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# The Cognitive Mechanism of Interaction between Cue Perception and Visual Attention

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# Abstract

## The Cognitive Mechanism of Interaction between Cue Perception and Visual Attention

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Attention is a highly efficient system to allow us to locate the most significant objects continuously and to direct our mental resources on them. Especially, we are depending on visual attention to focus on what is relevant and to respond appropriately under most circumstances. Orienting, shifting, and dwelling of the attention concern to the way in which attention is allocated over the visual field and reallocated from time to time. Commonly, attention orienting and shifting happened after perceiving an attentional cue, which indicated incoming events that are important for behavior.

This thesis systematically explored the four important issues about the attention orienting by symbolic cues, which have not been clearly addressed in the previous literatures. Specifically, the spatial cueing paradigm was used. Participants responded to a peripheral target while a central cue (e.g., a pointing arrow or an averted gaze) indicated the possible target locations. The magnitude of attention orienting was measured by cueing effect, i.e., participants' RT (reaction time) in valid trials minus RT in invalid trials.

The first issue is associated with the origin of gaze-evoked attention orienting. Although gaze-cueing effect was usually attributed to mechanisms specialized for gaze perception, this view was challenged by the results of recent studies. Because averted

gaze stimuli have an asymmetric layout in nature, it is still not clear whether gaze-evoked cueing effects are simply due to spatial compatibility that originates from asymmetric local-feature information of the eyes, or due to gaze perceptual systems that specialized for social cognition. In this thesis, a novel method was used to discriminate between the two possibilities of gaze-cueing effect.

The second issue focuses on the sequence effects between two consecutive cueing processes in arrow cueing. The traditional way for measuring attention orienting ignored another important influence on the cueing effect: the influence of previous trial types on current trial performance. Such sequence effects are important because they may reflect some temporal characteristics of attention orienting in humans.

In the third issue, a gaze cue is used to further investigate the sequence effects in cueing paradigm. Another person's gaze has been considered as a special attentional cue for its biological significance. The results will help to reveal the universality of sequence processing and provide better understanding of human cognition systems.

The fourth issue is aimed to explore the detailed mechanisms under the sequence effects of cueing paradigm. Between two consecutive trials, there are three variable factors: cue validity, cue direction, and target location. Previous studies only focused on the repetition/switch effect of cue validity, it is still not clear whether the sequence effects modulated by the repetition/switch effect of cue direction and target location. A more detailed and accurate understanding of sequence processing can be acquired based on this investigation.

The major contribution of the thesis can be summarized briefly as: (1) This thesis systematically performed a comprehensive survey on the latest studies and findings related to the attention orienting. (2) The experiments were conducted to

investigate the four important issues; the experimental results provide the further insight into the mechanisms of human visual attention system and towards a better understanding about the spatial cueing paradigm. (3) The academic attributions of the present findings and the possible future inquiry were discussed.

**Key words**

Visual attention, Attention orienting, Cueing effect, Gaze perception, Sequence effect

# Contents

<b>Chapter 1</b> .....	1
<b>General Introduction</b> .....	1
<b>1.1 Visual attention and attention orienting</b> .....	1
<b>1.2 The spatial cueing paradigm</b> .....	3
<b>1.3 Research motivations</b> .....	7
<b>Chapter 2</b> .....	10
<b>Gaze cueing as a function of perceived gaze direction</b> .....	10
<b>2.1 Introduction</b> .....	10
<b>2.2 Experiment 1</b> .....	14
<b>2.2.1 Participants</b> .....	14
<b>2.2.2 Apparatus</b> .....	15
<b>2.2.3 Stimuli</b> .....	15
<b>2.2.4 Design</b> .....	17
<b>2.2.5 Procedure</b> .....	17
<b>2.2.6 Results</b> .....	18
<b>2.2.7 Discussion</b> .....	20
<b>2.3 Experiment 2</b> .....	21
<b>2.3.1 Participants</b> .....	21
<b>2.3.2 Apparatus and stimuli</b> .....	21
<b>2.3.3 Design and procedure</b> .....	22
<b>2.3.4 Results and discussion</b> .....	22
<b>2.4 General Discussion</b> .....	24
<b>Chapter 3</b> .....	28
<b>Sequence effects by non-predictive arrow cues</b> .....	28
<b>3.1 Introduction</b> .....	28

<b>3.2 Method</b> .....	35
<b>3.2.1 Participants</b> .....	35
<b>3.2.2 Apparatus</b> .....	35
<b>3.2.3 Stimuli</b> .....	36
<b>3.2.4 Design</b> .....	36
<b>3.2.5 Procedure</b> .....	36
<b>3.3 Results</b> .....	37
<b>3.3.1 Errors</b> .....	37
<b>3.3.2 Cueing effects</b> .....	37
<b>3.3.3 Sequence effects of previous cue validity</b> .....	37
<b>3.3.4 Influence of previous and current SOAs on sequence effects</b> .....	38
<b>3.3.5 Influence of previous catch trials</b> .....	40
<b>3.3.6 Control tasks</b> .....	41
<b>3.4 Discussion</b> .....	42
<b>Chapter 4</b> .....	50
<b>Sequence effects of gaze cueing</b> .....	50
<b>4.1 Introduction</b> .....	50
<b>4.2 Experiment 1</b> .....	53
<b>4.2.1 Participants</b> .....	53
<b>4.2.2 Apparatus</b> .....	53
<b>4.2.3 Stimuli</b> .....	53
<b>4.2.4 Design</b> .....	54
<b>4.2.5 Procedure</b> .....	55
<b>4.2.6 Results</b> .....	55
<b>4.2.7 Discussion</b> .....	58
<b>4.3 Experiment 2</b> .....	58
<b>4.3.1 Participants</b> .....	58
<b>4.3.2 Apparatus and stimuli</b> .....	59
<b>4.3.3 Design and procedure</b> .....	59
<b>4.3.4 Results</b> .....	60

4.3.5 Discussion .....	64
4.4 Experiment 3 .....	65
4.4.1 Participants .....	65
4.4.2 Apparatus and stimuli.....	65
4.4.3 Design and procedure.....	65
4.4.4 Results and discussion .....	66
4.5 Experiment 4 .....	67
4.5.1 Participants .....	67
4.5.2 Apparatus and stimuli.....	68
4.5.3 Design and procedure.....	68
4.5.4 Results and discussion .....	68
4.6 General Discussion .....	69
<b>Chapter 5 .....</b>	<b>74</b>
<b>The functional role of alternation advantage in the sequence effect of arrow cueing .....</b>	<b>74</b>
5.1 Introduction .....	74
5.2 Experiment .....	79
5.2.1 Participants .....	79
5.2.2 Apparatus .....	79
5.2.3 Stimuli.....	80
5.2.4 Design.....	80
5.2.5 Procedure .....	80
5.3 Results.....	81
5.4 Discussion .....	84
<b>Chapter 6 .....</b>	<b>87</b>
<b>General Conclusion and Future Inquiries.....</b>	<b>87</b>
6.1 General conclusion .....	87
6.2 Future Inquiries.....	91

<b>Acknowledgment</b> .....	93
<b>References</b> .....	94
<b>Publications</b> .....	101



## List of Figures

- 1-1.** The four types of attentional shift. Controlled attention represents a voluntary shift and automatic attention represents an involuntary shift.....2
- 1-2.** Basic spatial cueing paradigm, using a peripheral sudden-onset cue (Panel A) or a central symbolic cue (Panel B). In panel A, the target appears in the previously cued location (valid trial), whereas Panel B shows an invalid trial in which the target appears in the uncued location.....3
- 1-3.** Basic gaze-cueing paradigm, using a schematic drawing (Panel A) or a real face photograph (Panel B). Panel A shows a valid trial and Panel B shows an invalid trial.....7
- 2-1.** Illustration of stimuli tested in experiment 1 and 2. Only one of the cued directions (either left or right) was illustrated. ....15
- 2-2.** Mean reaction times (RTs) for all cue conditions in experiment 1. The asterisk marks the statistically significant differences (significant level 0.05). ....18
- 2-3.** Panel A: Mean ratings of the perceived gaze direction under different face contexts in experiment 1. The vertical axis represents the perceived gaze direction, from 0 (i.e., direct gaze) to 5 (i.e., left or right gaze). Panel B: The magnitude of cueing effects under different cue types in experiment 1. The asterisk marks the statistically significant differences (significant level 0.05). Error bars denote standard errors of the mean.....19
- 2-4.** Mean reaction times (RTs) for all cue conditions in experiment 2. Panel A: Arrow cue condition. Panel B: Inverted face condition. The asterisk marks the statistically significant differences (significant level 0.05). ....23
- 3-1.** Mean reaction times (RTs) under different previous and current cue validity, previous and current SOAs.....39

<b>3-2.</b> The magnitude of cueing effects (RTuncued-RTcued) under different previous cue validity, previous and current SOAs. The asterisks mark the statistically significant differences (significant level 0.05). Error bars denote standard errors of the mean. ....	40
<b>4-1.</b> Panel A: Stimuli illustration in present experiments. Panel B: Illustration of the sequence of events in a cued trial of experiment 1.....	54
<b>4-2.</b> Results of experiment 1 with schematic gaze cues. Panel A: The magnitude of cueing effects (mean RTuncued -RTcued) for trials preceded by cued or uncued trials with different SOAs. Error bars denote standard errors of the mean. Panel B: RTs of trials preceded by cued or uncued trials with different cue validities. The asterisk marks the statistically-significant differences (significant level 0.05 and 0.0001). Error bars denote standard errors of the mean. ....	57
<b>4-3.</b> Results of experiment 2. Panel A1 and B1 are gaze-cue condition and Panel A2 and B2 are arrow-cue condition. The meaning of the graph is the same as Figure 4-2. ....	61
<b>4-4.</b> The magnitude of cueing effects for trials preceded by cued or uncued trials with different repetition conditions of cue direction between trials in experiment 2. ....	64
<b>4-5.</b> Results of experiment 3. The meaning of the graph is the same as Figure 4-2. ....	66
<b>4-6.</b> Results of experiment 4. The meaning of the graph is the same as Figure 4-2. ....	69
<b>5-1.</b> The magnitude of cueing effects (RTuncued-RTcued) under different previous cue validity, and cue manipulation conditions. The asterisks mark the statistically significant differences (significant level 0.05 and 0.01). Error bars denote standard errors of the mean. ....	82

**5-2.** The magnitude of cueing effects under different repetition conditions of cue direction when the cue directions remain random. The asterisk marks the statistically significant differences (significant level 0.001). Error bars denote standard errors of the mean.....83

## List of Tables

<b>5-1.</b> The possible combinations of cue direction (Left or Right) and target location (Left or Right) between trial n-1 and trial n. The repetitions of validity, cue direction, or target location between trial n-1 and trial n were marked with an asterisk. ....	76
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# Chapter 1

## General Introduction

### 1.1 Visual attention and attention orienting

We are attentive when our minds are directed at something specific, such as when searching for a face in a crowd, listening to a particular conversation at a noisy party, or trying to focus on this page rather than many other things in the room. Attention is a highly efficient system for allowing us to continuously locate the most significant objects and direct our mental resources at these. Especially, we are depending on visual attention to focus on what is relevant and respond appropriately under most circumstances. The attentional system is so efficient that typically its activity goes unnoticed. However, the investigation of attention is essential for understanding human cognition systems, and psychologists have tried to uncover the mechanisms of visual attention for a long time.

The main character of attention is selectivity: to choose only the most important information for consciousness and behavior response. The selectivity is important for humans because we have capacity limitations when processing the information that is picked up by the eyes every moment. The selection of attention is directly related with the dynamics of deploying and reallocating attention. This gives rise to the questions, such as ‘How attention allocates?’ and ‘What controls the attention allocation from one region of the visual fields to another?’.

Orienting, shifting, and dwelling of the attention concern to the way in which attention is allocated over the visual field and reallocated from time to time. Attention

orienting can be goal-driven, in which case it is allocated on the basis of current task demands and expectations of the observers. It also can be stimulus-driven, in which case attention is guided by the properties of the stimuli in the visual field. In line with these two forms of attentional control, Posner (1980) proposed two separate orienting systems: endogenous orienting and exogenous orienting. Endogenous orienting is goal-driven (top-down); it is under the voluntary control of the observers. Exogenous orienting is stimulus-driven (bottom-up); it is automatic and reflexive without voluntary intervention (Klein, Kingstone, and Pontefract, 1992). From another perspective, a shift of attention can be accompanied by an eye movement (overt orienting), or attention can shift without a corresponding saccade (covert orienting). As a result, there have four distinct types of attention orienting (see Figure 1-1).

**ORIENTING**

	OVERT	COVERT
EXOGENOUS (bottom-up)	Involuntary saccade	Automatic attention
ENDOGENOUS (top-down)	Voluntary saccade	Controlled attention

Figure 1-1. The four types of attentional shift. Controlled attention represents a voluntary shift and automatic attention represents an involuntary shift.

Commonly, visual attention is evolved in the processing of the information that is present in our natural environment, but the real-world situations is typically too complex to be studied scientifically. Therefore, experimental psychologists usually try to isolate a few essential properties of a real-world situation to study under controlled

conditions in the laboratory. For example, the common task of searching a room for a particular object can be simplified as a response task, in which the appropriate button is pressed according to the existence of a simple target among several distractor objects in a computer display. The next section will introduce a famous paradigm that is used by many psychologists to investigate the mechanisms under the attention orienting.

## 1.2 The spatial cueing paradigm

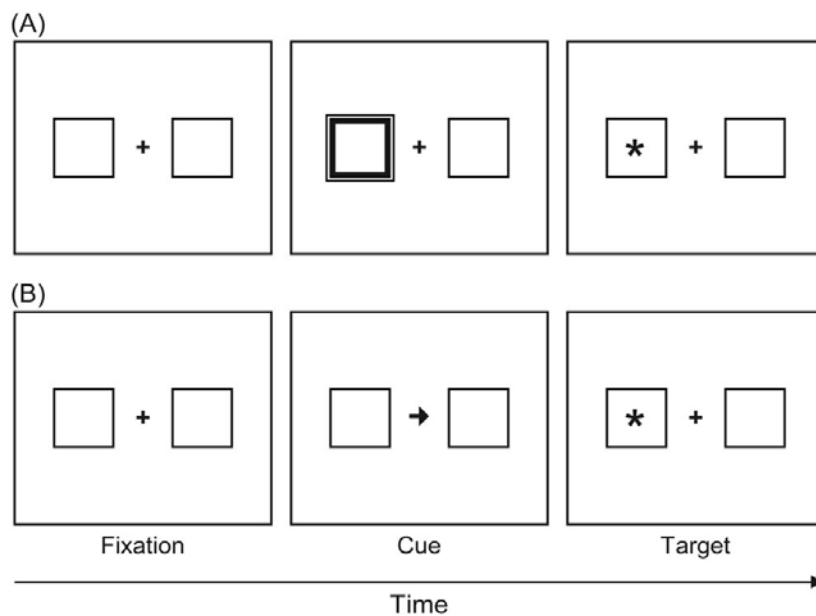


Figure 1-2. Basic spatial cueing paradigm, using a peripheral sudden-onset cue (Panel A) or a central symbolic cue (Panel B). In panel A, the target appears in the previously cued location (valid trial), whereas Panel B shows an invalid trial in which the target appears in the uncued location.

One famous experimental method to investigate attention orienting is spatial cueing paradigm (e.g., Posner, 1980). In a typical example of this paradigm (see Figure 1-2), participants are instructed to respond to the onset of a target that can appear to the left or right of the fixation point by making a rapid key-press response. Before the onset of the target, a cue that indicates one of the possible target locations is presented

for a certain time period (i.e., cue-target stimulus-onset asynchrony (SOA)). Faster reaction times (RTs) and/or more accurate performance with targets appearing in the cued location (compared with those in the uncued location) indicate attention shift to the cued location.

Traditionally, exogenous orienting and endogenous orienting are distinguished by using different cue types in spatial cueing paradigm. A peripheral cue (i.e., an exogenous cue), such as a sudden change of luminance, texture, motion, or depth in periphery, is assumed to automatically attract attention (e.g., Oonk and Abrams, 1998; Yantis and Hillstrom, 1994). A basic peripheral cueing paradigm can be illustrated by the Figure 1-2(A). Two empty placeholder boxes are showed to the left and right of the central fixation point. Before a target appears randomly in either box, the outline of one of the peripheral boxes is briefly brightened. The abrupt increase in luminance of the peripheral box is assumed to trigger a reflexive attention shift to the cued location, thus facilitating stimulus processing at that point in space. Specifically, RTs are faster when the target occurs in the box that had been brightened compared with targets in the opposite box. This type of orienting occurs rapidly even though it is not predictive of the actual target location. Furthermore, the cueing effect is not disrupted even if the participants know that the target is more likely to appear in the uncued location (Jonides, 1981; Remington, Johnston, and Yantis, 1992). In contrast to the automatic control of attention by exogenous cues, orienting in response to centrally presented symbolic cues (i.e., endogenous cues) appears to be under voluntary control of the observers. The central cues can be an arrow pointing to one direction (see Figure 1-2(B)) or other semantic cues such as a word indicating the likely target location (e.g., 'LEFT'). Unlike peripheral cues, these central cues do not directly indicate a spatial location but



rather require interpretation. Many early studies found that the cueing effect of central cues only appear when it is correctly predicted the target location on most trials (e.g., Jonides, 1981; Posner, Snyder, and Davidson, 1980). In other words, voluntary control of the observers is needed to orient attention in the direction of the cue.

The exogenous orienting and endogenous orienting appear to be involved different neural systems. Exogenous orienting is assumed to be mainly subserved by a posterior attention system involving subcortical structures such as the pulvinar and the superior colliculus (Posner, Cohen, and Rafal, 1982; Rafal, Calabresi, Brennan, and Sciolto, 1989). Endogenous orienting is probably supported more strongly by cortical areas in anterior (Carr, 1992; Corbetta et al., 1993) and posterior regions of the brain (Corbetta, Kincade, Ollinger, McAvoy, and Shulman, 2000). These two systems are assumed to interact, thus allowing salient sensory events to attract attention in a bottom-up fashion and to interrupt top-down control of the ongoing task (Corbetta and Shulman, 2002).

Another difference between exogenous and endogenous cues is the different time course of attention orienting. The initial beneficial effect of peripheral cues on target detection emerges rapidly but short lived, it reaches maximal facilitation effects at 100 ms and declines between 150 ms and 300 ms after cue onset (Müller and Findlay, 1988, Cheal and Lyon, 1991). Furthermore, this initial facilitation is overcome by inhibitory effects at longer cue-target SOAs. Inhibition refers to that RTs to targets on valid trials are now slower than on invalid trials (inhibition of return (IOR); Maylor, 1985; Maylor and Hockey, 1985; Posner and Cohen, 1984). This IOR effect is believed to aid the detection of new events in the environment by preventing attention from repeatedly returning to a location that has already been examined. In comparison, the RT

facilitation effect of endogenous cues sets up slowly and remains stable for long SOAs. The effect reaches maximal at SOAs of around 300 ms, and no inhibition effect is found even at longer SOAs.

Although early studies suggested that endogenous cues, such as arrows, can shift attention only when they explicitly predicted the target location, many later studies have obtained cueing effects even with spatially non-predictive arrow cues (e.g, Hommel et al., 2001; Pratt and Hommel, 2003; Ristic, Friesen, and Kingstone, 2002; Tipples, 2002). Furthermore, several studies have found cueing effects at short SOAs when the arrow counter-predicts the target location (e.g., Hommel et al., 2001; Tipples, 2008), which means arrow cueing could not be suppressed in the same way as peripheral cueing. These results suggest that orienting in response to endogenous cues is also reflexive and does not require voluntary control.

One fascinating finding of recent studies about endogenous cues is the significant cueing effects by centrally-presented gaze cues (see Figure 1-3). It seems that the encoding and interpretation of another person's gaze direction enables the observer to detect that person's focus of attention and to align their own attention accordingly. Friesen and Kingstone (1998) explored whether observed gaze shifts produce orienting in adults. Participants were asked to respond to target letters that appeared randomly to either the left or the right of a schematic face with varying SOAs after the pupils of the face appeared randomly to the left, right, or center of the eyes. Therefore, the eyes of the face looked either left, right, or straight ahead. On valid trials, the target appeared in the gazed-at location, whereas on invalid trials, it occurred in the opposite location. On neutral trials, the face gazed ahead, and the target appeared randomly on either side. Though percipients were informed that the direction of the gaze did not predict the

target location, the results showed that RT was facilitated on valid trials relative to neutral trials (i.e., cueing benefit), and the RT was slowed on invalid trials relative to neutral trials (i.e., cueing cost). This cueing effect occurred rapidly at short cue-target SOAs (105 ms and 300 ms) and disappeared with longer SOAs (1005 ms). Reflexive attention orienting by gaze was also found in many other studies, such as the studies using real faces as central cues (e.g., Driver et al., 1999; Downing, Dodds, and Bray, 2004), or the studies measuring saccades (e.g., Mansfield et al., 2003; Ricciardelli et al., 2002; Friesen and Kingstone, 2003b).

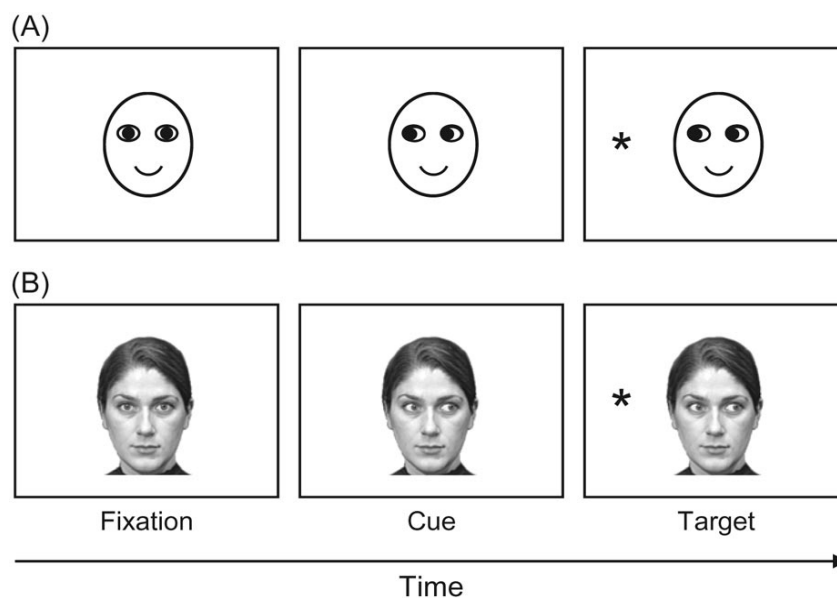


Figure 1-3. Basic gaze-cueing paradigm, using a schematic drawing (Panel A) or a real face photograph (Panel B). Panel A shows a valid trial and Panel B shows an invalid trial.

### 1.3 Research motivations

Though the previous cueing studies have contributed to our knowledge about attention orienting as well as the complex processes that allow different mechanisms

(e.g., gaze perception) to interact dynamically, there still have some important issues that have not been clearly addressed. The present thesis focuses on the attention orienting by centrally-presented symbolic cues, such as arrows and gazes, and tries to explore four important issues about it.

1. The contribution of low-level spatial compatibility and high-level gaze perception on the gaze-cueing effect
2. The sequence effects of arrow cueing
3. The sequence effects of gaze cueing
4. The influence of cue direction and target location on the sequence effects of arrow cueing

The first issue is associated with the origin of gaze-evoked attention orienting. Although gaze-cueing effects were usually attributed to mechanisms specialized for gaze perception (e.g., Friesen and Kingstone, 1998, 2003; Langton and Bruce, 1999), this view was challenged by the results of recent studies (see Birmingham and Kingstone, 2009, for a recent review). One important debate is that averted gaze stimuli have an asymmetric layout in nature (i.e., deviated pupil within eye socket), and this may have been allowing spatial correspondence between central cues and target locations to be automatically paired (Lambert, Roser, Wells, and Heffer, 2006; Lambert and Duddy, 2002), thus the asymmetric layout may have reflexively been cueing attention. Consequently, it is still not clear whether gaze-evoked cueing effects are simply due to spatial compatibility that originates from asymmetric local-feature information of the eyes, or due to perceptual systems that specialized for gaze perception. In this thesis, a novel method was used to discriminate between the two possibilities of the gaze-cueing effect.

The second issue focuses on the sequence effects between two consecutive cueing processes in arrow cueing. The traditional way for measuring attention orienting in a cueing paradigm ignored another important influence on the cueing effect: the influence of previous trial types on current trial performance. Such sequence effects are important because they may reflect some temporal characteristics of attention orienting in humans. Although several studies have investigated the sequence effects of cueing paradigm by either peripheral cues (Dodd and Pratt, 2007; Mordkoff, Halterman, and Chen, 2008) or arrow cues (Jongen and Smulders, 2006), their explanations are contradictory. In the present thesis, a modified arrow-cueing experiment was conducted to resolve this discrepancy.

In the third issue, a gaze cue was used to further investigate the sequence effect in cueing paradigm. Another person's gaze has been considered as a special attentional cue for its biological significance (e.g., Friesen and Kingstone, 1998, 2003). So far as I know, no one has explored whether the sequence effect of cueing paradigm can also be found when gaze stimuli are used as central cues. Such an investigation will help to reveal the universality of sequence processing and provide better understanding of human cognition systems.

The fourth issue was aimed to explore the detailed mechanisms under the sequence effect of cueing paradigm. Between two consecutive trials, there are three variable factors: cue validity, cue direction, and target location. Previous studies only focused on the repetition/switch effect of cue validity, it is still not clear whether the sequence effect is modulated by the repetition/switch effect of cue direction and target location. A more detailed and accurate understanding of sequence processing can be acquired based on such an investigation.

## Chapter 2

# Gaze cueing as a function of perceived gaze direction

### 2.1 Introduction

The eyes and the surrounding facial regions can communicate complex information about people's mental states, such as emotions, intentions, and desires. Gaze perception is a key tool for the guidance and interpretation of social behavior, and encoding of another person's gaze direction may be an integral part of a theory of mind (Baron-Cohen, 1995). Furthermore, people tend to automatically orient their attention to the object that other people are looking at. This gaze-following behavior appears very early in human life (Hains and Muir, 1996), and it is important in the development of social cognition (see Striano and Reid, 2006, for a review).

In behavior studies, the gaze-cueing paradigm, a modification of the traditional spatial cueing paradigm (Posner, 1980), has been used to investigate precise cognitive mechanisms underlying attention shifts in response to observed gaze direction (Friesen and Kingstone, 1998; see Frischen, Bayliss, and Tipper, 2007, for a recent review). In these studies, observers were presented with a centrally-presented face cue looking left or right, and after a certain cue-target stimulus onset asynchrony (SOA), were instructed to respond to the appearance of a target on the left or right of the screen. Although the observers were told that the gaze direction of the face stimulus did not predict where the target would occur, reaction time (RT) was reliably faster when the face's gaze was toward, rather than away from, the target. This facilitation of RT is referred to as the gaze-cueing effect, which is considered to be evidence of reflexive

attention orienting.

The fact that automatic shifts of attention could be triggered by centrally-presented, uninformative gaze cues has led some researchers to suggest that eye gaze is a special attentional cue for its biological significance, and gaze-cueing effects reflect the processing of specialized perception systems for social cognition (e.g., Friesen and Kingstone, 1998, 2003; Langton and Bruce, 1999).

However, the notion that gaze-cueing effects are attributed to the specialized processing for social cognition is challenged by recent studies (see Birmingham and Kingstone, 2009, for a recent review). One important debate is that averted gaze stimuli have an asymmetric layout in nature (i.e., deviated pupil within eye socket), and this may have been allowing spatial correspondence between central cues and target locations to be automatically paired (Lambert, Roser, Wells, and Heffer, 2006; Lambert and Duddy, 2002), thus reflexively cueing attention. Consequently, it is still not clear whether gaze-evoked cueing effects are simply due to spatial compatibility that originates from asymmetric local-feature information of the eyes, or due to perceptual systems that specialized for gaze perception.

Supporting the view that gaze-cueing effects may just a result of spatial compatibility between gaze directions and target locations, many studies have failed to show a significant influence of the face context on gaze cueing. In the study of Tipples (2005, 2006), the magnitude of the gaze-cueing effect was mainly determined by the local processing of the eye stimuli themselves, rather than the face context. Quadflieg, Mason, and Macrae (2004) found equivalent cueing effects for drawings of averted eyes within human faces, within animal faces (e.g., tiger, owl), or even within an apple or a gloved hand. Frischen and Tipper (2004) further showed that both the gaze-cueing

effect and the gaze-evoked inhibition effect they had obtained were not modulated by the identity of the face. In addition, many studies showed null effects of facial expression on gaze cueing (e.g., Hietanen and Leppänen, 2003; Bayliss, Frischen, Fenske, and Tipper, 2007; Fichtenholtz, Hopfinger, Graham, Detwiler, and LaBar, 2009).

Other evidence against the notion that gaze cueing involved special mechanisms for gaze perception came from researches examining whether other directional cues, such as arrows, produce automatic shifts of attention to the cued location. It was found that spatially non-predictive arrow cues also produce robust cueing effects that are very similar to those observed for gaze cues (e.g., Ristic, Friesen, and Kingstone, 2002; Tipples, 2002). Downing, Dodds, and Bray (2004, experiment 1) even found that a central face with its tongue pointing randomly left or right produced reflexive attention effects that were indistinguishable from gaze-cueing effects. This result prompted them to argue that gaze-cueing effects are not due to a specialized gaze perception mechanism and do not reflect the unique properties of gaze processing, but rather might depend on simple spatial and geometrical factors. Furthermore, though the fact that gaze cueing could not be suppressed (i.e., cueing effects were still induced despite of the observers' knowledge that targets were less likely to appear at the gazed location) was usually used as the evidence of the specialty of gaze cueing (e.g., Driver et al., 1999; Friesen, Ristic, and Kingstone, 2004), some other studies reported that arrow cueing also could not be suppressed (e.g., Hommel, Pratt, Colzato, and Godijn, 2001; Tipples, 2008). In all, the results of previous studies suggest that any cue having the potential for spatial compatibility with the target may produce reflexive orienting of attention, regardless of whether they are biological or non-biological. Therefore, it is necessary to investigate



whether the gaze-cueing effect is indeed attributed to high-level processes that involve gaze perception systems, or if it is just attributed to local-feature information of the eyes that brings spatial compatibility.

Previous researches on the perception of faces have repeatedly demonstrated that faces are processed in a holistic way and perceptions of different dimensions of the face (e.g., gaze direction, profile face orientation) interact with each other. For example, the processing of gaze direction was affected by the perceived face orientation (Langton, 2000; Langton, Watt, and Bruce, 2000), and the discrimination of gaze direction was found to be better when face and gaze were congruent than in other conditions (Langton, Honeyman, and Tessler, 2004). Therefore, perceiving of gaze direction is not solely determined by the local-feature of eyes, but is also affected by profile face contexts. Although several studies have tried to investigate the influence of profile face orientation on gaze cueing (e.g., Hietanen, 1999), these studies cannot be used to discriminate the influence of spatial compatibility from gaze perception, because both profile face context and eye region of their stimuli were changed across different conditions. In present study, the same eye region will be kept among different cue stimuli, and directly evaluate the influence of profile face contexts on the perceived gaze directions. Through this way, the change of the magnitude of gaze-cueing effects only can be attributed to the change of perceived gaze directions, rather than the low-level spatial compatibility of the eye stimulus.

The primary aim of the present study is to examine whether the change of perceived gaze directions by profile face contexts influences the size of gaze-cueing effects. In experiment 1, a stimulus of eye region was used to provide gaze cues, and then it was pasted onto three kinds of face contexts: a frontal face, a congruent-oriented

profile face, or an incongruent-oriented profile face. Though the local-feature information of the eye region was identical, the perceived gaze direction was changed depending on the orientation of the profile face contexts (Langton, 2000). If the gaze-cueing effect is based on high-level gaze perception systems, the magnitude of cueing effects should be modulated by the perceived gaze direction, even when the local-feature information of the eyes was identical. If the gaze-cueing effect is induced by spatial compatibility between gaze cues and targets, the face contexts that only affect the perceived gaze direction should have no influence on the gaze-cueing effect.

Furthermore, it is possible that a profile face context itself has introduced spatial compatibility toward the direction that it is oriented (see Figure 1). Therefore, even when the influence of the profile face contexts is observed, it can be explained as the interaction between the two kinds of spatial compatibilities (i.e., from the eye region and from the face context). In experiment 2, two control conditions were tested to show whether the spatial compatibility of the profile face contexts could influence the cueing effect.

## **2.2 Experiment 1**

### **2.2.1 Participants**

A total of 16 students (with a mean age of 27 years, range 22 to 31 years, 4 females) from Kochi University of Technology consented to participate in this experiment. All participants reported normal or corrected-to-normal vision and were naive as to the purpose of the experiment.

### 2.2.2 Apparatus

The stimuli were presented on a LCD display operating at a 60 Hz frame rate that was controlled by a Dell Pentium computer. The participants were seated approximately 60 cm away from the screen.

### 2.2.3 Stimuli

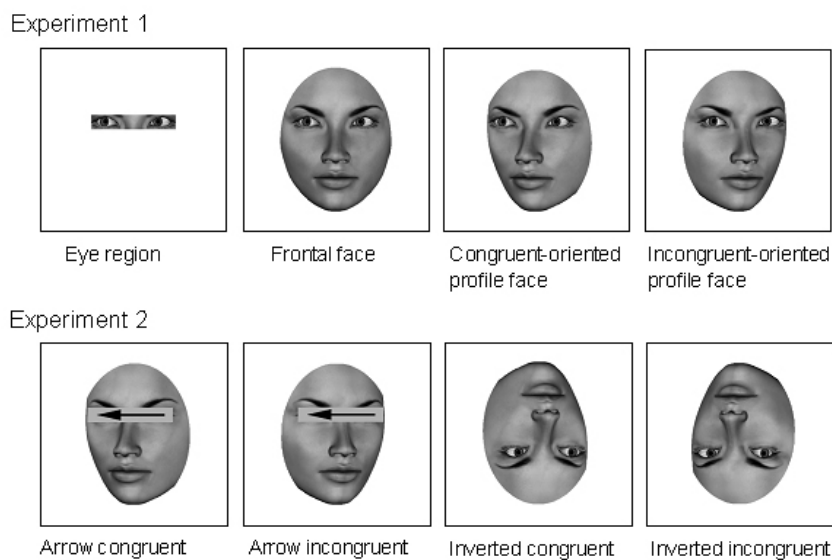


Figure 2-1. Illustration of stimuli tested in experiment 1 and 2. Only one of the cued directions (either left or right) was illustrated.

A cross, subtending  $0.5^\circ$ , was placed at the center of the screen as a fixation point. The target stimulus was a black capital letter 'T' measuring  $0.7^\circ$  wide,  $1^\circ$  high, and was presented  $15^\circ$  away from the fixation point on the left or right side. As illustrated in Figure 1, grayscale pictures of an eye region, a frontal face, a congruent-oriented profile face, and an incongruent-oriented profile face were included as four central cue conditions. The cue stimulus of eye region was presented  $2^\circ$  in height and  $11^\circ$  in width, while the cue stimuli of face contexts were presented  $18^\circ$  in height and  $14^\circ$  in width. During the experiment, the presentation of the cue stimuli was aligned so that the

fixation point was located on the center of the eye region between the eyes. The female 3D model was created by Poser 7.0 software, which provided a precise way to reduce the influence of low-level differences (e.g., light, shadow, and edges) between different stimuli. The eye stimulus was created by cutting the eye region from a frontal face that gazed at 15° left or right. After that, the eye region was pasted onto another frontal face with direct gaze to create the frontal face stimulus, and was pasted onto the 15° left-orienting or right-orienting profile faces to create the profile face stimuli. In order to reduce the image artifacts, the pixels around the edges of the eye region within the frontal or profile face contexts were carefully blurred using Photoshop CS2 software. However, the pixels of the eye region itself were not changed. Therefore, the local-feature information of the eye region was identical for all stimuli.

In order to ensure the perceived gaze direction was influenced by the face context, 20 participants were required to evaluate the gaze direction of the stimuli. The angle of gaze direction was rated from 0 (i.e., direct gaze) to 5 (i.e., left or right gaze). The average ratings for the four stimuli were 2.9 (eye region), 2.6 (frontal face), 3.4 (congruent-oriented profile face), 1.9 (incongruent-oriented profile face), and the ratings did not significantly differ for the left and right gazing stimuli. Paired samples t-test proved that the rating of the congruent-oriented profile face was significantly higher than the eye region and the frontal face ( $p < .049$ ), and the rating of the incongruent-oriented profile face was significantly lower than the other three stimuli ( $p < .038$ ). In other words, the gaze direction of the eye stimulus embedded in a congruent-oriented profile face context was perceived to be averted more toward left or right, and the gaze direction of the eye stimulus embedded in an incongruent-oriented profile face context was perceived to be closer to direct gaze. The perceived gaze

directions under different face contexts are illustrated in Figure 2-3(A). In addition, in order to confirm that pasting the eye region onto the face contexts did not bring perceptual segregation of the eye region, the participants were also instructed to evaluate whether the frontal face, congruent-and incongruent-oriented profile faces contained image artifacts that made them unnatural or different from each other. As a result, none of the participants reported that the stimuli had notable artifacts or that the artificial levels of the stimuli were different.

#### **2.2.4 Design**

The cue-target SOAs were 300 and 600 ms. On each trial, cue condition, gaze direction, target location, and SOA duration were selected randomly and equally. There were four blocks with 128 trials each. Including 20 training trials, there were in total 532 trials for each participant.

#### **2.2.5 Procedure**

Participants were instructed to keep fixating on the center of the screen. First, a fixation display appeared at the center of the screen for 1000 ms, and then the cue stimulus appeared. After a certain cue-target SOA, a target letter ‘T’ appeared at either left or right until participants had responded or 1500 ms had elapsed. Participants were instructed to indicate the target location by pressing the ‘z’ key for a left target and the ‘/’ key for a right target as quickly and accurately as possible. The localization task was used to increase the sensitivity to the compatibility effect, because the central cue and the response could also be automatically paired (Ansorge, 2003). Participants were informed that the central stimuli did not predict the location in which target would

appear, and should be ignored.

## 2.2.6 Results

Anticipations (RT of less than 100 ms) and outliers (RT over 1000 ms) were classified as errors and were excluded from analysis. As a result, about 0.75% of all trials were removed. The error rates did not vary systematically and no signs of any speed-accuracy trade-off were observed.

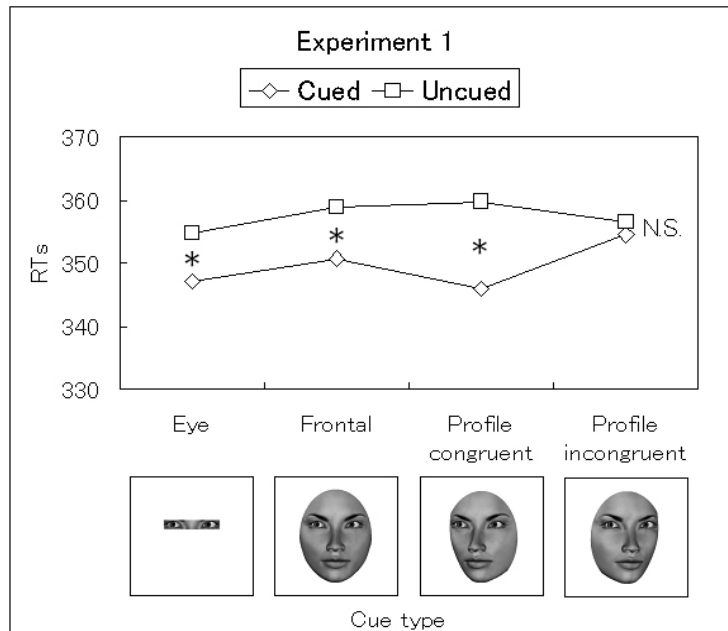


Figure 2-2. Mean reaction times (RTs) for all cue conditions in experiment 1. The asterisk marks the statistically significant differences (significant level 0.05).

Median RTs were calculated for each participant. The means of these RTs are illustrated in Figure 2-2. A three-way ANOVA was conducted on the RTs with cue type (eye region, frontal face, congruent-oriented profile face, and incongruent-oriented profile face), SOA (300 and 600 ms), and cue validity (cued and uncued) as within-participants factors. There was a significant main effect of cue validity,  $F(1, 15) = 104.275$ ,  $p < .0001$ , indicating gaze-cueing effects, i.e., RTs were shorter at cued than

at uncued trials. The main effect for SOA was significant,  $F(1, 15) = 94.459, p < .0001$ , with RTs becoming shorter as the SOA was increased. The main effect of cue type was also significant,  $F(3, 45) = 4.731, p < .006$ , indicating that RTs were relatively fast when only eye region was presented as a central cue. Importantly, the cue type  $\times$  cue validity interaction was significant,  $F(3, 45) = 7.924, p < .0001$ , indicating that different cue types induced different cueing effects. No other factors or interactions were significant.

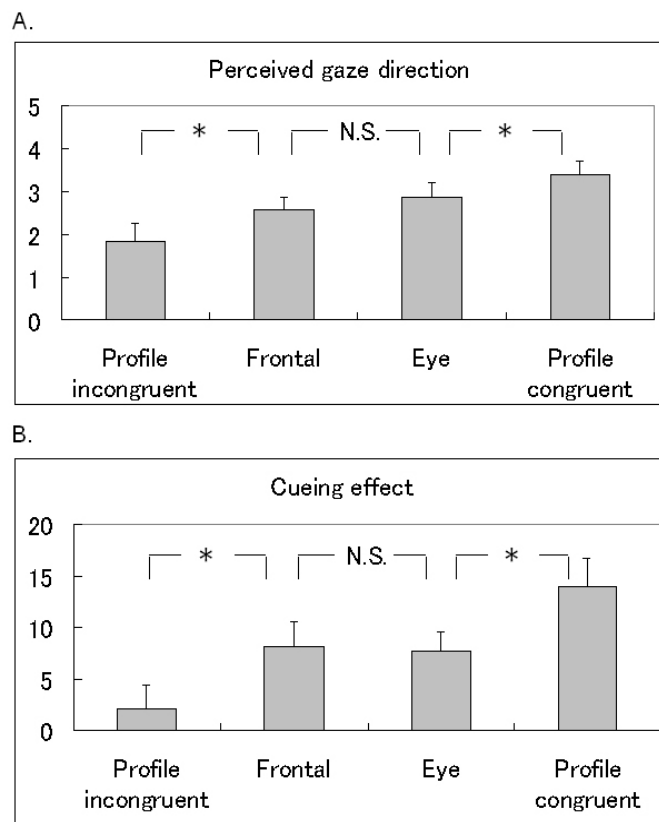


Figure 2-3. Panel A: Mean ratings of the perceived gaze direction under different face contexts in experiment 1. The vertical axis represents the perceived gaze direction, from 0 (i.e., direct gaze) to 5 (i.e., left or right gaze). Panel B: The magnitude of cueing effects under different cue types in experiment 1. The asterisk marks the statistically significant differences (significant level 0.05). Error bars denote standard errors of the mean.

To further investigate the influence of cue types on cueing effects, a paired-samples *t*-test was used to compare the magnitude of cueing effects between different cue types.

The difference between the eye region (average cueing effect = 7.69 ms) and the frontal face (8.12 ms) did not reach significance,  $t(15) = 0.262$ ,  $p > .79$ . However, the congruent-oriented profile face induced a stronger cueing effect (13.93 ms) than the eye region and the frontal face ( $ps < .038$ ). On the other hand, the incongruent-oriented profile face induced a weaker cueing effect (2.07 ms) than the eye region, the frontal face, and the congruent-oriented profile face ( $ps < .035$ ). The magnitude of cueing effects under different cue types is illustrated in Figure 2-3(B).

### **2.2.7 Discussion**

The results showed that the orientation of the profile face contexts influenced the perceived gaze directions, which in turn influenced the magnitude of gaze-cueing effects. Because the local-feature information of the eye region is remained the same for all stimuli, the results cannot be attributed to the low-level spatial characteristics of the eye region, but to high-level gaze perception, which was based on the holistic processing of the eye region and the face context.

However, because a profile face context itself has an asymmetric layout, the different presentation area of the surface between left and right of the screen, or the facial features of the profile face, such as the side-oriented nose or mouth, may have induced spatial compatibility effects as well. Therefore, the different cueing effects between congruent and incongruent-oriented profile faces may have been due to the fact that the two kinds of spatial compatibilities (i.e., from the eye region and from the face context) along the same axis interacted with each other, thus enhancing cueing effects when they were congruent and reducing cueing effects when they were incongruent. Experiment 2 aimed to clarify this possibility by testing two control conditions. In the



first condition, an arrow, which was embedded in a congruent-oriented or an incongruent-oriented profile face context, was tested. If the profile face context brings spatial compatibility, stronger cueing effects should be observed when the arrow and the profile face context are congruent-oriented than when they are incongruent-oriented. In the second condition, inverted congruent-and incongruent-oriented profile faces were tested. Inverting the face has been suggested to disrupt holistic processing (Bartlett and Searcy, 1993), while the low-level spatial information is kept. If the results of experiment 1 are based on low-level compatibility effects, similar results should be observed even when the congruent-and incongruent-oriented profile faces are inverted.

## **2.3 Experiment 2**

### **2.3.1 Participants**

A total of 22 students (with a mean age of 26 years, range 22 to 29 years, 4 females) from Kochi University of Technology consented to participate in this experiment. Twelve of them participated in the arrow cue condition, and ten of them participated in the inverted face condition. All participants reported normal or corrected-to-normal vision and were naive as to the purpose of the experiment.

### **2.3.2 Apparatus and stimuli**

The apparatus was the same as that in experiment 1. In arrow cue condition, the central cue stimuli were created by an arrow embedded in a congruent-oriented or an incongruent-oriented profile face context. In inverted face condition, the central cue stimuli were the inverted edition of the congruent-and incongruent-oriented profile

faces that had been used in experiment 1. Though the stimuli were inverted, the fixation point was still on the central region between the eyes. The stimuli are illustrated in Figure 1.

In order to ensure the inversion disrupted the holistic processing of the faces, ten participants were asked to rate the gaze direction of the inverted faces (from 0 (i.e., direct gaze) to 5 (i.e., left or right)), the results showed that though the perceived gaze direction was still averted (3.9 and 3.7 for congruent-and incongruent-oriented faces, respectively), there was no significant difference between congruent-and incongruent-oriented profile faces after inversion ( $p > .30$ ).

### **2.3.3 Design and procedure**

The design and procedure were the same as those in experiment 1, with the following differences. Participants joined one of the two experimental conditions. For either condition, there were two blocks with 128 trials each. Including 20 training trials, there were in total 276 trials for each participant.

### **2.3.4 Results and discussion**

Error calculation was identical with experiment 1. About 0.85% and 0.5% of all trials were removed as errors in the two experimental conditions, respectively. The error rates did not vary systematically and no signs of any speed-accuracy trade-off were observed.

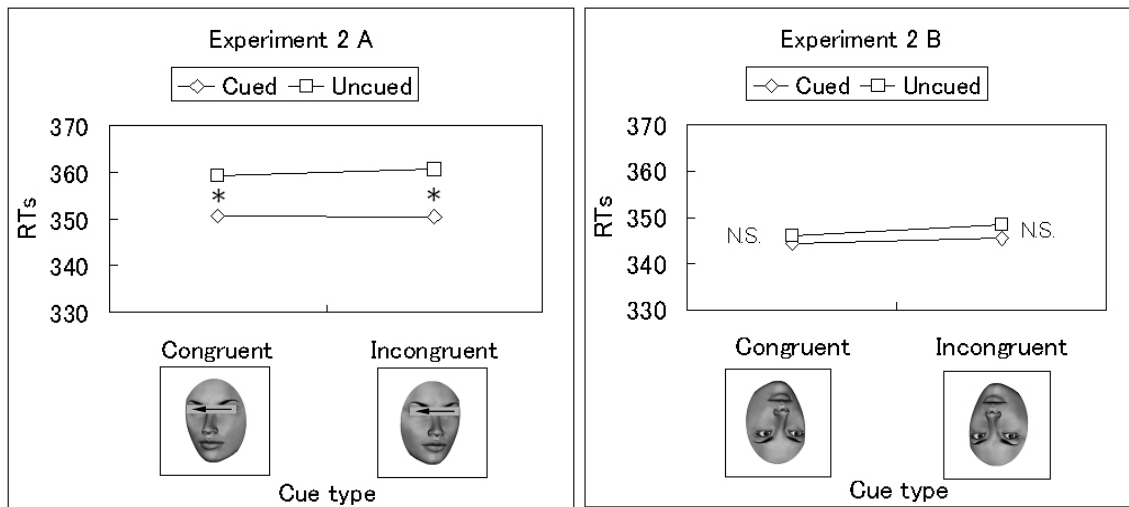


Figure 2-4. Mean reaction times (RTs) for all cue conditions in experiment 2. Panel A: Arrow cue condition. Panel B: Inverted face condition. The asterisk marks the statistically significant differences (significant level 0.05).

Median RTs were calculated for each participant. The average RTs of different cue types are illustrated in Figure 2-4. With regard to the arrow cue condition, a three-way ANOVA was conducted on the RTs with cue type (arrow with congruent-oriented profile face context, and arrow with incongruent-oriented profile face context), SOA (300 and 600 ms), and cue validity (cued and uncued) as within-participants factors. The main effect for SOA was significant,  $F(1, 11) = 126.128, p < .0001$ , with RTs becoming shorter as the SOA was increased. There was a significant main effect of cue validity,  $F(1, 11) = 32.157, p < .0001$ , indicating cueing effects. However, there was no significant influence of cue type or cue type  $\times$  cue validity interaction ( $ps > .69$ ), which means the spatial compatibility of profile face context could not influence the cueing effects. With regard to the inverted face condition, a three-way ANOVA was conducted on the RTs with cue type (inverted congruent-oriented profile face, and inverted incongruent-oriented profile face), SOA, and cue validity as within-participants factors. There was a significant main effect of SOA,  $F(1, 9) = 36.798, p < .0001$ . The main effect of cue validity was only

approached significance,  $F(1, 9) = 3.647$ ,  $p = .089$ . (The observation of impairment of gaze-cueing effects by face inversion is consistent with several previous studies (Kingstone, Friesen, and Gazzaniga, 2000; Langton and Bruce, 1999)). Furthermore, including cue type  $\times$  cue validity interaction, none of the other factors or interactions were significant (all  $p$ s  $> .20$ ), which means the cueing effects were not different between congruent-and incongruent-oriented profile faces when they were inverted. Taken together, these results suggest that the results of experiment 1 are indeed based on the holistic processing of the gaze direction, not low-level compatibility effects.

## **2.4 General Discussion**

The present study investigated whether the change of perceived gaze directions by face contexts could influence the gaze-evoked attention orienting. The results of experiment 1 showed that though the local-feature information of the eye region was preserved, gaze-cueing effects were varied when the perceived gaze directions were changed. Experiment 2 ruled out the possibility that the observed effect was due to the influence of low-level spatial compatibility from the profile face context. Since the critical factor which varied in the various conditions was the perception of gaze direction, the results suggest that gaze-cueing effects are based on mechanisms specialized for gaze perception, rather than low-level visual cues such as spatial compatibility.

Many studies have tried to manifest the specialty of gaze cueing, but the results are controversial. Some studies tried to discriminate gaze cueing from arrow cueing by evaluating the orienting ability of gaze cues in resistance to top-down biases (Friesen, Ristic, and Kingstone, 2004), and in eye movements (Ricciardelli, Bricolo, Aglioti, et al.,

2002). However, controversial results were found even when the same evaluation criteria were tested (in resistance to top-down biases, Hommel, Pratt, Colzato, et al., 2001; Tipples, 2008; in eye movements, Kuhn and Benson, 2007; Kuhn and Kingstone, 2009). More convincing evidence may come from the study of Ristic and Kingstone (2005), in which they found that attention orienting occurred only when an ambiguous stimulus (that was physically identical to the gaze cue but could be perceived as the wheels on a car) was perceived as eyes. Nevertheless, even this evidence was proved unstable by another study that used the same stimulus in an fMRI scanning task (Kingstone, Tipper, Ristic, et al. 2004). Therefore, new evidence, such as that provided by this study, is needed to clarify whether the mechanisms specialized for gaze perception are really involved in gaze cueing. Similar to the present study, two recent studies provided converging evidence to answer this question, either by the disruptive effect of negative contrast polarity on gaze perception (Ricciardelli, Betta, Pruner, Turatto, 2009) or by adaptation to gaze direction before going to cueing procedures (Bayliss, Bartlett, Naughtin, Kritikos, 2010). Further evidence might be derived from recording the neural activities of participants during an experiment similar in design to their and our studies.

The present study extends previous findings (e.g., Friesen and Kingstone, 1998; Driver et al., 1999), which showed that gaze cues automatically orient attention in the same direction, by demonstrating that attention shifts occur in response to the perception of gaze direction. Specifically, the present study investigated the influence of profile face context (head orientation) on the gaze cueing. Unlike previous studies that used profile face stimuli (Langton and Bruce, 1999; Hietanen, 1999), the present study ruled out the influence of local-feature information of the eyes by keeping the same eye

region among different cue stimuli, and investigated the relationship between perceived gaze directions and gaze-cueing effects. The results were as follows. First, the results showed equivalent cueing effects for the eye stimulus with and without a frontal face context. This result is reasonable because, according to the results of our evaluation task, gaze directions could be perceived from the eye stimulus alone and were not significantly influenced by the existence of the frontal face context. This is probably why some studies failed to find the influence of face contexts on attention orienting (e.g., Quadflieg, Mason, and Macrae, 2004; Frischen and Tipper, 2004), because in their studies, the perceived gaze directions were not varied. Second, as illustrated in Figure 3, it was found that cueing effects were significantly enhanced when the profile face context was congruent with the gaze direction, but were reduced when it was incongruent. This result is likely due to the fact that a congruent-oriented face context increased the perceived angle of the gaze direction toward left or right, and an incongruent-oriented face context reduced the perceived angle of the gaze direction (i.e., the perceived gaze direction was more close to direct gaze). In the literature, gaze-cueing effects have been investigated by simply dividing gaze directions as averted or direct (as a neutral condition); so far as I know, no one has considered the influence of gaze angle. Present results showed the first evidence that the magnitude of gaze-cueing effects was probably a function of the perceived gaze angle. Although the cueing effects under different gaze angles was not directly compared (e.g., 30° compared with 15° gaze angles), present method is more adequate for such an investigation, because the low-level influence was ruled out by using a constant eye stimulus. It suggests that gaze processing systems not only activate, but also modulate attention orienting systems. Further investigation is needed to reveal the precise mechanisms between gaze angle

and gaze cueing.

Overall, the present findings showed the interaction between gaze perception and attention orienting, and provided behavioral evidence supporting the existence of a direct link between the mechanisms involved in gaze processing and attention orienting systems. Neuropsychological and neuroimaging studies have suggested that perception of gaze information is processed by a specific neural area, the superior temporal sulcus (STS) (Allison, Puce, and McCarthy, 2000). The STS has been proved to be connected with the parietal cortex, which is implicated in the orienting of attention (Rafal, 1996), and the intraparietal sulcus (IPS), an area that is associated with spatial processing and covert shifts of attention (Corbetta, Miezin, Shulman, and Petersen, 1993). However, some recent studies found very few differences between the neural activations underlying gaze and arrow cueing (e.g., Hietanen, Nummenmaa, Nyman, Parkkola, and Hamalainen, 2006; Tipper, Handy, Giesbrecht, and Kingstone, 2008). Although it remains to be determined exactly which neural network underlies the gaze-following behavior, the present results fit and extend previous researches, which suggest that gaze perception triggers attention orienting for the biological significance of the gaze (e.g., Friesen and Kingstone, 1998, 2003; Ristic and Kingstone, 2005).

## Chapter 3

### Sequence effects by non-predictive arrow cues

#### 3.1 Introduction

At any one moment, people only can attend to a small part of the world for their limited processing resources. Therefore, it is highly beneficial for the human cognitive system to be able to select pertinent input for further processing. Orienting of attention refers to the alignment of some internal mechanisms with an external sensory input source, which makes people preferentially process that input. Such ability enables us to detect and respond quickly to potential danger or relevant events. A great deal of research has investigated the orienting to visual input by using the spatial cueing paradigm (e.g., Posner, 1980; Posner and Cohen, 1984). In a typical example of this paradigm, participants are instructed to respond to the onset of a target that can appear to the left or right of the fixation point by making a rapid key-press response. Before the onset of the target, a cue that indicates one of the possible target locations is presented for a certain time period (i.e., cue-target stimulus-onset asynchrony (SOA)). Faster reaction times (RTs) and/or more accurate performance with targets appearing in the cued location (compared with those in the uncued location) indicate attention shift to the cued location.

Orienting of attention may be elicited and controlled in different ways, and one way to distinguish between different forms of orienting is to examine the effects of different types of attentional cues. Traditionally, there are two major types: exogenous cues, such as sudden onset of peripheral events; and endogenous cues, such as centrally-presented



symbolic cues. It was commonly assumed that an exogenous cue automatically attracts attention, because the orienting by it occurs rapidly even though it is not predictive of the actual target location. Furthermore, the cueing effect is not disrupted even if the participants know that the target is more likely to appear in the uncued location (Jonides, 1981; Remington, Johnston, and Yantis, 1992). In contrast, orienting in response to endogenous cues (e.g., a pointing arrow or a directional word, like 'LEFT') appears to be under voluntary control. That is, such cues only shift attention when they correctly predict the target location on most trials to provide an explicit strategy for the participant to orient in the direction of the cue (Posner, Snyder, and Davidson, 1980; Jonides, 1981). Another difference between exogenous and endogenous cues is that the RT facilitation effect of exogenous cues emerge rapidly at short SOAs and then change into an inhibition effect at longer SOAs (i.e., slowed RTs at cued location relative to uncued location, inhibition of return (IOR), Maylor, 1985, Posner and Cohen, 1984), while the RT facilitation effect of endogenous cues sets up slowly and remains stable for long SOAs.

The traditional way for measuring attention orienting is to calculate the difference between the mean RTs to detect targets at cued and uncued trials. However, examining the cueing effect in this way leads one to ignore another important influence on the cueing effect: the influence of previous trial types on current trial performance. Although some early studies suggested that very little visual information is explicitly retained across views (Grimes, 1996; Ballard, Hayhoe, and Pelz, 1995), many recent studies have consistently showed that attention allocation is heavily influenced by the most recently viewed stimuli that were important for behavior (e.g., Chun and Nakayama, 2000; Wolfe et al., 2003). For instance, Maljkovic and Nakayama (1994)

found that in searching for a color singleton target, when target and nontarget colors are switched unpredictably from trial to trial, response in a trial is faster when the target color is the same as in the preceding trial than when it is different, a phenomenon that they called priming of pop-out (PoP). Besides color, this sequence effect on visual search performance has also been observed in investigations of other properties such as orientation (Hillstrom, 2000), shape (Lamy et al., 2006), location (Maljkovic and Nakayama 1996), and even emotional expression (Lamy, Amunts, and Bar-Haim, 2008). PoP was generally believed to be afforded by implicit visual memory mechanisms without voluntary intervention (Kristjansson, 2006). Another good demonstration of sequence effects between trials is negative priming (e.g., Neill and Valdes, 1992; Tipper, 2001), which refers to the phenomenon that a target stimulus is more slowly responded to on a current trial when the same stimulus was to be ignored on a previous trial. Negative priming was mainly explained as selective inhibition or episodic retrieval (Egner and Hirsch, 2005). All of these studies showed that some crucial information from previous views could be used to guide attention allocation shortly afterward. Considering the important role of cue validity states (i.e., cue direction and target location is congruent or incongruent) in cueing paradigm, it is likely that after attention deployment to a target followed by a given cue, the relationship between the cue and the target (cued or uncued) in that trial can also be utilized, thus influencing subsequent cueing processes. Such sequence effects of cueing paradigm are important because they may reflect some temporal characteristics of attention orienting in humans, and can provide better understanding of the cueing paradigm for future researches.

The first study to investigate the sequence effect of spatial cueing paradigm was

reported by Maylor and Hockey (1987). They used a modified cueing paradigm with 500 ms SOA, in which the location cued by a peripheral cue (i.e., an exogenous cue) was maintained over 1, 5, or 30 trials during separate blocks. It was found that responses to a target at a given location were slowed when either the cue of the current trial or the target of the previous trial had been presented at that location. By using a standard exogenous cueing paradigm in which both the cue and the target occurred at random, Dodd and Pratt (2007) showed that the magnitude of IOR (i.e., RT inhibition effect) was greater when the target appeared at an uncued location on the previous trial, relative to when the target appeared at a cued location. This effect was due to the fact that participants were slower to respond to targets on cued trials when they were preceded by an uncued trial relative to a cued trial, and the participants were faster to respond to targets on uncued trials when they were preceded by an uncued trial relative to a cued trial. Dodd and Pratt interpreted the result as automatic memory check (Logan, 1988) in which information of previous trials was automatically retrieved from memory to facilitate performance on current trials. This explanation is in line with the implicit memory account for the phenomenon of PoP (Maljkovic and Nakayama, 2000; Kristjansson, 2006) and the episodic memory retrieval account for negative priming (Egner and Hirsch, 2005). While the results of Dodd and Pratt were obtained during the inhibition period of exogenous cueing (the SOA was 800 ms), a recent study by Mordkoff, Halterman, and Chen (2008) extended the finding by showing that a similar sequence effect could be found at short 50 ms SOA during the facilitation period of exogenous cueing: the cueing effect (i.e., RT facilitation effect) was reduced after an uncued than after a cued trial. This observation provided further evidence for the automaticity of the sequence effect, because the consensus in the literature has been that attention shifts

on this timescale (i.e., less than 200 ms) are not under any form of voluntary control (Klein, Kingstone, and Pontefract, 1992, Nakayama and Mackeben, 1989).

On the other hand, Jongen and Smulders (2006) investigated the sequence effect by a centrally-presented arrow, a typical endogenous cue. In their experiment, the target appeared at cued location for 80% of all trials (i.e., a standard endogenous cueing task, which involved voluntary control of participants) and the cue-target SOA was 900 ms. Similar to the findings from exogenous cueing tasks, it was found that the cueing effect was larger after a cued trial than after an uncued trial. However, since voluntary control was involved, Jongen and Smulders explained this sequence effect as momentary strategical adjustments, by which participants adapt their utilization of the cue depending on whether it is correctly or wrongly directed their attention on the previous trial. Specifically, a cued trial enhances the expectation for repetitions so that it is beneficial to direct attention to the cued location, whereas an uncued trial weakens this expectation or even promotes orienting to the uncued location. This explanation is completely different from the automatic memory check hypothesis mentioned above, even though a very similar phenomenon was interpreted. If both hypotheses are true, there should be two different mechanisms under the sequence effects of cueing paradigm, one for exogenous cues, which is reflexive, and one for endogenous cues, which is voluntary. However, due to the limitations of the task used in the study of Jongen and Smulders, they cannot rule out the possibility that the observed sequence effects are actually automatic and do not require voluntary control. Therefore, this study aimed to investigate whether the sequence effect of arrow cueing could emerge when voluntary control was not required to detect the target by using non-predictive arrow cues. If the sequence effect is based on strategy adjustments, the manner in

which one adjusts when the cue is non-predictive should differ from the manner in which one adjusts when the cue is predictive. Specifically, Jongen and Smulders suggest that a cued trial would enhance the expectation for repetitions, whereas an uncued trial would weaken this expectation. With non-predictive cues (i.e., the cue predicts 50% of the time), participants should either have no expectation or even have an expectation for alternations, because the more cued trials participants perceive the more uncued trials they should expect to subsequently appear. If the sequence effect is based on automatic memory check, the same sequence effect as previous studies will be expected.

There is another reason to believe that sequence effects by arrow cues do not require voluntary control, in addition to the evidence from the studies that used peripheral cues (Dodd and Pratt, 2007; Mordkoff, Halterman, and Chen, 2008). Though early studies suggested that endogenous cues, such as arrows, can shift attention only when they explicitly predicted the target location, many later studies have obtained cueing effects even with spatially non-predictive arrow cues (e.g., Hommel et al., 2001; Pratt and Hommel, 2003; Ristic, Friesen, and Kingstone, 2002; Tipples, 2002). Furthermore, several studies have found cueing effects at short SOAs when the arrow counter-predicts the target location (e.g., Hommel et al., 2001; Tipples, 2008), which means arrow cueing could not be suppressed in the same way as peripheral cueing. These results suggest that orienting in response to arrow cues is also reflexive and does not require voluntary control. Therefore, it was expected that both the cueing effect within one trial and the sequence effect between trials could be triggered automatically by non-predictive arrow cues.

Another purpose of this study is to investigate the time course of sequence effects. From a memory perspective, there may be two major phases for the sequence processes:

initial encoding phase in previous trials and later retrieval phase in current trials. In the former phase, the relationship between a cue and a target needs to be encoded into memory; in the later phase, the relationship information will be retrieved from memory to affect performance. Cue-target SOA is an important time factor in both phases. For peripheral cues, the sequence effect has been found at both short (Mordkoff, Halterman, and Chen, 2008) and long SOAs (Dodd and Pratt, 2007). For arrow cues, only a long SOA was investigated (Jongen and Smulders, 2006).

One may expect sequence effects of arrow cues to also occur at short SOAs. However, this may not be the case. Previous studies have shown that the time course of arrow cueing is slower than that of peripheral cueing (e.g., Posner and Cohen, 1984; Jonides, 1981; Frischen, Bayliss, and Tipper, 2007), probably because symbolic cues like an arrow do not directly indicate a spatial location but rather require interpretation. Gibson and Bryant (2005) further showed that deliberate processing of the cue stimuli modulates orienting to uninformative central arrow cues. Thus, during the encoding phase, the relationship between an arrow and a target may not be encoded into memory if the perceiving time of the arrow is not sufficient. On the other hand, once the relationship information is encoded, it should be retrieved rapidly in an automatic way at both short and long SOAs depending on the automatic memory check hypothesis. Another possibility is that when the perceiving time of the arrow is short, the encoded relationship information from the previous trial will not be totally updated by the new relationship in the current trial, which in turn impairs the sequence effect in the next trial. Therefore, it was expected that sequence effects of arrow cues were influenced by the SOAs of previous trials, but not influenced by the SOAs of current trials. Specifically, when the previous SOA is short, no sequence effect will be shown; however, when the

previous SOA is long, sequence effects will be shown despite the length of the current SOAs.

In addition to the sequence effect of cue validity in arrow cueing, there was another finding about the influence of previous trials in the study of Jongen and Smulders (2006). They found that, following catch trials in which the target did not appear, the overall RTs were slowed compared with other trials, but the cueing effect was not influenced. They interpreted this result as a reduction in alertness and as support for the dissociation between spatial and temporal attentional mechanisms. In this study, whether the same result can be observed when relatively short SOAs are used and voluntary control is not required will be examined.

## **3.2 Method**

### **3.2.1 Participants**

A total of 16 students (with a mean age of 26 years, range 21 to 29 years, 5 females) from Kochi University of Technology consented to participate in this experiment. All participants reported normal or corrected-to-normal vision and were naive as to the purpose of the experiment.

### **3.2.2 Apparatus**

The stimuli were presented on a LCD display operating at a 60 Hz frame rate and the display of the stimuli was controlled by E-Prime software (Schneider, Eschman, and Zuccolotto, 2002). The participants were seated approximately 60 cm away from the screen.

### **3.2.3 Stimuli**

A cross, subtending 1.5°, was placed at the center of the screen as a fixation point and remained at the screen during the whole experiment. The cue was an arrow to the left (<<) or to the right (>>) just around the central cross and was presented 1.5° in height and 5° in width. The target stimulus was a capital letter 'T' measuring 1° wide, 1° high, and was presented 15° away from the fixation point on the left or right side.

### **3.2.4 Design**

The cue-target SOAs were 100 and 700 ms. On each trial, cue direction, target location, and SOA duration were selected randomly and equally. There were five blocks with 100 trials each. In each block, 20 trials were catch trials in which the target did not appear. The participants were instructed not to respond if the target did not appear. Including 20 training trials, there were in total 520 trials for each participant. The RT of the first trial on each block was excluded from analysis because it was not preceded by any trials.

### **3.2.5 Procedure**

Participants were instructed to keep fixating on the center of the screen. First, a fixation display appeared at the center of the screen for 2000 ms, and then the cue stimulus appeared. After a certain cue-target SOA, a target letter 'T' appeared either at left or right until participants had responded or 1500 ms had elapsed. Participants were instructed to respond to the appearance of the target by pressing the 'SPACE' key as quickly and accurately as possible. Participants were also informed that the central



stimuli did not predict the location in which target would appear and that they should try to ignore the central cues.

### **3.3 Results**

#### **3.3.1 Errors**

The participants missed an average of about 0.1% of the targets and made false alarm errors on approximately 0.5% of the catch trials. Anticipations (RT of less than 100 ms) and outliers (RT over 800 ms) were classified as errors and were excluded from analysis. As a result, about 0.6% of all trials were removed. The error rates did not vary systematically and no signs of any speed-accuracy trade-off were observed.

#### **3.3.2 Cueing effects**

A two-way ANOVA with SOA (100 and 700 ms), cue validity (cued and uncued) as within-participants factors was conducted on the RTs to investigate the overall cueing effects independent of previous trial types. There was a significant main effect of SOA,  $F(1, 15) = 46.232$ ,  $p < .0001$ , with RTs becoming shorter as the SOA was increased. The main effect of cue validity was also significant,  $F(1, 15) = 14.135$ ,  $p < .002$ , indicating cueing effects, i.e., RTs were shorter at cued than at uncued trials. The interaction between SOA and cue validity was not significant ( $p > .67$ ). The average cueing effect (i.e., RTs of uncued trials – RTs of cued trials) was 8 ms.

#### **3.3.3 Sequence effects of previous cue validity**

A three-way ANOVA with previous cue validity (pre-cued and pre-uncued), cue

validity (cued and uncued), and cue direction (same or different than previous trial) as within-participants factors was conducted on the RTs to show the sequence effects and the influence of cue direction. There was a main effect of cue validity,  $F(1, 15) = 12.666$ ,  $p < .003$ , indicating cueing effects. Importantly, there was a significant interaction between previous cue validity and cue validity,  $F(1, 15) = 10.489$ ,  $p < .006$ , demonstrating that the cueing effect of current trials was significantly reduced following an uncued trial compared with a cued trial, i.e., a typical sequence effect reported by previous studies. Furthermore, neither the main effect of cue direction nor the previous cue validity  $\times$  cue validity  $\times$  cue direction interaction were significant,  $F(1, 15) = 1.573$ ,  $p > .22$ , and  $F(1, 15) = 2.014$ ,  $p > .17$ , respectively. No other factors or interactions were significant. A similar analysis was conducted to investigate the influence of target location (same or different than previous trial). Again, neither the main effect of target location nor the previous cue validity  $\times$  cue validity  $\times$  target location interaction were significant ( $ps > .15$ ). In all, these results replicated sequence effects of cueing paradigm with non-predictive arrow cues and suggested that the sequence effects were not significantly influenced by the repetition/switch of cue direction and target location between trials.

### **3.3.4 Influence of previous and current SOAs on sequence effects**

A four-way ANOVA was conducted on the RTs with previous SOA (100 and 700 ms), previous cue validity (pre-cued and pre-uncued), current SOA (100 and 700 ms), and cue validity (cued and uncued) as within-participants factors. Similar to the previous analysis, the cueing effect and the sequence effect were significant ( $ps < .006$ ). The main effect for SOA was also significant,  $F(1, 15) = 53.020$ ,  $p < .0001$ , with RTs becoming

shorter as the SOA was increased. Importantly, the previous SOA  $\times$  previous cue validity  $\times$  cue validity interaction was significant,  $F(1, 15) = 8.275$ ,  $p < .012$ , indicating that the sequence effect was influenced by the previous SOAs. No other factors or interactions were significant. The RTs under different conditions were illustrated in Figure 3-1.

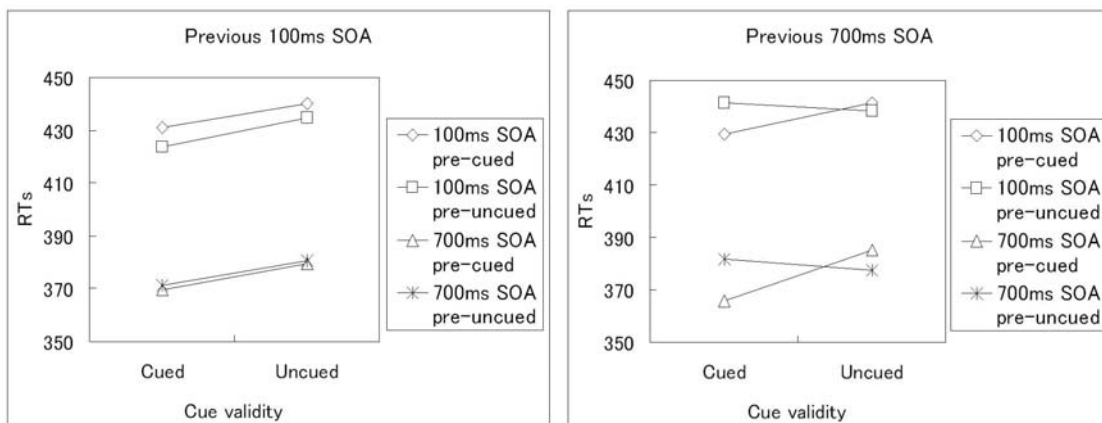


Figure 3-1. Mean reaction times (RTs) under different previous and current cue validity, previous and current SOAs.

To further investigate the influence of the previous SOAs on the sequence effect, a paired-samples t-test was used to compare the magnitude of cueing effects under different conditions. The magnitude of cueing effects are illustrated in Figure 3-2. When the previous SOA was relatively short (100 ms), no significant sequence effects were observed for both current SOAs (both  $ps > .79$ ). When the previous SOA was relatively long (700 ms), regular sequence effects were observed despite the length of current SOAs (both  $ps < .025$ ). From the right part of figure 2 where sequence effects showed, there is a tendency for sequence effects of current trials with a 700 ms SOA to be stronger than those with a 100 ms SOA; however, this tendency was not significant ( $p > .37$ ). The average sequence effect (i.e., cueing effects of pre-cued trials – cueing effects of pre-uncued trials) was 19 ms.

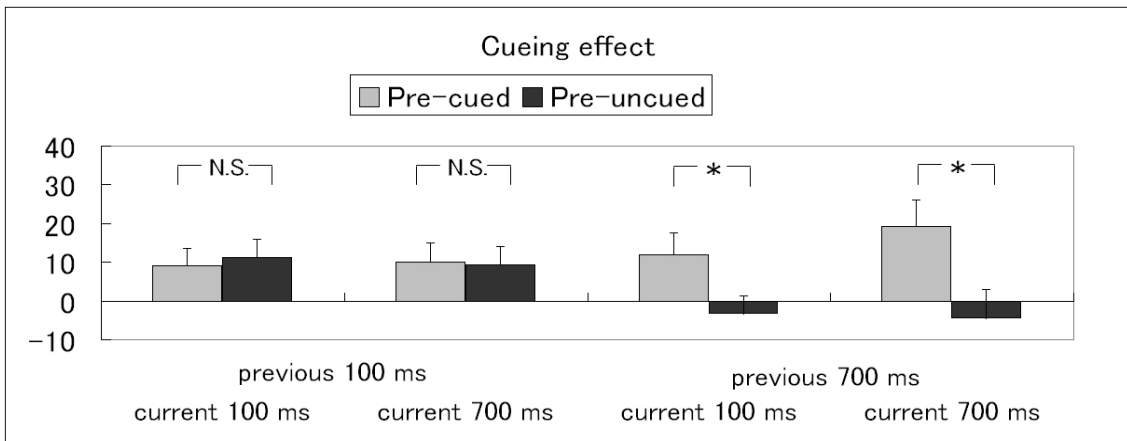


Figure 3-2. The magnitude of cueing effects ( $RT_{uncued} - RT_{cued}$ ) under different previous cue validity, previous and current SOAs. The asterisks mark the statistically significant differences (significant level 0.05). Error bars denote standard errors of the mean.

### 3.3.5 Influence of previous catch trials

As for the influence of preceding catch trials, a three-way ANOVA was conducted on the RTs with previous condition (the previous trial was a catch trial and it was not), SOA (100 and 700 ms), and cue validity (cued and uncued) as within-participants factors. Similar to the previous analysis, the main effect of SOA was significant,  $F(1, 15) = 32.375$ ,  $p < .0001$ . Importantly, the main effect of previous condition was significant,  $F(1, 15) = 6.348$ ,  $p < .024$ , indicating that after a catch trial, RTs were faster (393 ms) than after the average of the other trial types (407 ms). The main effect of cue validity was also significant,  $F(1, 15) = 8.864$ ,  $p < .009$ , representing cueing effects. However, the interaction of previous condition and cue validity was not significant ( $p > .60$ ). No other factors or interactions were significant. In sum, the results showed a facilitation effect of preceding catch trials on RTs and this effect was independent of the cueing effect.

### 3.3.6 Control tasks

Until now, sequence effects were only investigated from one previous trial. To investigate the influence of two trials prior to the current trial may be helpful to add more insight to the mechanisms under the sequence effects. The sequence effects could be divided into two groups depending on the repetition condition of previous two trials: repeated (e.g., both trial  $n-2$  and trial  $n-1$  is cued trials) or switched. No change in the magnitude of sequence effects between the two groups would be more consistent with the automatic memory check hypothesis whereas a change in magnitude would be more consistent with the strategy adjustment hypothesis. However, an analysis based on current data is not reliable, because the preceding trials with a 100 ms SOA did not induce significant sequence effects and should be removed, which will result in a small sample size. Therefore, an additional control experiment was conducted by twelve participants. The SOA was 700 ms only and each participant completed a total of 273 trials (including 21 catch trials). A three-way ANOVA was conducted on the RTs with repetition condition between trial  $n-2$  and trial  $n-1$  (repeated and switched), cue validity of trial  $n-1$  (pre-cued and pre-uncued), and cue validity of trial  $n$  (cued and uncued) as within-participants factors. The results showed a significant cueing effect and a significant sequence effect,  $F(1, 11) = 52.868$ ,  $p < .0001$ , and  $F(1, 11) = 8.610$ ,  $p < .014$ , respectively. Importantly, the influence of repetition condition on the sequence effect was not significant,  $F(1, 11) = .05$ ,  $p > .82$ , indicating that the sequence effect was not significantly influenced by the cue validity of trial  $n-2$ .

Additive sequence effects were not observed from the results of the previous control experiment, possibly because the memory to the cue validity was updated consecutively. However, there still has the possibility that sequence effects actually

occurred on a response level, which abolished after each response. Therefore, in the second control experiment, a neutral-cue trial (instead of arrow, the cue is two vertical lines aside the fixation point without spatial meaning) was inserted into the middle of trial  $n-1$  and trial  $n$ . If the sequence effect is indeed a phenomenon of memory, the sequence effect should still exist despite of the additional responses in neutral-cue trials. Fourteen participants were tested and each of them completed a total of 200 trials (no catch trials were included). The cue-target SOA was 700 ms. The results again showed a significant cueing effect and a significant sequence effect,  $F(1, 13) = 9.576$ ,  $p < .009$ , and  $F(1, 13) = 4.829$ ,  $p < .047$ , respectively. These results suggest that the sequence effect observed in this study was indeed based on memory mechanisms.

### **3.4 Discussion**

The present study investigated whether the sequence effect of cueing paradigm could be triggered by non-predictive arrow cues. The results showed that the sequence effect of arrow cueing could be observed when voluntary control was not required to detect the target (i.e., the arrow cue did not predict the target location). Additionally, when the previous SOA is short, no sequence effect was observed; however, when the previous SOA is long, the sequence effect was shown both at the short and long current SOAs. Furthermore, though both the study of Jongen and Smulders (2006) and the present study found that cueing effects were not influenced by a preceding catch trial, interestingly, it was observed that following a catch trial, the overall RTs were facilitated, rather than slowed.

Sequence effects of cueing paradigm have been reported by several studies. Some of them (Dodd and Pratt, 2007; Mordkoff, Halterman, and Chen, 2008) have shown the

sequence effect by using non-predictive peripheral cues. These results support the automatic memory check hypothesis (Logan, 1988), which suggests that when performing a task, participants are highly likely to automatically and unintentionally retrieve information from memory in order to facilitate current task performance. Specifically, when the previous trial type (cued or uncued) is consistent with the current trial type, performance will be facilitated, whereas when the previous and current trial types differ, performance is slowed due to the conflict between the two trial types. As a result, the magnitude of cueing effects (i.e., RT facilitation effect) was reduced during short SOAs and the magnitude of IOR was increased during long SOAs after an uncued trial compared with a cued trial. Similar phenomena of automatic memory mechanisms, such as priming of pop out (e.g., Lamy, Amunts, and Bar-Haim, 2008; Maljkovic and Nakayama, 2000; Kristjansson, 2006), and negative priming (e.g., Neill and Valdes, 1992; Egner and Hirsch, 2005), have also been reported by using other paradigms. All of these studies suggested that the sequential processes were afforded by implicit visual memory mechanisms, which operated in an automatic way without conscious intervention. A different hypothesis was proposed when arrow cues were tested by Jongen and Smulders (2006). They argued that the sequence effect was due to some strategies under the voluntary control of the participants. However, because the arrow cues predicted the target location in most of their experimental trials, their explanation may have confounded the voluntary cueing effect within one trial and the automatic sequence effect between trials. The present study extends the findings of Jongen and Smulders (2006) by demonstrating that sequence effects can be observed even when arrow cues are non-predictive to the actual target location. The strategy adjustment hypothesis will predict either no sequence effects or reversed sequence effects with

non-predictive arrow cues. Therefore, the present results suggest that sequence effects of arrow cueing are not attributed to the voluntary control or explicit strategies of participants, but attributed to memory retrieval mechanisms, as suggested by the automatic memory check hypothesis.

Although the automatic memory check hypothesis may have revealed the nature of memory under the sequence effect, it does not explain the details of the sequential processes, such as what exactly happens within a spatial cueing task and how the information of previous trials is processed. Some recent studies by Hommel and his colleagues (Hommel, Proctor, and Vu, 2004; Hommel, 2004) proposed a feature-integration account, which tried to explain the sequence effects in spatial attention tasks. The basic idea is that co-occurrence of a cue and a target leads to a transient representation of the relation in which their features (at least the features related to task) are spontaneously integrated without need for voluntary control. This relation would be reactivated in the next trial, and good performance would be expected if the same relation is repeated but interference would occur if it were alternated. According to this feature-integration account, the spatial meaning of the arrow cues and the spatial location of the targets in the present experiment were integrated to form a relation (either cued or uncued). This relation was retrieved in the next trial, and faster response was conducted when the same relation is repeated than when it is alternated.

One thing need to point out is that the magnitude of the sequence effect observed in present study (19 ms) is very close to the results of previous studies (15 ms at Dodd and Pratt (2007); 17 ms at Mordkoff et al. (2008); around 20 ms at Jongen and Smulders (2006), perceived from their figure 4). The stable magnitude of sequence effects across very different experiments provided further evidence to support the automatic memory



check hypothesis. In addition, considering the weak average cueing effect in the present study (only 8 ms), it is not difficult to explain why the cueing effect of trials was completely lost when the previous trial was uncued with a 700 ms SOA. The answer is probably that the cueing effect was overpowered by the sequence effect.

In addition, the influence of previous SOAs and current SOAs on the sequence effect was investigated. It was found that when the previous SOA was short, no sequence effect was observed; but when the previous SOA was long, sequence effects were shown at both short and long current SOAs. This is a novel finding in the investigation of sequence effects of cueing paradigm. As mentioned in the introduction, the result can be explained by the different time course of two phases (i.e., initial encoding phase in previous trials and later retrieval phase in current trials) in the sequential processes. However, there are still some issues that need to be considered. First, the impairment of sequence effects when previous trials had a short SOA apparently contradicts the results of Mordkoff et al. (2008), in which the SOA was also very short but resembling sequence effects were observed. One critical difference between the two studies is the different attentional cues. The arrow cue involved in present study is perceptually different but spatially similar whereas the peripheral cue in their study is perceptual identical but the spatial location differs. Therefore, it is easy to integrate a peripheral cue with a target directly based on their spatial locations. On the contrary, arrow cues need to be discriminated before the spatial meaning of them can be acquired. It is widely accepted that though both peripheral cueing and arrow cueing can orient attention reflexively, their relative time courses are very different. In the same way, it is possible that though both peripheral cues and arrow cues could induce sequence effects automatically, some different processes have been involved, like

different processing routes and different information that are encoded. This assumption is to some extent supported by the results of several pilot experiments, which are in preparation for a new research in our laboratory. The results showed that alternation of cue types (peripheral onset vs. central arrow) abolished overall sequence effects, while alternation of cue types (central gaze vs. central arrow) did not.

Second, it is suggested that the influence of previous SOA may reflect a difficulty in encoding the relation between an arrow and a target with a short SOA relative to a long SOA. One may argue that the time interval between trials when a fixation point was presented for a full 2000 ms should be sufficient to let the relation be encoded. However, this view ignores the important fact that the cue and the target have disappeared before the 2000 ms sequence interval. Automatic processing is usually transient and stimulus-driven, so it is unlikely that the automatic encoding of the trial could occur without stimulus inputs during the sequence interval.

Third, whether or not the influence of previous SOAs can be explained by the strategy adjustment hypothesis. In our opinion, the answer is probably no. Although similar explanation can be made, i.e., that a short perceiving time of the arrow may not sufficient to enable participants to perceive the trial types on an initial trial, this notion faces the same question as why the perceiving cannot be done during a full 2000 ms sequence interval. This period of time should be enough for participants to discriminate between cued and uncued trials voluntarily. Another explanation could be that participants formed the expectation on an initial trial based on not only trial types, but also cue-target SOAs of that trial. Consequently, the participants adapted their utilization of the cue depending on if it correctly or wrongly directed their attention to a location on the previous trial, only when the cue-target interval of the previous trial was

long enough. However, it is hard to believe that such a complex and resource-consuming strategy was maintained by participants across the whole experiment in spite of the fact that they explicitly knew the arrow cue was uninformative and SOAs were chosen randomly. In addition, the strategy explanation mentioned above will face many new questions. For example, how participants perceive the length of cue-target SOA as long or as short; is there a certain threshold or is it a relative adjustment? Therefore, at this stage, the influence of previous trial SOA cannot be used to discriminate between automatic and strategy hypotheses, it is more reasonable to consider this effect as originating from the different spatial representations between peripheral and central symbolic cues. On the other hand, the automatic memory check hypothesis is supported by the other results of present study, such as significant sequence effects by non-predictive arrow cues and the stable magnitude of the sequence effects across different studies. In all, though more systematic investigations are needed to reveal the precise mechanisms under the present results, our results are more consistent with the automatic memory check hypothesis and might reflect some different temporal characteristics of sequential memory mechanisms between peripheral cues and arrow cues.

Another effect that was examined in this experiment was the influence of preceding catch trials. Consistent with the findings of Jongen and Smulders (2006), it was found that though the overall RTs were influenced following a catch trial, it did not influence the cueing effect. This observation supports the distinction between orienting and alerting processes of attention (e.g., Fernandez-Duque and Posner, 1997; Posner and Petersen, 1990). However, contrary to the findings of the present study, Jongen and Smulders found that overall RTs were delayed, rather than facilitated, after a catch

trial. Besides their study, the overall delay in RTs after a catch trial has been reported by several other studies (Alegria, 1978; Correa, Lupianez, and Tudela, 2004), and it was attributed to a decrease in preparation for the target. The preparation refers to the general readiness to respond to an anticipated target stimulus after the occurrence of a warning cue. Therefore, if catch trials were considered as trials with extended cue-target SOA, a previous catch trial will reduce the target expectation of participants, resulting in a delayed RT at other SOAs.

Depending on the preparation account, arrow cues need to be utilized under some degree of strategy control to form expectancies about the target appearance. Therefore, it is not surprising to find that the RT delay effect of catch trials was not shown in the present experiment when voluntary control was not required and participants were encouraged to ignore the central cues. Another difference between the experiment of Jongen and Smulders and ours is the cue-target SOA; while the single SOA of their experiment was relatively long, the present experiment used two SOAs with relatively short lengths. This setting may have increased the temporal uncertainty of the target appearance, which in turn reduced the influence of the attention preparation effect. In an exogenous cueing study, Los (2004) reported that target detection was slower when the cue-target SOA of the preceding trial was longer than the SOA of the current trial. However, at the shortest SOA (100 ms) of the two experiments that he conducted, he observed that responses after a preceding catch trial were faster, rather than slower, than that after a preceding long SOA. This observation is very similar to the finding of the present experiment. In all, these results suggest that a catch trial cannot be simply considered as a trial that extended cue-target interval, and it may have a complex influence on the RTs depending on experimental contexts. Further investigation is

needed to reveal the precise mechanisms under the RT effect of preceding catch trials.

The present study also has some implications on current and future investigations that involved cueing paradigm. As mentioned previously, a traditional way for measuring attention orienting is to calculate the difference between the mean RTs to detect targets at cued and uncued trials. This manipulation ignored the potential influence of trial-by-trial effects. Though most cueing experiments included an equal number of cued and uncued trials, some researchers used a different proportion of cued trials relative to uncued trials in their experiments to investigate the influence of voluntary control on attention orienting (e.g., Driver et al., 1999; Friesen, Ristic, and Kingstone, 2004). Sequence effects may have influenced their results. For example, when the cue predicts the target location with a rate of 80 percent, there will be more pre-cued trials than pre-uncued trials. As a result, larger average cueing effects for predictive cues than for non-predictive or counter-predictive cues are due in part to sequence effects, not only due to the voluntary control of participants. It is clearly important for future studies to take the influence of sequence effects into account when results are evaluated.

In summary, the present experiment mainly demonstrated that sequence effects of cueing paradigm could be observed for non-predictive arrow cues. In addition, the sequence effects are influenced by the SOA of previous trials. Although the precise mechanisms under the different influence of previous SOAs between peripheral cues and arrow cues need further investigations, overall, our results support the automatic memory check hypothesis for the sequence effects of cueing paradigm more than the strategy adjustment hypothesis.

## Chapter 4

### Sequence effects of gaze cueing

#### 4.1 Introduction

Humans receive an abundance of visual information whenever their eyes are open, but not all of this input may be relevant to their current behavioral goals. Therefore, it is essential that the human cognitive system is able to select input for further processing by attending selectively to relevant aspects of the environment. Eye-gaze, as an important communication tool, has been shown to attract observers' attention (Birmingham, Bischof, and Kingstone, 2008) and to shift their attention toward the location that the eyes are looking at (Friesen and Kingstone, 1998). In order to investigate the gaze-evoked attention shift, gaze-cueing paradigm has been used by many researchers. In a typical study of this paradigm, a face stimulus looking left or right was presented to observers, and after a certain time interval (stimulus onset asynchrony (SOA)), observers responded to the appearance of a target to the left or right of the face. Although observers were instructed that the gaze direction of the face stimulus did not predict where the target would occur, reaction time (RT) was reliably faster when the face's gaze was toward the target, rather than away from it. This facilitation of RT is referred to as the gaze-cueing effect, and is considered to be evidence of attention orienting (see Frischen, Bayliss, and Tipper, 2007, for a recent review).

In gaze-cueing paradigm, there were two different cue validity states for experimental trials: cued trials, in which the target occurred either on the left or right

side as indicated by the gaze cue; and uncued trials, in which the target occurred at the location that was not indicated by the gaze cue. Randomly changing the cue validity states (cued and uncued) from trial to trial has been used as a common experimental setting in many previous investigations (e.g., Friesen and Kingstone, 1998; Langton and Bruce, 1999). However, to the best of our knowledge, whether the change of cue validity states between trials could influence gaze-cueing effects has not been investigated. For example, when the previous trial is a cued trial, we should know whether the gaze-cueing effect of current trials is different from one when the previous trial is an uncued trial. Such sequence effects are important because they may reflect some memory mechanisms of attention orienting in humans, and can provide better understanding of the gaze-cueing paradigm for future researches.

Although very little visual information is explicitly retained across views (Grimes, 1996; Ballard, Hayhoe, and Pelz, 1995), it has been suggested that attentional selection of pertinent information is heavily influenced by the most recently viewed stimuli that were important for behavior (Chun and Nakayama, 2000; Wolfe et al., 2003). For instance, Maljkovic and Nakayama (1994) found that in searching for a color singleton target, when target and nontarget colors are switched unpredictably from trial to trial, response in a trial is faster when the target color is the same as in the preceding trial than when it is different, a phenomenon that they called priming of pop-out (PoP). Besides color, this sequence effect on visual search performance has also been observed in investigations of other properties such as orientation (Hillstrom, 2000), shape (Lamy et al., 2006), location (Maljkovic and Nakayama 1996), and even emotional expression (Lamy, Amunts, and Bar-Haim, 2008). All of these studies showed that some crucial information from previous views could be stored and used to guide attention allocation

shortly afterward without need for voluntary control. Considering the important role of cue validity states in gaze-cueing paradigm, it is likely that after attention deployment to a target followed by a given gaze cue, the relationship between the gaze and the target (i.e., cue validity states) in that trial can also be stored and retrieved, thus influencing subsequent gaze-cueing processes. Specifically, similar to the phenomenon of PoP, it is possible that RT will be faster when the trial type (cued or uncued) is the same as in the preceding trial than when it is different. If this prediction is true, it will lead to a relatively stronger cueing effect for the group of trials that was preceded by a cued trial, because it leads to a relatively short cued RT. In contrast, the cueing effect will be smaller for the group of trials that was preceded by an uncued trial, because it leads to a relatively short uncued RT.

The goal of this study is to investigate whether the change of cue validity states between trials influences gaze-cueing effect. Gaze-cueing effects induced by a centrally-presented face were divided into two groups according to the cue validity of previous trials: pre-cued or pre-uncued. If repeating one trial type quickens RT, a significant larger cueing effect should be observed for the pre-cued group compared with the pre-uncued group. In experiment 1, schematic faces were used as central cues to investigate sequence effects. In experiment 2, real faces and arrows were tested to show whether sequence effects could be found for real faces and other symbolic cues. In experiment 3, central cues (real face or arrow) were alternated between trials to show whether sequence effects could generalize across different cue categories. Furthermore, a discrimination task was used in experiment 4 to investigate whether experimental tasks could influence the sequence effect.



## **4.2 Experiment 1**

### **4.2.1 Participants**

A total of 30 students (with a mean age of 26 years, range 20 to 34 years, 8 females) from Kochi University of Technology consented to participate in this experiment. All participants reported normal or corrected-to-normal vision and were naive as to the purpose of the experiment.

### **4.2.2 Apparatus**

The stimuli were presented on a LCD display (EIZO Ltd., Color Edge CG222W) operating at a 60 Hz frame rate, which was controlled by a video board (Cambridge Research Systems, VSG2/5) using a Dell Pentium computer. The experiment program was written by CRS Toolbox based on R2007b Matlab software. An IR CB6 Response Box was used to collect responses from participants.

### **4.2.3 Stimuli**

A cross, subtending  $0.3^\circ$ , was placed at the center of the screen as a fixation point. The target stimulus was a black capital letter 'T' measuring  $0.5^\circ$  wide,  $1^\circ$  high, and was presented  $10^\circ$  away from the fixation point on the left or right side. The schematic face stimulus, which is illustrated in Figure 4-1(A) and similar to the stimulus in the study of Friesen and Kingstone (1998), consisted of a black line drawing of a round face subtending  $3^\circ$  with a light gray background. The center of the face's eye region was located at the fixation point.

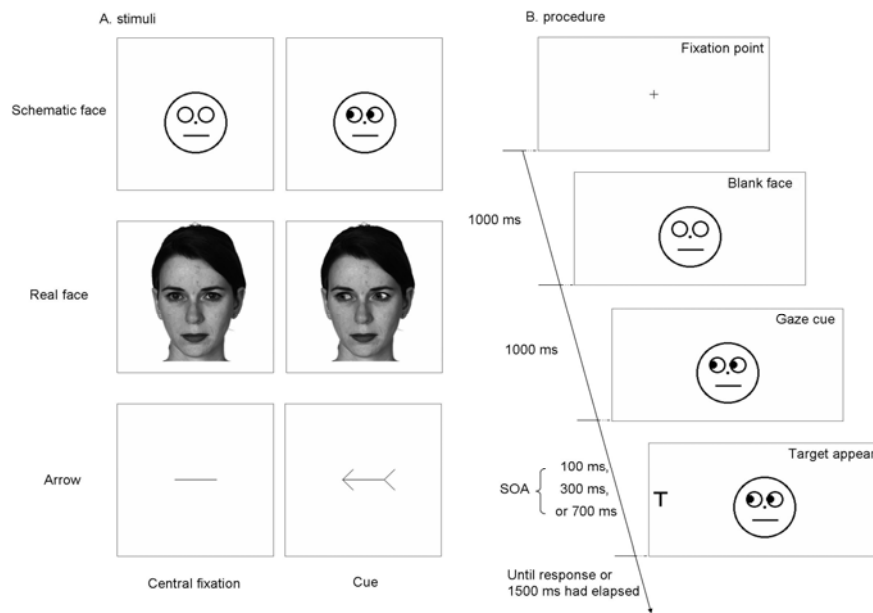


Figure 4-1. Panel A: Stimuli illustration in present experiments. Panel B: Illustration of the sequence of events in a cued trial of experiment 1.

#### 4.2.4 Design

The cue-target SOAs were 100, 300, and 700 ms. In each trial, gaze direction, target location, and SOA duration were selected randomly and equally. This random setting aimed to replicate the setting usually used in gaze-cueing studies. Including 20 training trials, there were a total of 80 trials for each participant. The RT of the first trial was excluded from analysis because it was not preceded by any trials.

In order to make an equal number of pre-cued and pre-uncued trials for each participant, the number of cued-cued, cued-uncued, uncued-cued, and uncued-uncued trial-pairs between trial  $n-1$  and trial  $n$  was counted after the main experiment. After that, extra trial pairs were joined up and tested to retain the number of these trial-pairs equal for each participant.

### 4.2.5 Procedure

Participants were instructed to keep fixating on the central fixation point. Figure 1(B) provides a representative illustration of the sequence of events on a single trial. First, a fixation display appeared at the center of the screen for 1000 ms, followed by blank faces at the central area for 1000 ms, and then the pupils appeared within the eyes looking left or right. After a certain cue-target SOA, a target letter ‘T’ appeared at either the left or right side until participants had responded or 1500 ms had elapsed. Participants were instructed to indicate whether a target appeared to the left or the right side of the screen by pressing the left button with their left thumb for a target on the left, and the right button with their right thumb for a target on the right as quickly and accurately as possible. Participants were also informed that the gaze directions of face stimuli did not predict the location in which target would appear, and the central face should be ignored.

### 4.2.6 Results

Anticipations (RT of less than 100 ms), incorrect responses (in which participants pressed left button for a right target or right button for a left target), and outliers (RT over 1000 ms) were classified as errors and were excluded from analysis. After that, responses with RTs exceeding plus or minus two standard deviations of the participant’s mean RT were also removed as errors. As a result, about 1.4% of all trials were removed. Analysis of percentage errors revealed that participants made more errors in uncued trials than they did in cued trials,  $F(1, 29) = 9.330$ ,  $p < .005$ ; however, RTs were slower in uncued trials than that in cued trials. There was no sign of any speed-accuracy trade-off.

A three-way ANOVA was conducted on the RTs with previous cue validity (pre-cued and pre-uncued), SOA (100, 300, and 700 ms), and cue validity (cued and uncued) as within-participants factors. There was a significant main effect of cue validity,  $F(1, 29) = 11.165$ ,  $p < .002$ , indicating gaze-cueing effects, i.e., RTs were shorter at cued than at uncued trials. The main effect for SOA was significant,  $F(2, 58) = 74.849$ ,  $p < .0001$ , with RTs becoming shorter as the SOA was increased. The interaction between SOA and cue validity was marginally significant,  $F(2, 58) = 2.905$ ,  $p = .063$ , representing that the amount of cueing effects was larger for the 300 ms SOA than other SOAs.

Importantly, the interaction of previous cue validity  $\times$  cue validity was significant,  $F(1, 29) = 10.195$ ,  $p < .003$ , meaning that the gaze-cueing effect of current trials was significantly influenced by the cue validity of previous trials, i.e., there is a sequence effect in gaze cueing. This sequence effect of gaze cueing is attributed to the fact that the cueing effect of trials preceded by cued trials (magnitude of cueing effect (mean  $RT_{\text{uncued}} - RT_{\text{cued}} = 19$  ms) was stronger than the cueing effect of trials preceded by uncued trials (5 ms),  $t(29) = 3.182$ ,  $p < .003$ . The magnitude of cueing effects with different previous cue validity states and SOAs is shown in Figure 4-2(A). In addition, the interaction of previous cue validity  $\times$  cue validity  $\times$  SOA failed to reach significance ( $p > .61$ ), indicating that the SOA latencies had no significant influence on the sequence effect. No other factors or interactions were significant.

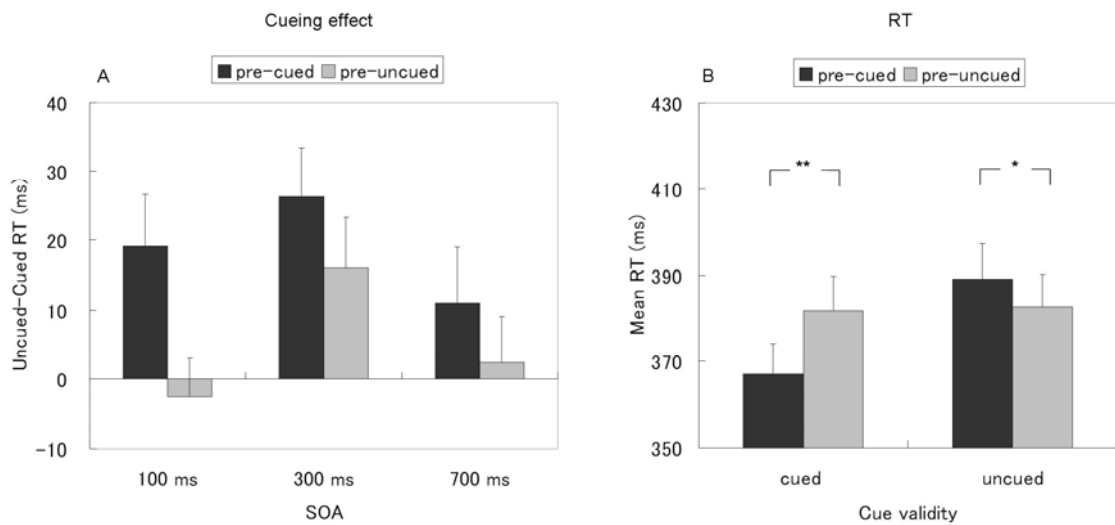


Figure 4-2. Results of experiment 1 with schematic gaze cues. Panel A: The magnitude of cueing effects (mean  $RT_{uncued} - RT_{cued}$ ) for trials preceded by cued or uncued trials with different SOAs. Error bars denote standard errors of the mean. Panel B: RTs of trials preceded by cued or uncued trials with different cue validities. The asterisk marks the statistically-significant differences (significant level 0.05 and 0.0001). Error bars denote standard errors of the mean.

In order to investigate whether the sequence effect can indeed be attributed to the fact that repeating a trial type quickens RT, the RTs of cued (or uncued) trials with different SOAs were combined, and then divided into two groups: pre-cued and pre-uncued groups. After that, these two groups were compared by a paired-samples t-test. As illustrated in Figure 2(B), it was found that the RTs of cued trials were significantly faster when the trials were preceded by cued trials (i.e., trial type repeated) than by uncued trials (i.e., trial type switched),  $t(29) = 4.105$ ,  $p < .0001$ . Also, the RTs of uncued trials were significantly faster when the trials were preceded by uncued trials (i.e., trial type repeated) than by cued trials (i.e., trial type switched),  $t(29) = 2.095$ ,  $p < .045$ .

### **4.2.7 Discussion**

The basic gaze cueing pattern reported by Friesen and Kingstone (1998) and others (Driver et al., 1999; Langton and Bruce, 1999) was replicated: uninformative gaze direction triggered a rapid shift of attention to the location gazed at.

Interestingly, the present results showed that the magnitude of cueing effects was significantly influenced by the cue validity of previous trials. To the best of our knowledge, this sequence effect of gaze cueing is a novel finding in the study of gaze-cueing paradigm and gaze perception in humans.

It should also be noted that there were some limitations to this experiment. First, the number of tested trials for each participant was relatively small, so that it is not reliable to further analyze the details of the sequence effect based on current data, such as the influence of long runs of one trial type. Second, gaze cues were provided by a schematic face, which has less ecological information than a real face. Whether the same sequence effect could be found for real face stimuli still requires further investigation. Third, some studies suggest that symbolic cues, such as arrows, can also induce significant cueing effects (Ristic, Friesen, and Kingstone, 2002; Tipples, 2002, 2008), but it is not known whether the sequence effect is specific to gaze cues or whether it also occurs with arrow cues. Therefore, in experiment 2, real face photographs and arrows were included as central cues, and were tested with more experimental trials.

## **4.3 Experiment 2**

### **4.3.1 Participants**

A total of 20 students (with a mean age of 27 years, range 21 to 35 years, 4 females)

from Kochi University of Technology consented to participate in this experiment. All participants reported normal or corrected-to-normal vision and were naive as to the purpose of the experiment.

### **4.3.2 Apparatus and stimuli**

The apparatus was the same as that in experiment 1. Face photographs and arrows, as illustrated in Figure 1(A), were included as central cues. For real gaze cues, the central fixation stimulus was a photograph of a female face with direct gaze, about  $4^\circ$  wide and  $7^\circ$  height, displayed in eight-bit grayscale. The face photograph was manipulated to produce the left-gaze and right-gaze cues by cutting out the pupil/iris area of each eye and pasting it into the left and right corner of each eye, respectively, using Photoshop CS2 software. Thus, only the area within the eyes differed between the cue and straight-gaze stimuli. For arrow cues, the central fixation stimulus was a horizontal line centered on the screen,  $2^\circ$  in length. An arrow head and an arrow tail appeared at the ends of the central line, both pointing left or both pointing right. The length of an arrow, from the tip of the arrow head to the ends of the tail, was  $2.5^\circ$ . Other stimuli were the same as those in experiment 1.

### **4.3.3 Design and procedure**

The design and procedure were the same as that in experiment 1 with the following exceptions. There were two sessions, one for gaze cues and one for arrow cues. The order of sessions was counterbalanced across participants. Each session contained two blocks with a total of 192 trials. Including 20 training trials for each session, there were in total 424 trials for each participant. The RTs of the first trial in each block were

excluded from analysis. The central cue stimuli were real face photographs or arrows, rather than schematic faces.

In order to make an equal number of pre-cued and pre-uncued trials for each participant, the number of cued-cued, cued-uncued, uncued-cued, and uncued-uncued trial-pairs between trial n-1 and trial n was counted after the main experiment. After that, extra trial pairs were joined up and tested to retain the number of these trial-pairs equal for each participant. Because no significant difference was observed when the equal trial number was retained or not retained in both experiment 1 and experiment 2, extra trial pairs were not tested for the rest experiments.

#### **4.3.4 Results**

Error calculation was identical to experiment 1. About 5.4% and 4.9% of all trials were removed as errors in gaze-cue and arrow-cue conditions, respectively. The error rates did not vary systematically and no signs of any speed-accuracy trade-off were observed.

A four-way ANOVA with cue type (gaze-cue and arrow-cue), previous cue validity (pre-cued and pre-uncued), SOA (100, 300, and 700 ms), and cue validity (cued and uncued) as within-participants factors was conducted on the RTs. There was a significant main effect of cue validity,  $F(1, 19) = 29.283$ ,  $p < .0001$ , replicating gaze-cueing effects in real face and arrow conditions. The interaction of cue type  $\times$  cue validity was significant,  $F(2, 38) = 7.818$ ,  $p < .012$ , indicating that gaze cues induced relatively stronger cueing effect (16 ms) than arrow cues (11 ms). The magnitude of cueing effects with different previous cue validity and SOAs for gaze-cue and arrow-cue conditions is shown in Figure 4-3(A1, A2). The main effect for SOA and the interaction



between SOA and cue validity were also significant, at  $F(2, 38) = 130.525, p < .0001$ , and  $F(2, 38) = 8.339, p < .001$ , respectively.

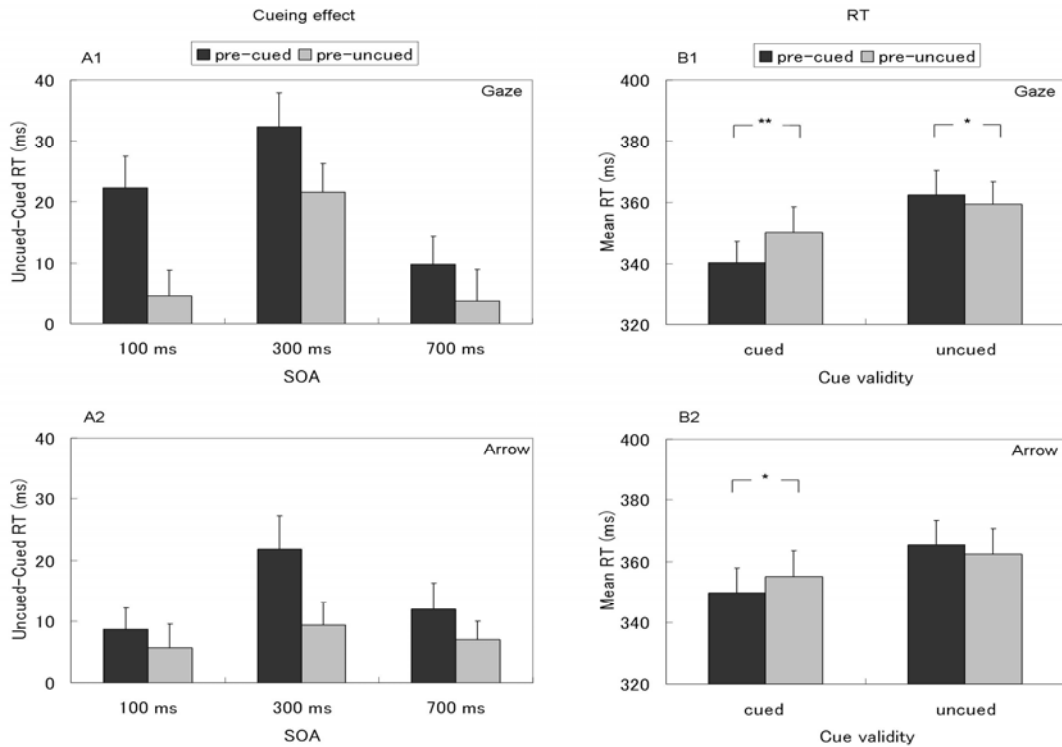


Figure 4-3. Results of experiment 2. Panel A1 and B1 are gaze-cue condition and Panel A2 and B2 are arrow-cue condition. The meaning of the graph is the same as Figure 4-2.

Similar to the observations for experiment 1, the previous cue validity  $\times$  cue validity interaction was significant,  $F(1, 19) = 18.008, p < .0001$ , replicating the sequence effect. In addition, this sequence effect did not interact with cue type or SOA (both  $ps > .27$ ), indicating that neither cue types nor SOAs had a significant influence on the sequence effect. No other factors or interactions were significant.

A paired-samples t-test was used to further compare the RTs between pre-cued and pre-uncued trials, and the results are illustrated in Figure 3(B1, B2). In gaze-cue condition, the RTs of cued trials were significant faster when the trials were preceded by cued trials (i.e., trial type repeated) than by uncued trials (i.e., trial type switched),  $t(19)$

= 4.384,  $p < .0001$ . The RTs of uncued trials were significant faster when the trials were preceded by uncued trials (i.e., trial type repeated) than by cued trials (i.e., trial type switched),  $t(19) = 2.323$ ,  $p < .031$ . These observations again confirmed that repeating a trial type quickens RT. The patterns in arrow-cue condition were very similar to those in gaze-cue condition, though the RT difference for uncued trials between pre-cued and pre-uncued conditions failed to reach significance ( $t(19) = 2.508$ ,  $p < .021$ , and  $t(19) = 1.617$ ,  $p = .122$ , for cued and uncued trials, respectively).

In addition, in order to confirm that the sequence effect was attributed to the repetition/switch effect that occurs between trial  $n-1$  and trial  $n$ , rather than the long runs of one trial type (e.g., cued trials appeared repeatedly in a long trial sequence), the trials that were preceded by repetitions of the same trial type were removed. For example, as to the cued (trial  $n-1$ ) -cued (trial  $n$ ) trial pairs, the RTs of trial sequence cued (trial  $n-2$ ) -cued-cued would be removed, only the RTs of trial sequence uncued-cued-cued remained. This operation removed about half of the experimental trials and the analysis again showed a significant main effect of cue validity,  $F(1, 19) = 48.902$ ,  $p < .0001$ , and a significant previous cue validity  $\times$  cue validity interaction,  $F(1, 19) = 13.480$ ,  $p < .002$ , indicating the cueing effect and the sequence effect. This result proved that the sequence effect was significant even when the potential influence of long runs of one trial type was excluded.

Frischen and Tipper (2006) reported a long-term gaze cueing effect wherein perceiving the gaze cue (e.g., a left gaze) of a specific face could induce attention shift when the face with direct gaze was re-encountered some minutes later. Their study demonstrated a memory effect for gaze direction in gaze-cueing paradigm. Under a random experimental setting, left (or right) cues can be followed by left and right cues

equally often. Thereby, in order to investigate whether the sequence effect is cue-direction based, a four-way ANOVA with cue type (gaze-cue and arrow-cue), repetition condition of cue direction (repeated, switched), previous cue validity (pre-cued and pre-uncued), and cue validity (cued and uncued) as within-participants factors was conducted on the RTs. The sequence effect under different repetition conditions of cue direction is illustrated in Figure 4-4. The analysis showed a significant main effect of cue validity,  $F(1, 19) = 34.777$ ,  $p < .0001$ , indicating cueing effects, and a significant previous cue validity  $\times$  cue validity interaction,  $F(1, 19) = 39.238$ ,  $p < .0001$ , indicating sequence effects. As for the influence of repetition of cue direction, there was a significant main effect of repetition,  $F(1, 19) = 17.446$ ,  $p < .001$ , indicating that RTs were shorter when cue direction repeated than when it switched. Interestingly, the interaction of repetition  $\times$  cue validity was also significant,  $F(1, 19) = 5.994$ ,  $p < .024$ , which was further qualified by a significant three-way interaction between repetition, previous cue validity, and cue validity,  $F(1, 19) = 6.421$ ,  $p < .020$ , reflecting that sequence effects mainly occurred when the cue direction switched, rather than repeated. No other factors or interactions were significant.

Finally, the results of Maylor and Hockey (1987) showed that observer's response was slowed when the same target location was repeated in a spatial cueing paradigm. So, in order to investigate the influence of target repetition in present study, a two-way ANOVA with cue type (gaze-cue and arrow-cue), repetition condition of target location (repeated, switched) as within-participants factors was conducted on the RTs. The main effect of repetition was indeed significant,  $F(1, 19) = 4.764$ ,  $p < .042$ , indicating that RTs were longer when target location repeated than when it switched. No other factors or interactions were significant.

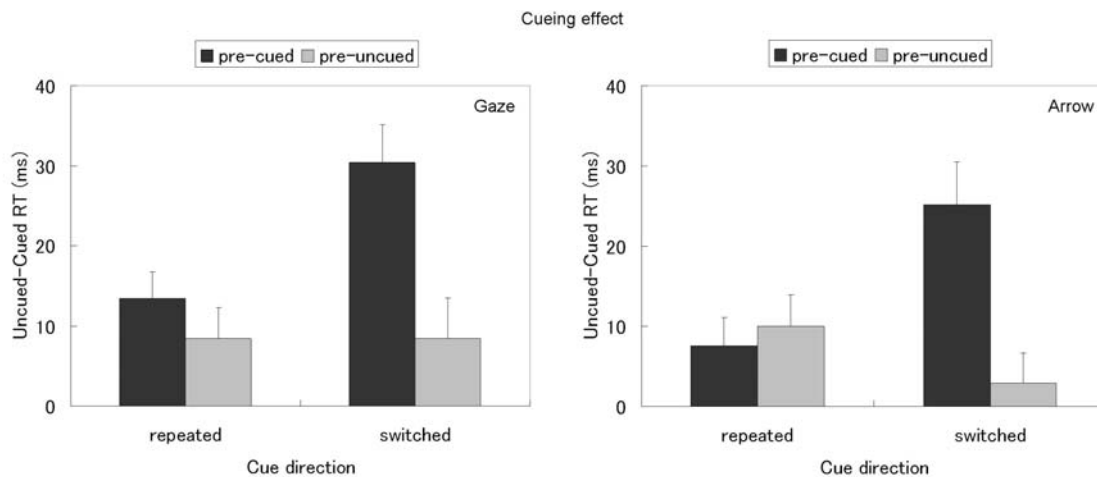


Figure 4-4. The magnitude of cueing effects for trials preceded by cued or uncued trials with different repetition conditions of cue direction between trials in experiment 2.

#### 4.3.5 Discussion

The sequence effect of gaze cueing observed in experiment 1 was replicated with real faces and arrows as central cues, even when the potential influence of long runs of one trial type was excluded. Furthermore, because significant sequence effects were observed when cue directions between trial  $n-1$  and trial  $n$  switched, the present results suggested that the sequence effect is indeed based on memory to the cue validity states, rather than cue direction. The findings that sequence effects were relatively weak when the cue direction repeated might be due to the fact that repetition of cue direction quickened RT; thus, observers might be near ceiling performance in this condition and repeating a trial type would not quicken RT any more. Another possibility is that the repetition/switch effect of the target location canceled the sequence effect in this condition. Specifically, when gaze direction is repeated, the cueing effect of pre-cued trials will be reduced, because target repetition will lead to a relatively long cued RT; in contrast, the cueing effect of pre-uncued trials will be enhanced, because target

repetition will lead to a relatively long uncued RT.

Despite the small difference for uncued trials, there had no significant difference in sequence effects for gaze and arrow cues. This result may suggest that the sequence effect is a common phenomenon for attentional cues. In order to further investigate whether or not the sequence processing can generalize across cue categories, in experiment 3, the central cues (gaze and arrow) were alternated between trials.

## **4.4 Experiment 3**

### **4.4.1 Participants**

A total of 21 students (with a mean age of 27 years, range 23 to 34 years, 6 females) from Kochi University of Technology consented to participate in this experiment. All participants reported normal or corrected-to-normal vision and were naive as to the purpose of the experiment.

### **4.4.2 Apparatus and stimuli**

The apparatus and stimuli were the same as those in experiment 2.

### **4.4.3 Design and procedure**

The design and procedure were the same as those in experiment 2, with the following exceptions. The central cues were either real face photographs or arrows and they were alternated between trials. There were two blocks with a total of 192 trials. Including 20 training trials, there were a total of 212 trials for each participant.

#### 4.4.4 Results and discussion

Error calculation was identical to experiment 1. The data of one male participant was removed because of a high error rate (more than 15%). About 4.7% of all trials were removed as errors. The error rates did not vary systematically and no signs of any speed-accuracy trade-off were observed.

A three-way ANOVA with previous cue validity, SOA, and cue validity as within-participants factors was conducted on the RTs. The main effects of cue validity and SOA were significant,  $F(1, 19) = 19.211$ ,  $p < .0001$ , and  $F(2, 38) = 93.361$ ,  $p < .0001$ , respectively. The interaction between SOA and cue validity was also significant,  $F(2, 38) = 3.646$ ,  $p < .036$ .

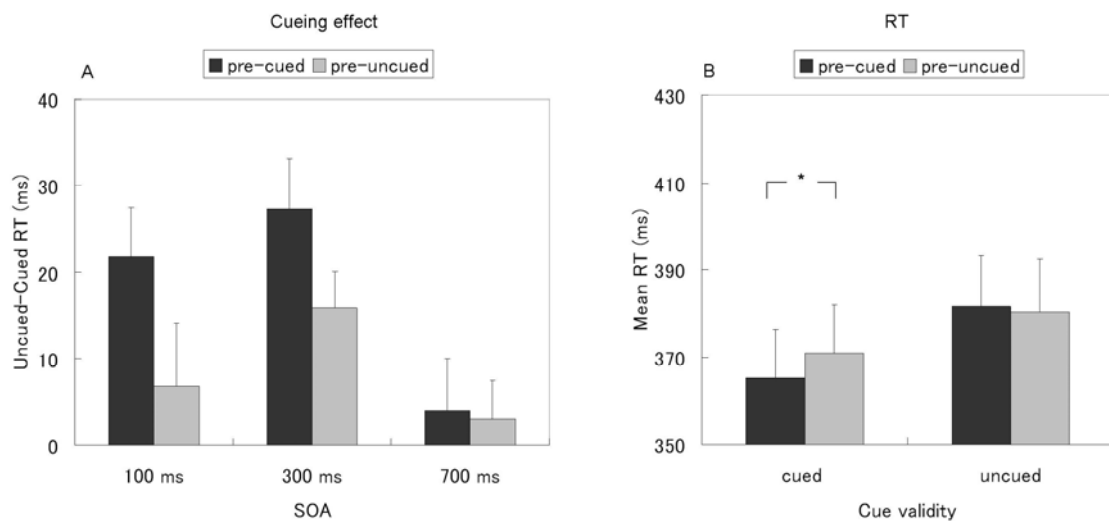


Figure 4-5. Results of experiment 3. The meaning of the graph is the same as Figure 4-2.

Again, the previous cue validity  $\times$  cue validity interaction was significant,  $F(1, 19) = 5.197$ ,  $p < .034$ , indicating sequence effects. This result suggests that sequence processing can generalize across different cue categories. The magnitude of cueing effects with different previous cue validity and SOAs is shown in Figure 4-5(A). No other factors or interactions were significant.

A paired-samples t-test revealed that the RTs of cued trials were significantly faster when the trials were preceded by cued trials (i.e., trial type repeated) than by uncued trials (i.e., trial type switched),  $t(19) = 2.184$ ,  $p < .042$ , and that the RTs of uncued trials were not significantly different when the trials were preceded by cued and uncued trials ( $p > .57$ ). The results are illustrated in Figure 4-5(B).

## **4.5 Experiment 4**

In experiments 1 to 3, the participants were asked to indicate the location of a target by pressing left or right buttons with their left or right hands. This localization task may have introduced stimulus-response mapping effects into the experiment. Though such effects probably have no influence on the sequence effect because they are averaged across pre-cued and pre-uncued trials, the present experiments may have been measuring the response correspondence effect, rather than orienting of attention. In experiment 4, a discrimination task was used to clarify this issue. Participants were asked to respond to the target identity so that the response was irrelevant to the cue direction. If the sequence effect relies on specific tasks that involve response correspondence, it should not be observed in this experiment.

### **4.5.1 Participants**

A total of 14 students (with a mean age of 26 years, range 21 to 31 years, 2 females) from Kochi University of Technology consented to participate in this experiment. All participants reported normal or corrected-to-normal vision and were naive as to the purpose of the experiment.

### **4.5.2 Apparatus and stimuli**

The stimuli were presented on a LCD display operating at a 60 Hz frame rate and the display of the stimuli was controlled by E-Prime software (Schneider, Eschman, and Zuccolotto, 2002). The participants were seated approximately 60 cm away from the screen.

The stimuli were the same as that in experiment 2 except that only gaze cues were tested and the target could be either letter 'O' or 'X', which was displayed randomly for each trial.

### **4.5.3 Design and procedure**

The design and procedure were the same as in experiment 2, with the following exceptions. The participants were asked to respond to the identity of the target with one hand. Half of the participants were asked to press the 'UP' arrow key on the keyboard for a target letter 'O' and 'DOWN' arrow key for a target letter 'X', the other half of the participants were asked to press 'DOWN' arrow key for a 'O' and 'UP' arrow key for a 'X'. There were two blocks with a total of 160 trials. Including 20 training trials for each session, there were in total 180 trials for each participant.

### **4.5.4 Results and discussion**

Error calculation was identical to experiment 1. About 7.9% of all trials were removed as errors. The error rates did not vary systematically and no signs of any speed-accuracy trade-off were observed.

A three-way ANOVA with previous cue validity, SOA, and cue validity as within-participants factors was conducted on the RTs. The main effects of cue validity



and SOA were significant,  $F(1, 13) = 12.826$ ,  $p < .003$ , and  $F(1, 13) = 45.462$ ,  $p < .0001$ , respectively. Importantly, the previous cue validity  $\times$  cue validity interaction was significant,  $F(1, 13) = 5.895$ ,  $p < .030$ , indicating sequence effects. This result suggests that sequence effects are not related to specific tasks and indeed acts on the orienting of attention. The magnitude of cueing effects with different previous cue validity and SOAs is shown in Figure 6(A). No other factors or interactions were significant.

A paired-samples t-test revealed that the RTs of cued trials were significant faster when the trials were preceded by cued trials (i.e., trial type repeated) than by uncued trials (i.e., trial type switched),  $t(13) = 2.234$ ,  $p < .044$ . The RTs of uncued trials were significant faster when the trials were preceded by uncued trials (i.e., trial type repeated) than by cued trials (i.e., trial type switched),  $t(13) = 2.310$ ,  $p < .038$ . The results are illustrated in Figure 4-6(B).

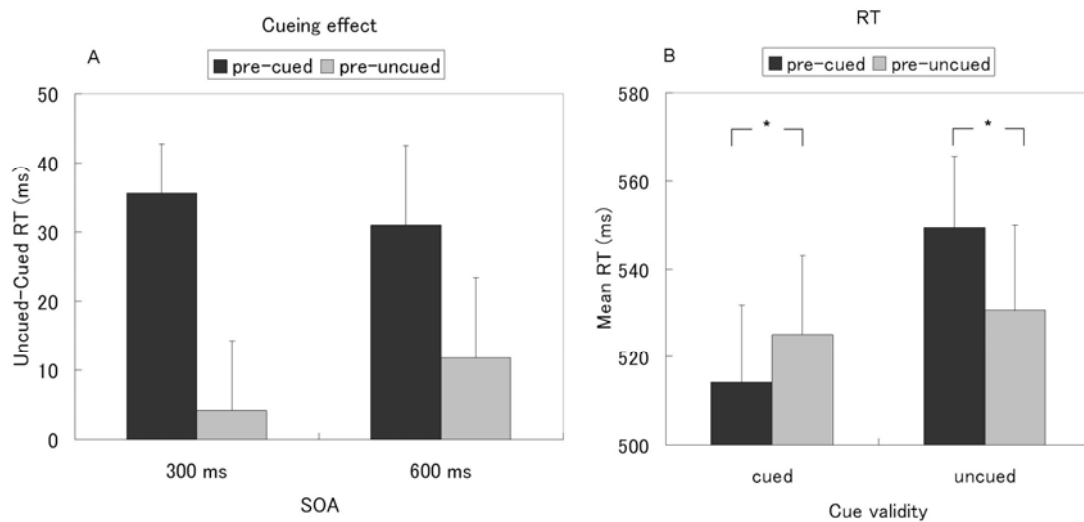


Figure 4-6. Results of experiment 4. The meaning of the graph is the same as Figure 4-2.

#### 4.6 General Discussion

Four experiments were conducted to examine whether the change of cue validity

states between trials influences gaze-cueing effects. The results showed that the magnitude of cueing effects is significantly influenced by the cue validity of previous trials, and this sequence effect is attributed to the repetition/switch effect (i.e., RT is faster when the trial type repeated than when it is switched) that occurs for both cued and uncued trials. Furthermore, sequence effects could occur and generalize across different cue categories (gaze and arrow), suggesting that the sequence effect is probably a common phenomenon in the processing of directional cues. In sum, the present results strongly suggest that with each attentional deployment to a target followed by a given cue (gaze or arrow, in this case), there is a process that effectively associates the deployment of attention with this cue to boost performance significantly.

The observed sequence effect of gaze cueing is not attributed to the voluntary control or explicit strategies of participants for the following reasons. First, the participants knew the gaze direction was uninformative and they were instructed to ignore the central face. Therefore, there was no intention for participants to explicitly remember the cue validity of previous trials and use it to guide their next reaction. Second, the sequence effect occurred at a very short SOA (100 ms). The consensus in the literature has been that attention shifts on this timescale are not under any form of voluntary control (Klein, Kingstone, and Pontefract, 1992; Nakayama and Mackeben, 1989). Third, sequence effects were observed for both localization and discrimination tasks, suggesting that the sequence effect does not rely on the goal or intention of the participant. Fourth, according to the results of a survey made after experiments for all participants, although most of the participants felt that during one trial central gaze cue had some influence on their reactions, none of them reported that they remembered the cue validity of previous trials or that the previous cue validity influenced their

reactions on later trials (for the importance of subjective reports, see Kingstone, Smilek, and Eastwood, 2008). All the evidence suggests that the sequence effect of gaze cueing is not under voluntary control, and is probably afforded by implicit visual memory mechanisms, which retains information of previous views without conscious intervention (Kristjansson, 2006; Chun and Nakayama, 2000).

The evidence for the role of implicit visual memory mechanisms on attention allocation has mainly come from studies of visual search paradigm, and most of these studies focused on simple features, such as color, shape, and location. Whether or not the implicit memory also operates for more complex and natural stimuli is still unclear. One study that tried to solve this question is the study of Lamy, Amunts, and Bar-Haim, (2008). In their study, participants detected the face displaying a discrepant expression of emotion in an array of four face photographs. The detection performance was faster when the target face displayed the same emotion (either angry or happy) on successive trials. Their results suggest that facial expressions of emotion can be stored into the implicit memory, and then be retrieved to influence attention allocation in the next trials. By a gaze-cueing task, it was showed that not only simple stimuli like arrows, but also complex and biological significant gaze cues are involved in the processing of implicit memory mechanisms. The implicit memory processing of gaze cues is reasonable considering the important role of gaze perception in real-life situations. The detailed effects of the implicit memory on gaze cueing, such as how long it lasts and how vulnerable it is, should be addressed in further research.

It is now well established that when a gaze shift is observed, the observer's attention rapidly and automatically orients to the same location in space (e.g., Friesen and Kingstone, 1998). The common view about such attention shifts is that they are

relatively transient and reflexive. One may expect gaze-cueing effects to be purely automatic and not influenced by high-level processes, such as memory. However, recent studies have consistently shown the influence of memory on gaze cueing. Frischen and Tipper (2006) demonstrated a memory effect for gaze direction in gaze-cueing paradigm wherein perceiving the gaze cue (e.g., a left gaze) of a specific face can induce attention shift when the face with direct gaze is re-encountered some minutes later. In another study, Frischen and Tipper (2004) reported a long-term inhibitory effect wherein RTs were inhibited at a long cue-target SOA (2400 ms) and this longer term attentional effect did not appear to be contingent on retrieval associated with a particular face identity (see also Frischen, Smilek, Eastwood, and Tipper, 2007). These studies clearly suggested that gaze cueing is not purely automatic or reflexive, but is influenced by the attentional states in previous views. Consistent with this suggestion, the present results showed another form of influence from previous views in gaze cueing. Specifically, gaze-cueing effects are influenced by the memory to the attentional states between two consecutive trials. Such observation provides a more general and complete understanding of the role of memory on gaze-evoked attention orienting.

Furthermore, it was demonstrated that the influence of memory on attention orienting is not necessarily limited to gaze cues, but can also be observed for arrow cues or even the cues that changed between trials. These observations are in line with recent studies that reported similar attentional effects between gaze and arrow cues (e.g., Tipples, 2008; Birmingham and Kingstone, 2009). Nevertheless, this does not mean sequence effects of gaze cueing are completely identical to those of arrow cueing. Indeed, there had a small difference in the sequence effect between gaze and arrow cues: the RT difference between pre-cued and pre-uncued groups of uncued trials reached

significance only for gaze cues, but not for arrow cues or the cues changed between trials. This phenomenon may have originated in the different RT cost-benefit effects between gaze and arrow cues (Longdon and Smith, 2005). However, because neutral conditions were not included, more conclusions cannot be made based on the current results. The details of the sequence effect among different attentional cues will be systematically investigated in future research.

Finally, the significant influence of previous cue validity on cueing effects also has some implications on studies that involved gaze-cueing paradigm, especially for studies that aimed to investigate predictive or counter-predictive cues (e.g., Driver et al., 1999; Friesen, Ristic, and Kingstone, 2004). For example, when the gaze cue predicts the target location with a rate of 80 percent, there will have more pre-cued trials than pre-uncued trials. As a result, larger average cueing effects for predictive cues than non-predictive cues is due in part to sequence effects, not only due to the voluntary control of observers. Clearly it is important for future studies to take the influence of sequence effects into account when results are evaluated.

## Chapter 5

# The functional role of alternation advantage in the sequence effect of arrow cueing

### 5.1 Introduction

Although some early studies suggested that very little visual information is explicitly retained across views (e.g., Grimes, 1996; Ballard, Hayhoe, & Pelz, 1995), many recent studies have consistently shown that attention allocation is heavily influenced by the most recently viewed stimuli that were important for behavior (e.g., Chun & Nakayama, 2000; Wolfe et al., 2003). For instance, Maljkovic & Nakayama (1994) found that in searching for a color singleton target, when target and nontarget colors are switched unpredictably from trial to trial, response in a trial is faster when the target color is the same as in the preceding trial than when it is different, a phenomenon that they called priming of pop-out (PoP). Besides color, this sequence effect on visual search performance has also been observed in investigations of other properties such as orientation (Hillstrom, 2000), shape (Lamy et al., 2006), location (Maljkovic & Nakayama 1996), and even emotional expression (Lamy, Amunts, & Bar-Haim, 2008). PoP was generally believed to be afforded by implicit visual memory mechanisms without voluntary intervention (Kristjansson, 2006). Another good demonstration of sequence effects between trials is negative priming (e.g., Neill and Valdes, 1992; Tipper, 2001), which refers to the phenomenon that a target stimulus is more slowly responded to on a current trial when the same stimulus was to be ignored on a previous trial. Negative priming was mainly explained as selective inhibition or

episodic retrieval (Egner and Hirsch, 2005). All of these studies showed that some crucial information from previous views could be used to guide attention allocation shortly afterward.

Sequence effects between trials were also found in endogenous spatial cueing paradigm, in which observers respond to a left or right target following a valid or invalid central symbolic cue that indicated the possible target locations. By using a predictive central arrow cue (i.e., the ratio of valid trials among all trials were 80%), Jongen and Smulders (2006) reported that the cueing effect (i.e., RT of invalid trials - RT of valid trials) was larger after a valid trial than after an invalid trial. They explained this sequence effect as momentary strategical adjustments, in which participants adapt their utilization of the cue depending on whether it correctly or wrongly directed their attention on the previous trial. Specifically, a valid trial enhances the expectation for repetitions so that it is beneficial to direct attention to the cued location, whereas an invalid trial weakens this expectation or even promotes orienting to the uncued location. However, the sequence effect observed in the study of Jongen and Smulders can also be well explained by automatic memory processes (Logan, 1988) in which information of previous trials is automatically retrieved from memory to facilitate performance on current trials. For example, when the previous trial type (valid or invalid) is consistent with the current trial type, performance will be facilitated, whereas when the previous and current trial types differ, performance is slowed due to the conflict between the two trial types. This automatic retrieval hypothesis is in line with the view from exogenous cueing studies (Dodd and Pratt, 2007; Mordkoff, Halterman, and Chen, 2008) and further supported by the results of our previous study (Qian, Shinomori, and Song, 2011), in which the sequence effect was still found when the arrow cues did not predict

the target location and the participants were explicitly asked to ignore the arrow cues.

trial n-1		trial n		cue validity		repetition condition		
cue direction	target location	cue direction	target location	trial n-1	trial n	validity	cue direction	target location
L	L	L	L	valid	valid	*	*	*
L	R	L	R	invalid	invalid	*	*	*
L	L	R	R	valid	valid	*		
L	R	R	L	invalid	invalid	*		
L	L	L	R	valid	invalid		*	
L	R	L	L	invalid	valid		*	
L	L	R	L	valid	invalid			*
L	R	R	R	invalid	valid			*
R	R	R	R	valid	valid	*	*	*
R	L	R	L	invalid	invalid	*	*	*
R	R	L	L	valid	valid	*		
R	L	L	R	invalid	invalid	*		
R	R	R	L	valid	invalid		*	
R	L	R	R	invalid	valid		*	
R	R	L	R	valid	invalid			*
R	L	L	L	invalid	valid			*

Table 5-1. The possible combinations of cue direction (Left or Right) and target location (Left or Right) between trial n-1 and trial n. The repetitions of validity, cue direction, or target location between trial n-1 and trial n were marked with an asterisk.

One important issue in the investigation of sequence effects in cueing paradigm is the influence of cue direction and target location. The automatic retrieval hypothesis interpreted the sequence effect as the repetition advantage effect of cue validity between trials. However, when taking the cue direction and target location into account, there are two possible repetition conditions (see Table 5-1). For example, following a valid trial in which both the cue direction and target location are left, the cue direction and target location of the next valid trial can be both left again (line 1 of Table 5-1) or both right (line 3 of Table 5-1). In the former condition, cue validity, cue direction, and target location repeat at the same time. In the later condition, only the cue validity of the trials repeats, but the cue direction and target location are both switched. The same circumstances can be found for trial pairs with repeated invalid cue validities (e.g., line 2 and line 4 of Table 5-1). Whether or not the sequence effect of cueing paradigm is influenced by the repetition/switch of cue direction and target location has not been well investigated.

Jongen and Smulders (2006) did not directly investigate the influence of cue



direction and target location on the sequence effect. Though they conducted an ANOVA on the RTs and found a significant four-way interaction between previous cue direction, previous target location, current cue direction, and current target location, which indicated sequence effects, the potential influence of cue direction and target location on the sequence effects could not be seen in this analysis. In our previous study (Qian et al., 2011), we found a tendency for the sequence effect to be stronger when the cue direction between trials switched compared with when it repeated. However, this tendency failed to reach significance ( $F = 2.014$ ,  $p = .017$ ). The failure to show a significant influence may be attributed to two factors. First, the number of participants was relatively small (only sixteen). Second, the time interval between arrow cues and targets (stimulus onset asynchrony (SOA)) was either 100 ms or 700 ms, and the sequence effect in that study was proved not significant when the SOA of previous trials was 100 ms. This means the sequence effect was not shown during the half of the trials in that study, and this may have hindered the investigation into the influence of cue direction and target location. Therefore, we were motivated to carry out a systematic investigation on the influence of cue direction and target location on the sequence effect of arrow cueing. Such an investigation is important because it may reveal the detailed mechanisms under the sequence effects and provide better understanding of the endogenous cueing paradigm for future researches.

The aim of the present study is to investigate the potential influence of repetition/switch effect of cue direction and target location on the sequence effects of arrow cueing. Three conditions with different manipulation of cue directions will be tested. In the first condition, the arrows always cue the same location among one block (either left or right) while the target locations remain random. Therefore, following a

valid or invalid trial, the next trial with repeated cue validity will always have the same cue direction and target location as the previous trial. In the second condition, the arrows always cue a different location away from the previous arrow (the cue sequence will be ...left, right, left, right...) while the target locations remain random. Therefore, when the cue validity of consecutive trials repeats, both the cue direction and the target location are alternated. In the third condition, the previous two conditions are randomly combined to form a common cueing procedure, in which both cue directions and target locations remain random.

Notice that in the first and the second conditions, the cue direction on each trial is manipulated depending on the cue direction of previous trials. Therefore, cue direction uncertainty has been lost. The disappearance of cue direction uncertainty should have no significant influence on the sequence effect according to the automatic retrieval hypothesis. However, if the uncertainty of cue directions is an important requirement for the sequence effects, there should be no sequence effect in both of these conditions. Regarding the influence of repetition/switch effect of cue direction and target location, there are several possibilities. First, if the sequence effect is only dependent on repetition advantage effect of cue validity, a similar magnitude of sequence effect should be observed for all three conditions. Second, if the repetition of the cue direction and the target location can facilitate performance just like the repetition of the cue validity, the first condition with repeated cue directions should induce stronger sequence effects than the other two conditions, because cue validity, cue direction, and target location repeat at the same time. Third, many previous studies have reported that RT was slower when the same target location or response was repeated than when it was switched (e.g., Maylor and Hockey, 1987; Fecteau et al., 2004), i.e., alternation of target

location facilitates observer's performance and repetition of target location slows observer's performance. If this alternation advantage effect of target location occurs in cueing paradigm, the second condition with alternated cue direction should induce a stronger sequence effect than the other two conditions, because the performance will be facilitated by both the repetition of cue validity and the accompanying alternation of cue direction and target location. In addition, under the first condition with repeated cue direction, the performance will be facilitated by the repetition of cue validity, but will be slowed by the accompanying repetition of cue direction and target location, resulting in an impaired sequence effect compared with the other two conditions.

## **5.2 Experiment**

### **5.2.1 Participants**

A total of 20 students (with a mean age of 27 years, range 22 to 32 years, 6 females) from Kochi University of Technology consented to participate in this experiment. All participants reported normal or corrected-to-normal vision and were naive as to the purpose of the experiment.

### **5.2.2 Apparatus**

The stimuli were presented on a LCD display operating at a 60 Hz frame rate that was controlled by a Dell Pentium computer. The participants were seated approximately 60 cm away from the screen.

### **5.2.3 Stimuli**

A cross, subtending  $1.5^\circ$ , was placed at the center of the screen as a fixation point and remained on the screen during the whole experiment. The cue was an arrow to the left ( $\ll$ ) or to the right ( $\gg$ ) just around the central cross and was presented  $1.5^\circ$  in height and  $5^\circ$  in width. The target stimulus was a capital letter 'T' measuring  $1^\circ$  wide,  $1^\circ$  high, and was presented  $15^\circ$  away from the fixation point on the left or right side.

### **5.2.4 Design**

The cue-target SOA was 500 ms. There were three sessions with different manipulation of cue directions. The order of sessions was counterbalanced across participants. The cue directions remained the same within blocks (but switched between blocks) in the first session; the cue directions changed every trial in the second session; the cue directions remained random in the third session. The number of blocks in each session was two, two, and four. Each block included 112 trials in total, and 16 trials were catch trials in which the target did not appear. The participants were instructed not to respond if the target did not appear. Including 20 training trials, there were in total 916 trials for each participant. The RT of the first trial on each block and the RT of the trials followed a catch trial were excluded from analysis.

### **5.2.5 Procedure**

Participants were instructed to keep fixating on the center of the screen. First, a fixation display appeared at the center of the screen for 2000 ms, and then the cue stimulus appeared. After a certain cue-target SOA, a target letter 'T' appeared either at left or right until participants had responded or 1500 ms had elapsed. Participants were

instructed to respond when the target appeared by pressing the 'SPACE' key as quickly and accurately as possible. Participants were explicitly told the manipulation of cue directions in each session. Participants were also informed that the central stimuli did not predict the location in which target would appear and that they should try to ignore the central cues.

### 5.3 Results

The participants missed an average of about 0.1% of the targets and made false alarm errors on approximately 1.2% of the catch trials. Anticipations (RT of less than 100 ms) and outliers (RT over 1000 ms) were classified as errors and were excluded from analysis. As a result, about 0.5% of all trials were removed. The error rates did not vary systematically and no signs of any speed-accuracy trade-off were observed.

A three-way ANOVA with previous cue validity (pre-valid and pre-invalid), cue validity (valid and invalid), and manipulation condition of cue directions (always repeat, always switch, and random) as within-participants factors was conducted on the RTs. There was a main effect of cue validity,  $F(1, 19) = 16.998$ ,  $p < .001$ , indicating cueing effects, i.e., RTs were shorter in valid than in invalid trials. There was significant interaction between previous cue validity and cue validity,  $F(1, 19) = 6.012$ ,  $p < .024$ , demonstrating that the cueing effect was stronger after a valid trial than after an invalid trial, i.e., a typical sequence effect as reported by previous studies. Importantly, the three-way interaction of previous cue validity  $\times$  cue validity  $\times$  cue manipulation condition was significant,  $F(2, 38) = 7.844$ ,  $p < .001$ , indicating that the sequence effect was influenced by the manipulation condition of the cue directions. The magnitude of cueing effects under different conditions can be seen from Figure 5-1, and the

magnitude of sequence effects (i.e., cueing effects of pre-valid trials – cueing effects of pre-invalid trials) for each cue manipulation condition was -5 ms (always repeat), 29 ms (always switch), and 9 ms (random). Paired-samples t-tests proved firstly that the sequence effect when cue directions always switch was stronger than the sequence effects when cue directions always repeat or remain random ( $p < .002$ , and  $p = .055$ , respectively), and secondly that the sequence effect when cue directions remain random was stronger than the sequence effect when cue directions always repeat ( $p < .033$ ). The results showed that sequence effects were impaired when the cue direction always repeats between trials and were enhanced when the cue direction always switches between trials.

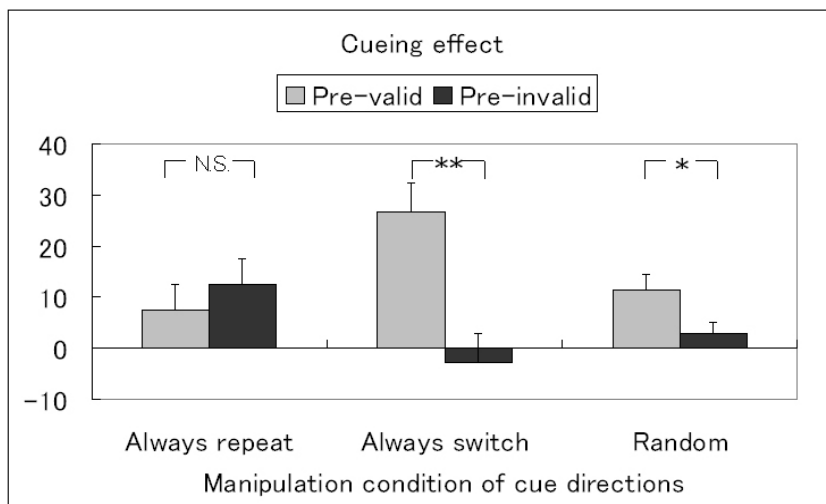


Figure 5-1. The magnitude of cueing effects ( $RT_{uncued} - RT_{cued}$ ) under different previous cue validity, and cue manipulation conditions. The asterisks mark the statistically significant differences (significant level 0.05 and 0.01). Error bars denote standard errors of the mean.

When the cue direction was chosen randomly at the last manipulation condition, the cue direction between trials could be either repeated or switched. This gives us an opportunity to investigate the influence of cue direction and target location without the loss of cue direction uncertainty. A three-way ANOVA with previous cue

validity (pre-valid and pre-invalid), cue validity (valid and invalid), and cue condition (same or different than previous trial) as within-participants factors was conducted on the RTs of the third condition with random cue directions. The main effect of previous cue validity and the main effect of cue validity were significant,  $F(1, 19) = 7.962$ ,  $p < .011$ , and  $F(1, 19) = 12.475$ ,  $p < .002$ , respectively, indicating that RTs were shorter at pre-invalid than at pre-valid trials, and were shorter in valid than in invalid trials. Importantly, the previous cue validity  $\times$  cue validity  $\times$  cue condition interaction was also significant,  $F(1, 19) = 5.722$ ,  $p < .027$ , replicating the previous observation that the sequence effect was significant when the cue direction switched but not significant when the cue direction repeated. The magnitude of cueing effects under different conditions can be seen from Figure 5-2, and the magnitude of sequence effects for each cue condition was -6 ms (repeat), 16 ms (switch).

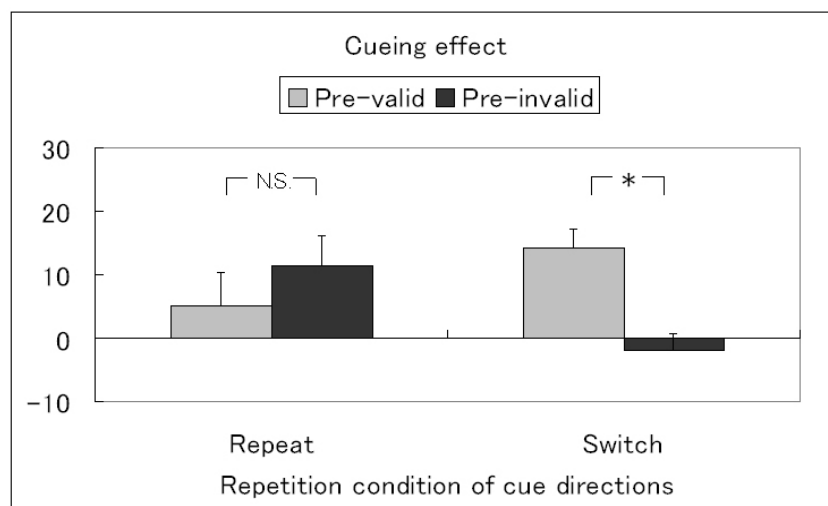


Figure 5-2. The magnitude of cueing effects under different repetition conditions of cue direction when the cue directions remain random. The asterisk marks the statistically significant differences (significant level 0.001). Error bars denote standard errors of the mean.

## 5.4 Discussion

The present study investigated whether the repetition/switch of cue direction and target location could influence the sequence effect in an arrow cueing paradigm. The results showed that sequence effects were impaired when the cue direction always repeats between trials and were enhanced when the cue direction always switches between trials. Similar results were also found in a common cueing procedure when the cue direction on each trial was chosen randomly. The results suggest that the sequence effect of endogenous cueing paradigm cannot be solely attributed to the repetition advantage of cue validity, but is also modulated by the repetition/switch effect of cue direction and target location.

According to the automatic retrieval hypothesis, information of previous trials is automatically retrieved from memory to facilitate performance on current trials. However, the present results suggest that the automatic retrieval hypothesis is not adequate to interpret all phenomena under the sequence effects of cueing paradigm. In fact, the participants' performance was slowed, rather than facilitated, by the repetition of cue direction and target location. As a result, the sequence effects were modulated by this alternation advantage effect of cue direction and target location. Alternation advantage effect has been reported by many studies in both detection and choice RT tasks (e.g., Maylor and Hockey, 1987; Fecteau et al., 2004). There are two explanations for the alternation advantage effect: guessing strategies of participants or inhibition mechanisms. According to the guessing strategy explanation, participants expect that a target appearing at a particular location is more likely to be followed by a target appearing at the opposite location even though the probability of either location is equal. Because the participants already know the cue direction of the next trial when the cue



directions always repeat or switch between trials, they do not need to guess the next cue direction. Therefore, if the alternation advantage effect is a result of guessing strategies, then the current influence of alternation advantage on the sequence effect can solely be attributed to the repetition/switch effect of target location, rather than the repetition/switch effect of cue direction. On the other hand, if the alternation advantage effect is a result of inhibition mechanisms, then we cannot discriminate the repetition/switch effect of cue direction from that of target location.

One thing that needs to be pointed out is that in an exogenous cueing paradigm, Dodd and Pratt (2007) failed to show the significant influence of target location on the sequence effect of peripheral cueing. One critical difference between this study and peripheral cueing studies is that the arrow cue is perceptually different but spatially similar, whereas the peripheral cue is perceptually identical but the spatial location differs. Shifts of attention by central cues tend to be slower than shifts to peripheral cues, and many studies have concluded that different processing mechanisms are involved between arrow cueing and peripheral cueing (e.g., Jonides, 1981; Müller and Rabbitt, 1989; Cheal and Lyon, 1991). Therefore, it is not surprising to find that the influence of repetition/switch of cue direction and target location on the sequence effects of cueing paradigm only appeared for arrow cues. In line with the current findings, our previous study (Qian et al., 2011) found that the sequence effect of arrow cueing was modulated by the cue-target SOAs of the previous trials, which was different from the findings of peripheral cueing tasks (Mordkoff, Halterman, and Chen, 2008). Further investigation is needed to reveal the precise mechanisms involved in the sequence effect of arrow cueing and peripheral cueing.

During the past three decades, spatial cueing paradigm has been widely used in the

study of attention orienting. However, very few studies have tried to investigate the trial-by-trial effects in the cueing paradigm. Several previous studies (e.g., Jongen and Smulders, 2006; Qian et al., 2011) have attributed this sequence effect to the repetition/switch effect of cue validity, however, the detailed mechanisms under the sequence effect are still unclear. The present study extends previous findings by demonstrating that the repetition/switch effect of cue direction and target location is also involved in the sequential processes of the arrow cueing. This result may have revealed the potential mechanisms involved in the sequence effect of endogenous cueing paradigm, and it could be used to guide future cueing studies. In addition, because the same result was not found in a peripheral cueing study (Dodd and Pratt, 2007), the present study may have found new evidence of the difference between endogenous and exogenous cueing.

In summary, the present study demonstrated that sequence effects of arrow cueing are modulated by the repetition/switch effect of cue direction and target location. The results suggest that automatic retrieval hypothesis is not sufficient to interpret all phenomena under the sequence effects of cueing paradigm. The sequence effects of endogenous cueing paradigm are probably a result of interaction between repetition facilitation effect of cue validity and alternation advantage effect of cue direction and target location.

## Chapter 6

### General Conclusion and Future Inquiries

#### 6.1 General conclusion

Vision is the essential source where we get information from the outside world. Visual attention allows us to focus on the task in hand continuously and to locate the most significant objects. During attention processes, attention orienting refers to the way in which attention is allocated over the visual field and reallocated from time to time. Thus, it has been a long history for researchers in physiological, psychological, and psychophysical fields to investigate the mechanisms about how attention allocates and what controls the attention allocation from one region of the visual fields to another. This thesis firstly introduced the spatial cueing paradigm that has been widely used in the investigation of attention orienting. Then, the following four issues that have not been well examined in previous literatures are pointed out. These four issues are important to obtain the better understanding of the cueing paradigm and human attention orienting systems.

1. The contribution of low-level spatial compatibility and high-level gaze perception on the gaze-cueing effect
2. The sequence effects of arrow cueing
3. The sequence effects of gaze cueing
4. The influence of cue direction and target location on the sequence effects of arrow cueing

The chapter 2 focuses on the origin of gaze-evoked attention orienting. This issue is

crucial to understand the contribution of low-level spatial compatibility and high-level gaze perception on the gaze-cueing effect. Two experiments were performed to investigate this issue. In the experiment 1, high-level gaze perception was manipulated by changing the face context (head orientation) of the gaze cue, while the local-feature information of the eye region was preserved for all stimuli. Therefore, any influence on the gaze-cueing effect only can be attributed to the high-level gaze perception, rather than low-level spatial compatibility of the eye region. The results showed that the orientation of the profile face contexts influenced the perceived gaze directions, which in turn influenced the magnitude of gaze-cueing effects. Specifically, gaze-cueing effects were enhanced when the perceived gaze direction was averted more toward left or right side, and reduced when the perceived gaze direction was closer to direct gaze.

In order to clarify that the observed influence of profile face contexts was not attributed to the possible interaction of spatial compatibilities between the eye region and the face context, experiment 2 tested two control conditions. The results of experiment 2 suggest that the results of experiment 1 are indeed based on the holistic processing of the gaze direction, not low-level compatibility effects. In all, since the critical factor that varied in the various conditions was the perception of gaze direction, the results of the two experiments suggest that gaze-cueing effects are based on mechanisms specialized for gaze perception, rather than low-level visual cues such as spatial compatibilities.

The chapter 3 investigated the sequence effect between two consecutive cueing processes in arrow cueing. Although several studies have investigated the sequence effect of cueing paradigm by either peripheral cues (Dodd and Pratt, 2007; Mordkoff, Halterman, and Chen, 2008) or arrow cues (Jongen and Smulders, 2006), their

explanations are contradictory. Specifically, while the results of peripheral cueing support automatic hypothesis for the sequence effect, Jongen and Smulders interpreted their results of arrow cueing as strategic adjustment because the arrows in their study predicted the target locations in most of trials. In order to clarify this discrepancy, voluntary control of participants was removed by using a non-predictive arrow cue in the present experiment. If the sequence effect is based on strategic adjustment, there should either have no sequence effect or even have a reversed sequence effect when the arrow cues are non-predictive. If the sequence effect is automatic, it should be still observed with non-predictive arrow cues.

There are two major observations in this study. First, significant sequence effects are still observed with non-predictive arrow cues. This result supports the automatic hypothesis of sequence effects in the spatial cueing paradigm. Second, the sequence effect of arrow cueing is significantly influenced by the SOAs of previous trials. That is, when the previous SOA is short, no sequence effect was observed; however, when the previous SOA is long, the sequence effect was shown both at the short and long current SOAs. This is a novel finding in the investigation of sequence effects of cueing paradigm.

The chapter 4 investigated the sequence effect of gaze cueing. Although previous studies have investigated the sequence effect of cueing paradigm, the cues in these studies were typically artificial and arbitrary (e.g., the brightening of the outlines of geometric shapes or the sudden onset of the pointing arrows). It is still not clear whether the sequence effect can be induced by more naturalistic, social cues of attention that had been used by many studies in development psychology: the perceived direction of another person's eye gaze. This issue was systematically investigated in the chapter

4.

Experiments 1 to 3 involved a localization task in which participants were asked to indicate the location of a target by pressing left or right buttons with their left or right hands. In the first experiment, schematic faces were presented at the center of the screen to provide gaze cues. Though the gaze cues did not predict the target locations, significant sequence effects were found. The second experiment further investigated the sequence effect with real face stimuli and compared this effect with the sequence effect by arrows. Again, the results showed significant sequence effects by gaze cues and no significant difference in the sequence effect between gaze cueing and arrow cueing. In order to further investigate whether or not the sequential processing can generalize across cue categories, in the experiment 3, the central cues (gaze and arrow) were alternated between trials. Interestingly, significant sequence effects still occurred despite the variation of the cue categories. This result well demonstrated the nature of the sequence effect: it is the encoding and retrieval of the cue validity states accounting for the sequence effect, rather than the memory to the cue identity. Furthermore, a discrimination task was used to investigate the sequence effect of gaze cueing in the experiment 4. As a result, significant sequence effects occurred and this observation ruled out the possible influence of the response correspondence effect that may happened in the experiments 1 to 3. In sum, the present results strongly suggest that with each attentional deployment to a target followed by a given cue (a gaze or an arrow, in this case), there is a process that effectively associates the deployment of attention with this cue to boost performance significantly.

The chapter 5 investigated the influence of cue direction and target location on the sequence effect of arrow cueing. The results showed that sequence effects were impaired

when the cue direction always repeats between trials and were enhanced when the cue direction always switches between trials. Similar results were also found in a common cueing procedure where cue direction on each trial was chosen randomly. The results suggest that the repetition advantage effect of cue validity interacts with the alternation advantage effect of cue direction and target location to form the sequence effect in the endogenous cueing paradigm.

## **6.2 Future Inquiries**

This thesis investigated the mechanisms of attention orienting by spatial cueing paradigm and focused on the interaction between symbolic-cue (e.g., gazes and arrows) perception and visual attention. Specifically, chapter 2 investigated the contribution of low-level spatial compatibility and high-level gaze perception to gaze-cueing effects and the rest of the chapters examined the sequence effect of cueing paradigm. As for the sequence effect of cueing paradigm, several future inquiries can be pursued to extend the current work.

First, previous and current studies have provided converging evidence to support the automatic hypothesis for the sequence effect of cueing paradigm. However, the extent to which this automatic processing can be modulated by the top-down control of the observers is still unclear. As one direction of future works, it should be interesting to investigate the influence of participants' voluntary control and attentional control settings on the sequence effect. For example, as for the influence of participants' voluntary control, the magnitude of sequence effects by a non-predictive cue can be directly compared with a predictive or counter-predictive cue. The magnitude of sequence effects should be influenced if the participants' voluntary control modulates

the sequence effect. In comparison, the influence of the attentional control settings of the participants may be more implicit, because it usually operates at a subconscious level. Attentional control settings refer to the participants' knowledge toward the experimental task, such as experiment procedure, possible target locations, and the set of stimulus features. Many studies have suggested that even automatic processing (like attentional capture) is contingent on attentional control settings (e.g., Folk et al. 1992). Therefore, it is likely that automatic sequence effects of cueing paradigm can also be modulated by the change of the attentional control settings of the participants.

Second, this thesis focused on the sequence effect of centrally-presented symbolic cues, such as arrows and gazes. However, there is another kind of attentional cues, i.e. peripheral cues. Although some difference in sequence effects between peripheral cueing and arrow cueing have been discussed in chapter 3, a clear explanation about the difference is still under debate. In the future, the detailed mechanisms under the sequence effect of peripheral cueing and arrow cueing will be explored. For example, in chapter 4, sequence effects have been found to be able to generalize across central cue categories (gaze versus arrow), whether the sequence effect can generalize across peripheral cues and central cues will be an interesting research point for future works.

Finally, the current work is based on a specific experimental paradigm: the spatial cueing paradigm. In order to further reveal the potential mechanisms of visual attention, it is beneficial for future researches to provide more extensive and intensive evidence by using various experimental methods, such as visual search paradigm.



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## Publications

### Proceedings

1. Qian Qian & Keizo Shinomori (2009). Influence of position and number of face stimuli on gaze-cueing effect. IEICE Technical Report: Human Communication Science, Vol.109, No.264, 13-18.
2. Qian Qian & Keizo Shinomori. Gaze direction of schematic faces as attentional cue modulates detection time of a simple target. The 2009 International Workshop on Information Technology (IWIT 2009). Changchun, China. Sep. 15-19, 2009.
3. Qian Qian, Keizo Shinomori, & Miao Song. The functional role of implicit memory on gaze-evoked attention orienting. The 2010 IEEE International Conference on Information and Automation (ICIA 2010). Harbin, China. June 20-23, 2010.
4. Qian Qian, Keizo Shinomori, & Miao Song. Inter-trial inhibition effect of gaze cueing. The 2010 Asia-Pacific Conference on Vision (APCV 2010). Taipei, Taiwan. July 23-26, 2010.
5. Qian Qian, Miao Song, & Keizo Shinomori. Influence of perceived gaze direction on gaze cueing. The 2010 International Workshop on Information Technology (IWIT 2010). Kochi, Japan. Oct. 20-23, 2010.
6. Qian Qian, Keizo Shinomori, & Miao Song. The influence of previous deceptive gaze on gaze cueing is modulated by time. The fifteenth Japanese Academy of Facial Studies. Tokyo, Japan. Oct. 23-24, 2010.

### Journal papers

1. Qian Qian, Keizo Shinomori, & Miao Song. Sequence effects by non-predictive arrow cues, *Psychological Research*, vol. 75, 2011, in press. (Online First™, 12 May 2011, <http://www.springerlink.com/content/p361517118r422k2/> )
2. Qian Qian, Keizo Shinomori, & Miao Song. Gaze cueing as a function of perceived gaze direction, *Journal of Cognitive Psychology* (submitted on 27 July, 2011).
3. Qian Qian, Keizo Shinomori, & Miao Song. The functional role of alternation advantage in the sequence effect of arrow cueing, *Psychonomic Bulletin & Review* (submitted on 14 June, 2011).