the target or in anticipation of the target was included a covariate in preliminary analyses. Saccadic eye movements did not account for significant variation present in the data, and as such did not change reported results. All analyses reported here show actual p values without eye movement rate included as a covariate.
### Table 2. Mean RTs and standard deviations for children. *Since there was no true “cued” and “uncued” target conditions in nonpredictive shape condition, corresponding numbers represent mean RTs for targets appearing on the left or right side locations for the two SOA intervals.

<table>
<thead>
<tr>
<th>Condition*</th>
<th>Arrow</th>
<th></th>
<th>Shape</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>nonpredictive</td>
<td>predictive</td>
<td>nonpredictive</td>
<td>predictive</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>100 ms SOA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cued</td>
<td>680.6</td>
<td>153</td>
<td>685.4</td>
<td>153.5</td>
</tr>
<tr>
<td>Uncued</td>
<td>686.8</td>
<td>136.6</td>
<td>724.2</td>
<td>168.5</td>
</tr>
<tr>
<td>900 ms SOA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cued</td>
<td>603.9</td>
<td>93.7</td>
<td>585.2</td>
<td>93.6</td>
</tr>
<tr>
<td>Uncued</td>
<td>630.8</td>
<td>118.74</td>
<td>618.3</td>
<td>146.3</td>
</tr>
</tbody>
</table>

### Table 3. Error rates and eye movement rates for all conditions. TO (timed out responses), IK (incorrect key presses), FA (false alarms), EM (eye movements).

<table>
<thead>
<tr>
<th>Condition</th>
<th>Adults</th>
<th></th>
<th>Children</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TO</td>
<td>IK</td>
<td>FA</td>
<td>EM</td>
</tr>
<tr>
<td>Arrow</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonpredictive</td>
<td>.45%</td>
<td>0</td>
<td>1.12%</td>
<td>2.5%</td>
</tr>
<tr>
<td>Predictive</td>
<td>0</td>
<td>0</td>
<td>2.2%</td>
<td>3.4%</td>
</tr>
<tr>
<td>Shape</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonpredictive</td>
<td>0</td>
<td>0</td>
<td>2.2%</td>
<td>2%</td>
</tr>
<tr>
<td>Predictive</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3.5%</td>
</tr>
</tbody>
</table>
Figure 2 shows results from Experiment 1. Results from two age groups are presented on the left (adults) and on the right (children). Figure 2a shows mean response times (RTs) plotted as a function of SOA and validity for nonpredictive and predictive directional arrow cues for both age groups. Figure 2b shows mean response times for nonpredictive and predictive central shape cues, with only an SOA effect plotted for nonpredictive shape condition. Figure 2c plots the difference between uncued and cued RTs for both adults (left panel) and children (right panel).
The results for the nonpredictive arrow condition (see Figure 2a) were analyzed using a three-way ANOVA where age group (children and adults) was included as a between-subject factor, and SOA and validity were within-subject factors. The analysis indicated that all main effects were significant: group [F (1, 28) = 88.92, p < .0001], SOA [F (1, 28) = 28.02, p < .0001], and validity [F (1, 28) = 4.43, p < .05]; and that no interactions were significant [all ps > .05]. These findings reflect the fact that while children were slower overall to respond to targets than adults, the effects of SOA and cue condition were similar for both age groups. Specifically, RT declined as SOA increased, reflecting a classic foreperiod effect; and RT was shorter for cued than uncued locations at both SOAs reflecting the fact that attention was shifted reflexively to the location indicated by a spatially nonpredictive arrow cue as reported previously by Ristic et al. (2002).

Median correct RTs for the two age groups that received predictive arrow cues were subjected to the same three-way ANOVA. This analysis also returned three significant main effects: age group [F (1, 28) = 42.78, p < .0001], SOA [F (1, 28) = 25.34, p < .0001], and validity [F (1, 28) = 27.88, p < .0001]. No interactions between group and validity were observed [all ps > .05]. As the Figure 2a illustrates, both age groups produced similar behavioral responses when presented with predictive arrow cues. While children were overall slower, both age groups responded faster as the time between the cue onset and target presentation increased. Furthermore, both age were faster to respond to targets appearing at the predicted location for both short and long SOA intervals. In summary, the data for the arrow cue conditions indicate that both children and adults detected cued targets faster than uncued targets regardless of whether the central arrow cue was spatially predictive or not.

In contrast to nonpredictive arrow cues, nonpredictive shape cues were not effective in eliciting reflexive orienting in either age group. Interparticipant means of
median RTs calculated for each group of participants were subjected to the subsequent analyses for nondirectional shape condition. They are illustrated in Figure 2b.

A four-way ANOVA that included age group as a between-subject variable, SOA, cue type (circle or square), and target position (left or right), as within-subject variables indicated that again overall children responded slower than adults [F (1, 28)= 66.67, p<.0001] and that on average both age groups responded faster as the SOA interval lengthened [F (1, 28)= 14.02, p<.001]. SOA x cue type x age group interaction was also significant [F (1, 28)= 4.92, p<.05] reflecting that at the 900 ms SOA children generated faster responses when the central cue was a circle than when it was a square. Importantly, however, cue type did not interact with target position [F<1] indicating that the shape cues did not trigger any specific directional orienting effects in either age group. Thus, shape cues represent a valid comparison set against which any contribution of voluntary attention can be assessed when the same cues are manipulated as spatially predictive of target location. The data for both age groups are illustrated in Figure 2b, showing mean RTs as a function of SOA.

Data for predictive shape cues were analyzed using a three-way ANOVA, with age group as between-subject variable, and SOA and validity as within-subject variables. The analysis returned significant main effects of group [F (1, 28)= 64.01, p<.0001] and SOA [F (1, 28)= 46.69, p<.0001] as well as a significant SOA x group interaction [F (1, 28)= 8.75, p<.01] reflecting a larger decline in RTs across SOAs (the foreperiod effect) for children. The validity effect was marginally significant [F (1, 28)= 4.15, p<.052] as was the three-way interaction between age group, SOA, and validity [F (1, 28)= 3.3, p<.07]. Four directional paired t-tests were conducted to compare mean RT for cued and uncued conditions across both SOA intervals for adults and children. The analysis indicated that, indeed, significant orienting effects were present at both SOAs.
of 100 and 900 ms for adults and only at an early SOA of 100 ms for children [all ps < .05].

Discussion

There are several findings worth noting in the present investigation. First, the data with nonpredictive arrow cues replicated those reported by Ristic, Friesen & Kingstone (2002), demonstrating again that children and adults alike will shift their attention to the location indicated by a nonpredictive arrow cue. Also in agreement with Ristic et al. (2002), it was observed that with a nonpredictive arrow cue the difference between cued and uncued target locations tends to grow for children as the cue-target SOA is increased.

Second, and in agreement with Brodeur and Enns (1997), the present study found that when the arrow cue was predictive, although both children and adults produced similar performance patterns, the effect of the cue declined substantially across SOAs for children, but the effect of the cue increased across SOAs for adults.

Third, by comparing these performances with nonpredictive and predictive arrow cues against performance with a predictive nondirectional shape cue, several important insights regarding attentional orienting were revealed. For adults, the cuing effect for a predictive arrow cue was found to exceed what would be expected by adding the reflexive attentional effect produced by a nonpredictive arrow cue and the volitional attentional effect produced by a predictive shape cue. As was reported previously in Chapter 1, reflexive and volitional components appear to interact to produce a larger cuing effect for predictive arrows than would be expected based on pure measures of the two components alone. In contrast, for children we found that the volitional attention effect for a shape cue was significant only at the 100 ms, consistent with the proposal of Brodeur and Enns (1997) that this form of orienting can only be sustained briefly by children younger than 8 years of age. Moreover, and again in
contrast with adults, it appears that the cuing effect of a predictive arrow reflects precisely what would be expected by adding the reflexive attentional effect produced by a nonpredictive arrow cue and the volitional attentional effect produced by a predictive shape cue (see Figure 2c). Indeed, it appears that the cuing effect observed for children with a predictive arrow at the 900ms SOA reflects the residual presence of reflexive orienting, as there is no volitional component present at this long SOA for a predictive shape cue, and the cuing effect for a predictive arrow converges with the cuing effect of a nonpredictive arrow.

To summarize, our data demonstrate that reflexive attention operates in a very similar manner for adults and children, but that endogenous attention operates and combines with reflexive attention differently between these two groups. Adults can orient attention endogenously for a sustained period of time; and when this form of orienting is combined with reflexive attention to a directional stimulus, the results is a superadditive interaction for predictive arrow cues. Children younger than 6 years, on the other hand, can also orient attention endogenously, but only for a brief period of time; and when this form of orienting is combined with reflexive attention to a direction stimulus, the two effects are additive. This finding suggests that the superadditive interaction with predictive arrow cues, that is observed with adults but not with children, may depend on the development of sustained, adult-like, volitional orienting.

These similarities and differences between adults and children as a function of type of attentional orienting dovetail with the fields’ current understanding of the maturation of the brain areas that subserve reflexive and volitional orienting. Research results to date indicate that because reflexive orienting is mediated by early developing subcortical and cortical brain areas, such as the superior colliculus and the parietal lobe, its presence can be behaviorally measured shortly after birth (e.g., Clohessy, Posner, Rothbart & Vecera, 1991; Johnson, Posner & Rothbart, 1991; Valenza, Simion & Umilta,
Moreover, when performance of adults and young children is compared behaviorally in a cuing paradigm, little or no differences are observed between the two groups of participants (Enns & Brodeur, 1989; Brodeur, Trick & Enns, 1997; Ristic et al., 2002). In contrast to reflexive orienting, voluntary attention develops much slower and exhibits adult-like properties only about 8 years of age (e.g., Brodeur, Trick & Enns, 1997; Goldberg, Maurer & Lewis, 2001). This agrees with the notion that controlled attention is mediated by mechanisms residing within the frontal cortex (e.g., Corbetta & Shulman, 2002), a brain region that matures more slowly than the parietal cortex or the superior colliculus (Johnson, 1997). Rudimentary control of volitional attention can be observed in infancy, with newborns able to make anticipatory saccades towards the interesting objects in the environment (e.g., Johnson, Posner & Rothbart, 1991; Hood, Atkinson & Braddik, 1998; Posner, 2001). However, when volitional orienting is examined using attentional cuing tasks, the results reported here and in the literature, indicate that at age 6 years voluntary orienting is still too immature to produce anything but short-lived orienting effects that quickly decrease in magnitude over time (Brodeur & Enns, 1997).
References


