An investigation of the relationship between normal aging,
visual attention and contrast sensitivity

Lyne Racette

PhD thesis

Carleton University

June 2004

© Lyne Racette 2004

Library and
Archives Canada

Bibliothèque et
Archives Canada

Published Heritage
Branch

Direction du
Patrimoine de l'édition

395 Wellington Street
Ottawa ON K1A 0N4
Canada

395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file Votre référence

ISBN: 0-612-97841-9

Our file Notre référence

ISBN: 0-612-97841-9

NOTICE:

The author has granted a non-exclusive license allowing Library and Archives Canada to reproduce, publish, archive, preserve, conserve, communicate to the public by telecommunication or on the Internet, loan, distribute and sell theses worldwide, for commercial or non-commercial purposes, in microform, paper, electronic and/or any other formats.

The author retains copyright ownership and moral rights in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

AVIS:

L'auteur a accordé une licence non exclusive permettant à la Bibliothèque et Archives Canada de reproduire, publier, archiver, sauvegarder, conserver, transmettre au public par télécommunication ou par l'Internet, prêter, distribuer et vendre des thèses partout dans le monde, à des fins commerciales ou autres, sur support microforme, papier, électronique et/ou autres formats.

L'auteur conserve la propriété du droit d'auteur et des droits moraux qui protègent cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

In compliance with the Canadian Privacy Act some supporting forms may have been removed from this thesis.

Conformément à la loi canadienne sur la protection de la vie privée, quelques formulaires secondaires ont été enlevés de cette thèse.

While these forms may be included in the document page count, their removal does not represent any loss of content from the thesis.

Bien que ces formulaires aient inclus dans la pagination, il n'y aura aucun contenu manquant.

Canada

PAGINATION ERROR.

TEXT COMPLETE.

ERREUR DE PAGINATION.

LE TEXTE EST COMPLET.

Abstract

The purpose of this research was to investigate the impact of visual attention on contrast sensitivity in normal aging. The aging brain undergoes diffuse and non-specific changes in function. These changes may result in deficits in processing complex visual information that impose a heavy processing load. Seven young participants (Mean: 21 years; SD: 4.9 years) and seven older participants (Mean: 71.9 years; SD: 6.8 years) were tested. All participants were equated perceptually on all targets. A two-alternative forced-choice orientation discrimination task was performed. Processing complexity was manipulated in the following ways: type of attention (exogenous and endogenous), array size (one and four gratings), cue validity (75% and 100%), drifting speed (static and dynamic) and contrast type (first-order and second-order). Attention improved performance on a contrast sensitivity task under both exogenous and endogenous cues. These attentional effects were observed mainly when multiple stimuli were presented. Age-related differences were found in perceptual and attentional processing. To achieve similar performance, older individuals had higher contrast thresholds than young individuals, particularly for second-order stimuli. Attentional age-related differences were observed when exogenous cues were used, but not when endogenous cues were used. These results suggest that both exogenous and

endogenous attention can improve contrast sensitivity and that older individuals may be able to compensate for deficits in exogenous attentional with endogenous attention. This has implications for the necessity to assess functional vision in the older population as well as for the possibility of training older individuals to use attention to compensate for visual deficits.

Acknowledgments

I would like to thank Dr. Evanne J. Casson, the primary supervisor of the present research. Dear Evanne, I am very grateful to you for going well beyond the call of duty on more than one occasion, to ensure that I would be a successful graduate student and researcher! I've appreciated your unfailing support in both the good and the "not so good" times! I promise to perpetuate the cycle of kindness and generosity that you initiated with me, by some day taking another student under my wing!

I also wish to thank Dr. Chris M. Herdman for co-supervising the present research as well as my graduate studies. Thank you Chris, for your availability and support.

Thank you to each member of my dissertation committee, for your availability and valuable comments. I extend my gratitude to Drs. John Logan, Jack B. Kelly, Lana M. Trick and David M. Dean. Thank you also to Dr. Michel Gaulin for chairing the defense meeting.

At different stages throughout the completion of the present research, I received technical support from Dr. Rejean Munger, Ali A. Dohadwala and Peter April. Thank you for your assistance with issues associated with computer equipment, data management and computer programming. I also

wish to acknowledge Tim Rice for proof-reading an earlier version of this manuscript.

To all the participants who volunteered in this research, I can't thank you enough for the numerous hours you have devoted to making this a successful project.

I wish to thank Lynn Giff, Kim Cook and Etelle Bourassa from the Department of Psychology at Carleton University, for your endless willingness to cheerfully provide guidance with respect to all the rules and deadlines.

I wish to thank everyone at the University of Ottawa Eye Institute, in Ottawa and at the Hamilton Glaucoma Center, in La Jolla. The dynamic research teams at both facilities are truly remarkable. You have provided me with an enriching and motivating work environment and I am proud to count many of you as my friends.

Thank you to my first mentor, Dr. Michael von Grünau, who supervised my undergraduate thesis. Dear Michael, thank you for believing in me, at a time when I did not have much confidence in myself. I have come a long way and I am happy to count you as my friend.

I wish to acknowledge Dr. David H. Zackon. I was recently reading "Research proposals: A guide to success" by Thomas E. Ogden and Israel A.

Goldberg and the following excerpt reminded me of how lucky I was to have worked with you:

“...Unfortunately, you will probably make little real progress until you find someone who knows the English writing, to carefully edit your work. If you are lucky, that person will be an experienced scientist in your department...”

David, you were that person for me. Thank you for your willingness to teach a little French-speaking girl how to master the English language. This is one of the most valuable gifts I was ever given and I think of you each time I am complimented on my writing style.

Finally, I wish to acknowledge Dr. Pamela A. Sample. Dear Pam, words cannot adequately express how much I appreciate you. On a professional level, working with you was a great experience. Your excitement for your work is contagious and your discipline is exemplary. On a personal level, I feel blessed that our paths have crossed when they did.

True friends are few and far in between and I am extremely grateful for the friendships I share with the following people. In different ways, each one is responsible for the completion of my degree. Thank you to Michelle Kwas (and the entire Dubé bunch), André Nadeau, Wendy Kim, Tarek El-Beltagi, Amy Bovell and Shannon Kleinhandler.

I wish to thank Dr. Randy P. Bouligny, not for his doctorship, but rather for his Randyship. Thank you for your support and for kicking ass when it was necessary. I will try to remember that the enemy of “good” is “perfect”, if you promise to remember that the friend of “Randy” is “Lyne”.

This list of acknowledgements would be incomplete without the name of Dr. Michael Monroe. Dear Dr. Monroe, you have had such a profound impact on my life. Perhaps the best way I have to thank you is to live a happy and successful life. Know that I am applying myself to this purpose every day. I am forever grateful to you. Merci de tout mon coeur.

Finalement, j’aimerais remercier ma famille qui veille constamment à mon bien-être. Merci d’avoir eu le courage de me sauver de moi-même, et de m’avoir ainsi redonné la chance de réaliser tous mes rêves. Gros merci à Mamy, Papy, Lorraine, Cliff, ainsi qu’à mon petit Pampousse et au nouveau petit bébé qu’on a tous bien hâte de connaître...

Je dédie cet ouvrage à la mémoire de mes grand-parents:

M. Gérard et Mme Jeanne Racette,

M. Albert et Mme Bernadette Morrissette.

Table of Contents

Title page.....	i
Acceptance form.....	ii
Abstract.....	iii
Acknowledgments.....	v
Table of contents.....	ix
List of illustrations.....	xviii
List of tables.....	xxi
List of appendices.....	xxii
1. General introduction.....	1
2. Contrast sensitivity.....	4
2.1. Parameters affecting the processing load of contrast gratings.....	5
2.1.1. Contrast type: first- and second-order stimuli.....	5
2.1.2. Drifting speed: static and dynamic gratings.....	7
2.1.3. Contrast type and drifting speed interaction.....	11
2.2. Conclusions.....	11
3. Impact of normal aging on contrast sensitivity.....	12
3.1. Physiological mechanisms involved in normal aging.....	12
3.2. Effect of normal aging on contrast sensitivity.....	13
3.3. Conclusions.....	15

4. Visual attention.....	17
4.1. Attentional network.....	17
4.2. Attentional processing complexity.....	18
4.2.1. Single versus multiple features.....	18
4.2.2. Exogenous and endogenous cueing.....	20
4.2.3. Array size.....	21
4.2.4. Cue validity.....	22
4.3. Attentional mechanisms.....	23
4.4. Conclusions.....	25
5. Impact of attention on contrast sensitivity.....	27
5.1. Physiological evidence.....	27
5.2. Psychophysical evidence.....	29
5.3. Conclusions.....	32
6. Impact of normal aging on visual attention.....	33
6.1. Effect of age on attention.....	33
6.2. Attentional training.....	34
6.3. Conclusions.....	35
6.4. Overall summary.....	35
7. The present study.....	37
7.1. Specific goals.....	38

7.2. Assumptions.....	38
7.3. Hypotheses.....	39
7.4. Theory-based predictions.....	39
7.5. Experimental organization.....	41
8. General methods.....	47
8.1. Participants.....	47
8.2. Apparatus.....	48
8.3. Stimuli.....	48
8.3.1. First-order stimuli.....	49
8.3.2. Second-order stimuli.....	50
8.3.3. Static and drifting stimuli.....	51
8.3.4. Attentional cues.....	51
8.4. Data collection.....	52
8.5. Testing order.....	54
8.6. Statistical analyses.....	55
8.6.1. Investigational data analysis.....	55
8.6.2. Neutral trial analysis.....	56
8.6.3. Family-wise error rate correction.....	57
9. Baseline experiment.....	60
9.1. Design.....	60

9.2. Procedure.....	61
9.3. Results.....	62
9.4. Discussion.....	63
10. Exogenous cueing with static gratings.....	72
10.1. Design.....	73
10.2. Procedure.....	73
10.3. Experiment I.....	79
10.3.1. Goals and Methods.....	79
10.3.2. Results.....	79
10.3.3. Discussion.....	81
10.4. Experiment II.....	83
10.4.1. Goals and Methods.....	83
10.4.2. Results.....	83
10.4.3. Discussion.....	84
10.5. Experiment III.....	87
10.5.1. Goals and Methods.....	87
10.5.2. Results.....	87
10.5.3. Discussion.....	88
10.6. Experiment IV.....	91
10.6.1. Goals and Methods.....	91

10.6.2. Results.....	91
10.6.3. Discussion.....	93
10.7. Neutral trial analysis.....	95
10.8. Summary of chapter 10.....	96
11. Exogenous cueing with dynamic gratings.....	99
11.1. Experiment I.....	101
11.1.1. Goals and methods.....	101
11.1.2. Results.....	101
11.1.3. Discussion.....	102
11.2. Experiment II.....	105
11.2.1. Goals and Methods.....	105
11.2.2. Results.....	105
11.2.3. Discussion.....	106
11.3. Experiment III.....	109
11.3.1. Goals and Methods.....	109
11.3.2. Results.....	109
11.3.3. Discussion.....	110
11.4. Experiment IV.....	112
11.4.1. Goals and Methods.....	112
11.4.2. Results.....	112

11.4.3. Discussion.....	113
11.5. Neutral trial analysis.....	116
11.6. Summary of chapter 11.....	116
12. Summary of results under exogenous attention.....	120
12.1. The effect of exogenous attention.....	120
12.2. Age-related differences in the effect of exogenous attention.....	122
13. Endogenous cueing with static gratings.....	126
13.1. Experiment I.....	131
13.1.1. Goals and Methods.....	131
13.1.2. Results.....	131
13.1.3. Discussion.....	132
13.2. Experiment II.....	135
13.2.1. Goals and Methods.....	135
13.2.2. Results.....	135
13.2.3. Discussion.....	136
13.3. Experiment III.....	139
13.3.1. Goals and Methods.....	139
13.3.2. Results.....	139
13.3.3. Discussion.....	140
13.4. Experiment IV.....	143

13.4.1. Goals and Methods.....	143
13.4.2. Results.....	143
13.4.3. Discussion.....	145
13.5. Neutral trials analysis.....	147
13.6. Summary of chapter 13.....	147
14. Endogenous cueing with dynamic gratings.....	150
14.1. Experiment I.....	152
14.1.1. Goals and Methods.....	152
14.1.2. Results.....	153
14.1.3. Discussion.....	153
14.2. Experiment II.....	156
14.2.1. Goals and Methods.....	156
14.2.2. Results.....	156
14.2.3. Discussion.....	157
14.3. Experiment III.....	160
14.3.1. Goals and Methods.....	160
14.3.2. Results.....	160
14.3.3. Discussion.....	161
14.4. Experiment IV.....	163
14.4.1. Goals and Methods.....	163

14.4.2. Results.....	163
14.4.3. Discussion.....	164
14.5. Neutral trials analysis.....	167
14.6. Summary of chapter 14.....	167
15. Summary of results under endogenous attention.....	171
15.1. The effect of endogenous attention.....	172
15.2. Age-related differences in the effect of endogenous attention.....	173
16. General discussion.....	177
16.1. The effect of attention on contrast sensitivity.....	178
16.1.1. The impact of processing load.....	179
16.1.2. Attentional mechanisms.....	181
16.2. Age-related differences.....	185
16.2.1. Perceptual differences.....	186
16.2.2. Attentional differences.....	187
16.2.3. The impact of drifting speed and contrast type.....	189
16.3. Implications and future research.....	190
16.3.1. Value of functional assessments in older individuals.....	191
16.3.2. Improving functional vision in older individuals.....	193
16.4. Limitations of the present research.....	194
16.4.1. Differences between baseline and experimental conditions...	194

16.4.2. Eye movements.....	196
16.4.3. Lack of formal medical, visual and cognitive assessments....	198
16.4.4. Statistical power.....	199
16.5. Conclusions.....	199
17. References.....	202

List of illustrations

Chapter 3: Impact of normal aging on contrast sensitivity

Figure 3.1: Contrast sensitivity curves per decade of life.16

Chapter 7: The present study

Figure 7.1: Experimental organization for exogenous attention.....45

Figure 7.2: Experimental organization for endogenous attention.....46

Chapter 8: General methods

Figure 8.1: Illustration of first- and second-order stimuli.....59

Chapter 9: Baseline experiment

Figure 9.1: Dimensions of the stimulus configuration.....65

Figure 9.2: Illustration of the sequence of events.....66

Figure 9.3: Three-way interaction.....69

Figure 9.4: Main effects of contrast type, age and drifting speed.....70

Figure 9.5: Two-way interaction between contrast type and age.....71

Chapter 10: Exogenous cueing with static gratings

Figure 10.1: Dimensions of the stimulus configuration.....75

Figure 10.2: Basic sequence of events in the neutral trials.....76

Figure 10.3: Basic sequence of events in the valid trials.....77

Figure 10.4: Basic sequence of events in the invalid trials.....78

Figure 10.5: Main effects and two-way interactions: EI.....	82
Figure 10.6: Main effects and two-way interactions: EII.....	86
Figure 10.7: Main effects and two-way interactions: EIII.....	90
Figure 10.8: Main effects and two-way interactions: EIV.....	94
Figure 10.9: Main effects and two-way interactions: neutral trials.....	98
Chapter 11: Exogenous cueing with dynamic gratings	
Figure 11.1: Main effects and two-way interactions: EI.....	104
Figure 11.2: Main effects and two-way interactions: EII.....	108
Figure 11.3: Main effects and two-way interactions: EIII.....	111
Figure 11.4: Main effects and two-way interactions: EIV.....	115
Figure 11.5: Main effects and two-way interactions: neutral trials...	119
Chapter 13: Endogenous cueing with static gratings	
Figure 13.1: Basic sequence of events in the neutral trials.....	128
Figure 13.2: Basic sequence of events in the valid trials.....	129
Figure 13.3: Basic sequence of events in the invalid trials.....	130
Figure 13.4: Main effects and two-way interactions: EI.....	134
Figure 13.5: Main effects and two-way interactions: EII.....	138
Figure 13.6: Main effects and two-way interactions: EIII.....	142
Figure 13.7: Main effects and two-way interactions: EIV.....	146
Figure 13.8: Main effects and two-way interactions: neutral trials...	149

Chapter 14: Endogenous cueing with dynamic gratings

Figure 14.1: Main effects and two-way interactions: EI.....155

Figure 14.2: Main effects and two-way interactions: EII.....159

Figure 14.3: Main effects and two-way interactions: EIII.....162

Figure 14.4: Main effects and two-way interactions: EIV.....166

Figure 14.5: Main effects and two-way interactions: neutral trials...170

Chapter 16: General discussion

Figure 16.1: Photograph of the experimental setting.....201

List of tables

Chapter 7: The present research

Table 7.1: Expected age-related perceptual differences.....42

Table 7.2: Expected age-related attentional differences.....43

Table 7.3: Expected compensatory effects of attention.....44

Chapter 9: Baseline experiment

Table 9.1: Contrast thresholds for young participants.....67

Table 9.2: Contrast thresholds for older participants.....68

Chapter 12: Summary of results under exogenous attention

Table 12.1: Summary of exogenous static results.....124

Table 12.2: Summary of exogenous dynamic results.....125

Chapter 15: Summary of results under endogenous attention

Table 15.1: Summary of endogenous static results.....175

Table 15.2: Summary of endogenous static results.....176

List of appendices

Appendix A: Statistical summary tables for all analyses.....	218
Appendix B: Graphs of the three-way interactions in all experiments.....	282

Chapter 1: General introduction

The richness of our visual experience is unique. Although each of our senses offers an exceptional window onto the world around us, none conveys as powerful an impression as vision. Through our visual system, we gain access to information about our environment, are able to coordinate our movements efficiently and can experience beauty, be it a newborn child or a Van Gogh painting. The visual system is as remarkable as it is intricate. It maximizes processing of a wide variety of stimuli and tasks by efficiently allocating resources through attentional mechanisms.

In humans, from retina to cortex, approximately fifty percent of the brain is involved in visual processing. This highlights the complexity of the visual system, which draws upon both sensory and attentional processing resources. The sensory system receives and encodes all visual stimulation, while the attentional system is responsible for selecting relevant stimuli from the visual array for further processing. Contrast sensitivity is one example of sensory processing that has a fundamental importance in performing a number of daily tasks. For example, while driving at night, performance will be more or less impaired by the glare caused by the headlights of oncoming vehicles, depending on the integrity of the contrast sensitivity mechanisms. Driving can also be used to illustrate visual attention mechanisms. While driving, either in

a city or rural environment, one is constantly bombarded with visual information. Although it is impossible to process all visual stimulation in great detail, it is crucial to process the relevant information. This is what the attentional system does. A child suddenly darting across the road will capture attention due to the unexpected nature of the event. A driver can also actively choose to attend to important information. For example, stop signs are sought out because they are important to safe driving.

Attention can have a large effect on sensory processing. In an elegant series of experiments on inattention blindness, Mack and Rock (1998) proposed that there may not be any conscious perception without attention. They demonstrated that stimuli as large as six degrees of visual angle, presented in the centre of the visual field, can go completely unnoticed when no attention is allocated to them. Their work emphasized the importance of the attentional system in the conscious perception of the visual world. Many visual functions, including contrast sensitivity, can be influenced by visual attention. Although much remains unknown, there is no doubt that visual attention and sensory processing both play a crucial role in the human visual experience.

Characteristic changes associated with normal aging have an impact on both sensory processing and attention. Studies have shown that contrast sensitivity is adversely affected by aging and that this effect is larger for

complex visual stimuli than for simple stimuli (Habak & Faubert, 2000). The detrimental effect of age has also been reported for attention. In a population in which people of 65 years and more are the fastest growing group, a greater emphasis needs to be put on understanding age-related changes. In Canada, for example, it is expected that the older population will at least double over the next forty years. While 3.92 million people were over the age of 65 in 2001, this number is expected to rise to 9.2 million by the year 2041.

The purpose of the present research is to investigate the relationship between contrast sensitivity, attention and aging. Although age has a larger impact on the perception of complex compared to simple contrast stimuli, it is unknown whether this larger age-related difference is also present for attending to these stimuli. One possibility is that normal aging has a negative impact on both perceptual and attentional mechanisms. However, it is also possible that the effects of perception and attention offset each other with increasing age, such that perceptual losses may be compensated for by attention. In the context of a rapidly aging population, it is important to understand the nature of these age-related changes. Indeed these deficits may have important implications in common tasks such as driving, in which visual demand is high, both in terms of contrast sensitivity and visual attention.

Chapter 2: Contrast sensitivity

To understand the interactions between contrast sensitivity, attention and aging, it is important to review each variable individually and to discuss what is currently known about the interactions among these variables. The background required to understand the rationale of the present research is presented in five chapters, each reviewing a particular area pertinent to the experiments presented here. In chapter 2, a review of the literature on contrast sensitivity is presented. In chapter 3, a review of the effect of aging on contrast sensitivity is provided. Chapter 4 provides a review of the literature on attention, while chapter 5 covers the impact of attention on contrast sensitivity. A review of the effect of normal aging on attention is presented in chapter 6. Finally, the present research is outlined in chapter 7.

Contrast can be defined as the amplitude of change in a visual parameter, for example, changes in luminance, over space or time. Contrast sensitivity is the reciprocal of contrast threshold, such that when high contrast levels are required to detect a visual stimulus, contrast sensitivity is low. Sensitivity to contrast allows us to see objects that may not be outlined very clearly or that do not stand out from their background. Experimentally, sine-wave gratings are commonly used in the study of contrast sensitivity. They consist of an array of light and dark bars, in which the intensity distribution follows a sinusoidal

pattern. In other words, there is a gradual change between the light and dark areas of the pattern such that the transitions are not perceived as sharp contours.

Contrast sensitivity varies with spatial and temporal frequencies. Robson (1966) obtained contrast sensitivity values for different levels of spatial and temporal frequencies. The results were presented in the form of contrast sensitivity curves. In subsequent experiments (Watson & Robson, 1981), contrast sensitivity was determined using a parameter estimation technique (PEST) (Taylor & Creelman, 1967; Pentland, 1980). This technique, which is also used in the baseline experiment reported here, is useful for determining thresholds in a rapid and reliable manner. With PEST, a supra-threshold stimulus is shown and manipulated in a staircase manner. Contrast is systematically decreased and increased until a pre-determined threshold level is obtained. After a pre-specified number of reversals, the threshold is determined as the average of the last two reversals.

2.1 Parameters affecting the processing load of contrast gratings

2.1.1 Contrast type: first- and second-order stimuli

For the purposes of the experiments included in the present research, two different types of contrast stimuli are used. Simple first-order stimuli are

defined by luminance modulations and impose a light processing load, while complex second-order stimuli are defined by contrast modulations and impose a heavier processing load. At the physiological level, Ledgeway and Smith (1994) suggest that first-order stimuli are processed by linear systems, while second-order contrast stimuli are processed by non-linear systems. In linear systems, the perceptual response is proportional to the luminance amplitude, while in non-linear systems, the response is not proportional to this amplitude. These two types of systems are thought to work in parallel from the primary visual area (V1) to areas V4 (form perception) or MT (motion perception) (Wilson, Ferrera, & Yo, 1992). The initial processing stages of both first- and second-order contrast stimuli are similar, requiring the same number of processing steps. However second-order contrast stimuli are believed to require an additional processing step (Victor & Conte, 1991). This additional step is referred to as rectification and can be defined as a non-linear process in which the negative areas of a cyclical pattern are multiplied by negative one, such that all areas become positive.

Evidence obtained from psychophysical studies also suggests that simple first-order stimuli are processed linearly (Sperling, 1989), while the mechanisms involved in processing second-order stimuli are non-linear (Sperling, 1989; Victor & Conte, 1991). In a series of psychophysical

experiments investigating aging effects on contrast thresholds, Habak and Faubert (2000) used first- and second-order contrast stimuli. In theory, the second-order stimuli require an additional processing step and thus impose a heavier processing load compared to first-order stimuli. Participants were tested on orientation and motion direction discrimination tasks and the dependent variable was contrast threshold. Their results show higher contrast thresholds for complex contrast stimuli compared to the simple first-order stimuli. Additionally, their results show age-related differences, which will be further discussed in chapter 4.

2.1.2 Drifting speed: static and dynamic gratings

Another way to manipulate the processing load is to introduce motion within the gratings. The impact of motion on the perception of sine-wave gratings may be different for first- and second-order stimuli. Lower orientation discrimination thresholds are observed for dynamic first-order gratings than for static first-order gratings (Habak & Faubert, 2000). From an evolutionary perspective, the motion detection system developed very early on and is very sensitive. It is therefore not surprising that lower thresholds are observed when simple dynamic gratings are presented, compared to simple static gratings.

When complex second-order stimuli are presented, however, higher orientation discrimination thresholds are observed for dynamic gratings than for static gratings (Habak & Faubert, 2000). Complex dynamic gratings are “drift-balanced”, meaning that Fourier analysis is unable to extract the direction of motion. In other words, the motion energy is equally distributed in opposite directions and is thus invisible to low-level, luminance-defined, motion detectors that operate by detecting motion energy. Although the motion energy is equally distributed in opposite directions in second-order motion stimuli, there is compelling psychophysical evidence that observers can readily perceive it (Anstis, 1980; Cavanagh & Mather, 1989; Ramachandran, Rao, & Vidyasagar, 1973).

Two competing theories have been proposed to explain the mechanisms underlying the processing of first- and second-order dynamic stimuli. However, there is still ongoing debate, with evidence supporting each of the theories. Some investigators argue that the first- and second-order dynamic stimuli are processed by a single, common, low-level system (Grzywacz, 1992; Johnston, McOwan, & Buxton, 1992). For example, Grzywacz (1992) proposed a model in which a single intensity-based mechanism is able to detect both first- and second-order dynamic stimuli, in which no separate linear

mechanism is required. In this model, all dynamic stimuli are detected through band-pass filtering followed by rectification and motion energy detection.

Other investigators, however, argue that first- and second-order dynamic stimuli are processed by two distinct systems (Chubb & Sperling, 1988, 1989; Werkhoven, Sperling & Chubb, 1993; Wilson et al., 1992; Wilson & Mast, 1993; Lu & Sperling, 1995, 1996; Sperling & Lu, 1998). The first-order system extracts motion based on luminance modulations while the second-order system extracts motion from contrast modulations. For example, Chubb and Sperling (1993) described a model in which motion energy is introduced into the neural representation of the second-order stimulus image by a process that can be modelled by rectifying the luminance profile of the image. The motion energy can then be detected in a way similar to conventional first-order stimuli. In essence, the negative parts of the curve are made positive, which doubles the frequency such that second-order dynamic stimulus can be processed in a way similar to first-order motion.

Several lines of psychophysical evidence support the dual mechanism theory of first- and second-order motion processing. For example, Harris and Smith (1992) showed that second-order dynamic stimuli do not elicit optokinetic nystagmus (OKN), while first-order dynamic stimuli of equal visibility were able to elicit OKN. Another example is provided by Mather and West

(1993), who created two-frame random-dot kinematograms (RDK) defined by either luminance (first-order) or contrast (second-order). When both frames consisted of either first- or second-order stimuli, participants were able to perceive the direction of the RDK displacement between the two frames. However, when the RDK in the two frames differed, that is the RDK on one frame was created based on first-order characteristics while the RDK on the other frame was created based on second-order characteristics, the participants detected the displacement direction at chance level only. This suggests that different mechanisms are processing first- and second-order stimuli. Doshier, Landy and Sperling (1989) showed that first-order motion detectors are the primary input for kinetic depth effects, while second-order motion detectors support only limited kinetic depth effects with low spatial resolution. Using the visual search paradigm, Horowitz and Treisman (1994) showed that first-order motion is computed in parallel while second-order motion is computed serially. Using a concurrent dual-task paradigm, Ho (1998) found that it was not possible to judge motion for two simultaneously presented second-order dynamic stimuli.

2.1.3 Contrast type and drifting speed interaction

Contrast type and drifting speed can be used in combination to manipulate the processing load. In the present research, the same four stimuli used by Habak and Faubert (2000) were used. Two contrast types (luminance-defined first-order gratings and contrast-defined second-order gratings) and two drifting speeds (static and dynamic gratings) were used. These stimuli require different levels of processing and they can be ranked in terms of the processing load they impose, based on the results obtained by Habak and Faubert (2000). From lightest to heaviest processing load, the following ranking was determined: 1) first-order dynamic gratings, 2) first-order static gratings, 3) second-order static gratings and 4) second-order dynamic gratings.

2.2 Conclusions

Contrast sensitivity can be measured rapidly and reliably using the PEST technique. There are differences between the amount of processing required for first- and second-order stimuli, as well as for static and dynamic gratings. Second-order stimuli require more processing than first-order stimuli. Dynamic stimuli require more processing than static stimuli for second-order stimuli and less processing than static stimuli for first-order stimuli.

Chapter 3: Impact of normal aging on contrast sensitivity

Normal aging is associated with a number of deficits in visual performance, from perception to attention. Age-related deficits in contrast sensitivity have been reported and are reviewed in this chapter.

3.1 Physiological mechanisms involved in normal aging

Although the mechanisms underlying age-related deficits in contrast sensitivity are not yet fully understood, there is mounting evidence suggesting that they occur following diffuse, non-specific reduction in cortical function. Early studies suggested that perceptual visual deficits in the elderly occurred following diffuse cell death within the aging brain (Weale, 1975). Although more recent evidence supports the diffuse, non-specific reduction in processing capacity of the aging brain, it is no longer believed that it is a consequence of cortical cell death. Evidence from cell count studies shows that there is only a minimal reduction in the number of cells present in the aged brain compared to the young brain (Morrison & Hof, 1997; Rapp & Gallagher, 1996). Instead, as outlined below, the generalized deficits are believed to be associated with a loss of cellular function (Spear, 1993).

Animal studies suggest the following as possible physiological mechanisms underlying the non-specific changes observed in normal aging:

1) a decrease in neocortical presynaptic boutons (Wong, Campbell, Ribeiro-da-Silva, & Cuello, 1998); 2) changes in physiological properties of hippocampal cells (Gazzaley, Thakker, Hof, & Morrison, 1997); 3) a decrease of interactions between cells (Rubin, 1997); or 4) degeneration of the myelin sheath wrapping the axons (Peters, Rosene, Moss, Kemper, Abraham, Tigges et al., 1996; Vincent, Peters, & Tigges, 1989).

3.2 Effect of normal aging on contrast sensitivity

Contrast sensitivity is reduced in normal aging, particularly for medium and high spatial frequencies (higher than 3 or 4 cycles per degree) (Arundale, 1978; Owsley, Sekuler, & Siemsen, 1983). Figure 3.1 illustrates this by presenting the contrast sensitivity functions for each decade of life. Elliott, Whitaker and MacVeigh (1990) proposed that although optical phenomenon such as increased light scattering due to lens opacities may play a role in age-related reduction in contrast sensitivity for high spatial frequency stimuli, other factors are likely also involved at medium spatial frequencies. These factors may include, but are not limited to, retinal and neural changes. Consistent with this view are results showing age-related differences in temporal contrast sensitivity, which is resistant to optical changes. When dynamic gratings of low spatial frequency (1 cycle per degree) are used, young participants show a

marked enhancement in contrast sensitivity compared to static gratings of the same spatial frequency. The elderly population does not benefit from increases in temporal frequencies and shows no improvement for dynamic stimuli (Owsley et al., 1983). Kline (1987) reports that older individuals are less sensitive to a 1 cycle per degree dynamic grating at slow and medium speeds, while Owsley et al. (1983) reported similar findings for medium speeds only. This suggests that there is a decrease in neural processing with normal aging and contrast sensitivity is reduced, mainly for high spatial frequencies and low temporal frequencies.

Most studies on aging and contrast sensitivity have used simple, first-order contrast stimuli. If normal aging has a widespread diffuse adverse effect on the brain, then aging differences in performance might be better observed under conditions that impose a heavier processing load. As increasing demand is placed on the aging visual system, widespread non-specific deficits may become apparent. For example, when complex stimuli such as random dot displays were used, older participants have higher coherence thresholds (Trick & Silverman, 1991) and direction discrimination thresholds (Ball & Sekuler, 1986).

Habak and Faubert (2000) found that complex second-order contrast stimuli show age-related perceptual deficits. In their study, they compared

young and older participants with normal vision to determine the effect of normal aging on the perception of higher-order stimuli. Their results show a greater elevation of contrast thresholds in the older group compared to the young group for complex contrast stimuli.

3.3 Conclusions

Contrast sensitivity is adversely affected by normal aging. This effect is larger for complex stimuli such as second-order and dynamic gratings. This is consistent with the theory that aging effects are the result of diffuse, non-specific loss. With increasing levels of processing, aging effects become more apparent. If the mechanisms underlying the processing of these stimuli are different, then the effect of attention may also be different for each type of stimuli.

Figure 3.1. Contrast sensitivity functions presented per decade of life (adapted from Schieber, 1992).

Chapter 4: Visual attention

The visual system draws upon sensory and attentional resources to process visual information. While the sensory resources encode stimuli, the main role of attention is to select which stimuli will receive detailed processing and which will not. In the previous chapters, the evidence presented suggests that at the perceptual level, stimuli of different processing complexity may be processed differently. The goal of this chapter is to present evidence suggesting that, in addition to the perceptual differences, there may also be attentional differences between stimuli or tasks of various processing complexity.

4.1 Attentional network

Many brain areas are involved in attentional processing (Colby, 1991) and each has a different influence on our visual experience. Primitive structures, such as the midbrain, are involved in low-level functions such as the control of eye movements. Cortical structures are involved in higher-level functions such as the voluntary processing of specific visual information. There is evidence suggesting that the primitive and cortical structures interact when processing visual information (Eason, Harter & White, 1969; Zackon, Casson, Stelmach, Faubert, & Racette, 1997). Since structures that emerged at

different times in the neural evolution appear to contribute to the attentional system, it would seem likely that the attentional network has an influence on both simple and complex processing.

4.2 Attentional processing complexity

The network approach to attentional processing suggests that attention is distributed along a continuum, rather than being an all-or-nothing process. Depending on the complexity of the stimuli or of the tasks at hand, attention may be deployed in different manners. In most psychophysical accounts of attention, however, a dichotomous view of attention is suggested.

4.2.1 Single versus multiple features

The Feature Integration Theory (FIT) proposed by Treisman and Gelade (1980) is a striking example of a dichotomous perspective on attention. The visual search paradigm, in which participants were asked to detect a target item embedded in an array of distractor items, was used. When defined by a single feature (search for a red circle among green circles), the target appears to pop-out from the display, regardless of the number of distractor items present. The perception is such that the target distinguishes itself from the distractor items

and captures attention automatically. The number of distractor items present in the display does not influence target detection.

When the target is defined by a conjunction of two or more features (search for a red circle among red squares and green circles), the search is thought to be serial. Participants need to actively search through the items in the display until they find the target. Under these conditions, the number of distractor items influences the detection of the target, such that longer detection latencies are observed when the number of distractor items is increased. The proposed explanation for the increased latencies is that the integration of the features into a single stimulus requires attention. The target no longer pops-out from the display and the attentional focus must be shifted serially across the visual field until the target is found.

According to the FIT, targets composed of a single feature do not require attention to be detected. These targets pop-out of the display automatically and are processed pre-attentively. In contrast, targets composed of two or more features require attention to bind the features into a single stimulus. The characteristics of the stimuli determine whether attention is required or not. This supports a dichotomous, all-or-nothing view of attention. However, more recent studies have provided conflicting results. Laarni, Näsänen, Rovamo and Saarinen (1996), for example, report serial search functions for targets

composed of a single feature. This result was obtained by increasing the complexity of the task. Flat search functions were also obtained for targets composed of two or more features (Nakayama & Silverman, 1986; Steinman, 1987; McLeod, Driver & Crisp, 1988; Theeuwes & Kooi, 1994). This supports the view that rather than being dichotomous, attention may be a process distributed along a continuum. The attentional resources allocated in any given situation may depend on the complexity of the stimuli and of the task at hand (Racette, 1997).

4.2.2 Exogenous and endogenous cueing

Different types of attentional cues can influence attentional deployment. The sudden onset or offset of a highly salient stimulus can attract attention and these events are also referred to as exogenous attentional cues. This type of attention is believed to be stimulus-driven and is thought to operate in a bottom-up fashion. In daily life, it is important to process sudden changes within the visual field, as they may contain critical information. For example, an animal has much to gain from processing the sudden appearance of its predator. When attention is captured, there is a natural tendency to orient towards that stimulus, such that under natural conditions, attended objects are also foveated. There is a strong link between attention and eye movements.

However, foveation and attention can be dissociated under experimental conditions and attention can be shifted covertly, without the occurrence of eye movements (Robinson & Kertzman, 1995). The pop-out targets described previously are examples of exogenous attentional cues. Because the target differs from the distractor items, it grabs attention and is processed rapidly.

Attention can also be directed voluntarily and this is referred to as endogenous attention. In daily life, endogenous attention is deployed, for example, when searching for a friend in a crowded room. Orienting attention to endogenous cues allows for the processing of stimuli that are potentially less salient but which may be important to the task at hand. Endogenous attention is believed to be task-driven and governed by top-down processes. From a processing complexity standpoint, endogenous attention requires more complex processing than exogenous attention.

4.2.3 Array size

Attention is a selective mechanism and by definition, it can not process all stimuli that are encoded perceptually. It is more difficult to attend to a large number of stimuli than to attend to a small number of stimuli. Using the visual search paradigm, Pashler (1987) suggested that for display sizes smaller than

eight items, searches may be conducted in parallel even for feature integration tasks.

Divided attention refers to the ability to allocate attentional resources on two or more stimuli simultaneously. When attention is divided, two or more tasks can be performed simultaneously. Experimentally, the Useful Field of View (UFOV) test, in which participants are asked to perform a central and a peripheral task simultaneously, has capitalized on this characteristic of attention (Ball & Owsley, 1993).

4.2.4 Cue validity

Under experimental settings, it is possible to test the effect of attention on attended stimuli, as well as the effect it has on unattended stimuli.

Attentional cues can be misleading on some trials, attracting attention onto a stimulus while another stimulus is tested. When the cue always accurately predicts the location of the stimulus, cue validity is set at 100%. The level of cue validity can be manipulated such that the cue predicts the location of the target on only 75% of the trials, as was done in the present research. Reducing the level of cue validity increases processing complexity.

4.3 Attentional mechanisms

The mechanisms underlying attentional processing are not yet fully understood and there is ongoing debate between the supporters of different theories. The signal enhancement hypothesis suggests that focusing attention strengthens the representation of the attended stimulus (Bashinski & Bacharach, 1980; Posner, 1980; Downing, 1988; Luck, Hillyard, Mouloua, Woldorff, Clark, & Hawkins, 1996; Müller, Picton, Valdes-Sosa, Riera, Teder-Sälejärvi, & Hillyard, 1998). This enhancement is thought to result from the amplification of neural activity. In other words, the firing rate in many brain areas is thought to increase for attended stimuli.

In contrast, the external noise reduction hypothesis suggests that attention reduces the strength of the representation of stimuli located outside the focus of attention (Kinchla, 1980; Davis, Kramer, & Graham, 1983; Shaw, 1984; Sperling & Doshier, 1986; Palmer, 1994; Shiu & Pashler, 1994; Eckstein, 1998; Foley & Schwartz, 1998). This hypothesis will be referred to as inhibition throughout this manuscript. Inhibition of processing of unattended stimuli is attributed to the suppression of the activity in specific brain areas.

It is possible, however, that both mechanisms (enhancement of attended stimuli and inhibition of unattended stimuli), occur simultaneously. Moran and Desimone (1985) found amplified magnitude of cellular recordings for

attended stimuli in awake monkeys; however, cells in area V4 simultaneously showed suppressed response to the unattended stimulus which was optimal for initiating cell firing. Another example of enhancement and inhibition is given by Chelazzi, Miller, Duncan and Desimone (1993). They showed that the same stimulus could either enhance the firing rate of a specific cell (when the stimulus was attended) or suppress that cell's firing when the stimulus was unattended.

Posner and Dehaene (1994) proposed an attentional network model that highlights how enhancement and inhibition can work together. They propose that inhibition of unattended stimuli occurs mostly at early processing stages and that enhancement of attended stimuli occurs later on in the processing stream. Their suggestion is that neurons in areas such as V1 fire strongly in response to visual stimuli, regardless of whether the stimuli are attended or unattended. Therefore, at early stages of processing, attentional modulations can only occur through selective suppression of the automatic neuronal activity. At later stages within the processing stream, attention can enhance the response of cells in extra-striate structures such as V4 for example. Even further up the cortical hierarchy, some cells are activated only when specific tasks are accomplished and never fire in passive situations: for these cells, attention appears to be required for firing to occur. This view proposed by

Posner and Dehaene implies that attention can have an impact at all stages of visual processing. Although it is a well-accepted fact that attention influences complex visual processing, whether attention has an effect on early visual processing is more controversial.

Psychophysically, it is possible to determine whether enhancement or inhibition underlie attentional processing by using a task developed by Posner (1980) in his three-stage orienting model. Within this attentional model, the mechanisms underlying attentional processing are determined by comparing performance on valid and invalid trials, to the performance on neutral trials. In the neutral trials, attention is not deployed to any specific location while on valid trials, attention is focused on the target. If performance on valid trials is better than on neutral trials, it is believed that there is attentional enhancement. On invalid trials, attention is focused on a stimulus other than the target. If performance is worse on invalid trials compared to neutral trials, then inhibitory mechanisms are likely to be involved.

4.4 Conclusions

Attention is a process distributed along a continuum and is affected by stimulus and task complexity. It can be focused by either exogenous or endogenous cues and can be selective or divided. Attention affects lower and

higher processing through inhibition and enhancement mechanisms. Many questions remain unanswered as to the interactions between attention, contrast sensitivity and aging.

Chapter 5: Impact of attention on contrast sensitivity

The studies presented in the previous chapter suggest that attention can influence perception in many ways, depending on the processing complexity of the stimuli, of the attentional cue and of the task. Although this may be the case, these studies leave many questions unanswered.

5.1 Physiological evidence

From a physiological standpoint, there is controversy as to whether attention can influence contrast sensitivity. Some studies have demonstrated that attention can influence contrast sensitivity for dynamic stimuli. In monkeys, motion is processed in the dorsal pathway, in the medio-temporal (MT) and medio-supero-temporal (MST) areas. Treue and Maunsell (1996, 1999) found attentional modulations in area MT of monkeys. They used extracellular techniques to record from neurons located in this area and show that attention modulates the processing of direction-selective neurons. However, this attentional modulation may be due to the manner in which attention is directed to a stimulus and to task demands. Indeed, in a similar study, Seideman and Newsome (1999) observed only very weak attentional modulation in area MT. On the other hand, motion-related attentional modulation has also been observed in humans using the functional magnetic

resonance imaging (fMRI) technique. O'Craven, Rosen, Kwong, Treisman and Savoy (1997) report attentional modulations in the human homologues of areas MT and MST in the monkey.

Other studies cast doubt on whether attention can influence contrast sensitivity. It is controversial whether area V1 (striate cortex) is influenced by attention. Some reports suggest that it is (Motter, 1993; Roelfsema, Lamme, & Spekreijse, 1998; Ito & Gilbert, 1999; Somers, Dale, Seiffert, & Tootell, 1999) while others suggest no effect or weak effects (Haenny & Schiller, 1988; Luck, Chelazzi, Hillyard, & Desimone, 1997; Luck & Ford, 1998; Wurtz & Mohler, 1976). Martinez, Anillo-Vento, Sereno, Frank, Buxton, Dubowitz et al. (1999), studied attentional processing using functional magnetic resonance imaging (fMRI) and evoked response potentials (ERPs). fMRI attentional activity was found within the striate cortex; however the ERP in that area was not modulated by attention. Therefore they concluded that the sensory processing implicated by the fMRI is not attentional in nature but is more likely due to feedback from higher cortical areas or to a bias of striate cortex neurons that occurs during attentional processing.

The size of the receptive fields within the striate cortex may explain why attentional modulation is not consistently observed in this area. Receptive fields in V1 are small, making it difficult to place two stimuli within the

receptive field of a single cell. It has been suggested that attentional modulations are observed when there is competition between two stimuli. For example, Moran and Desimone (1985) used single cell recordings in areas V4 and in the infero-temporal area (IT) and show that when two stimuli were present within the receptive field of a cell, the response of that cell is consistent with the attended stimulus. However, when one stimulus was presented within the receptive field and the other outside the receptive field, then the cell responds according to the stimulus located within the receptive field, regardless of the locus of attention. Luck et al. (1997) failed to observe attentional modulation in areas V1 and V2 due to the small size of the receptive fields of these cells. However, they found a subset of V2 neurons with larger receptive fields and attention did modulate the activity of these cells.

5.2 Psychophysical evidence of attentional modulation on contrast sensitivity

Psychophysical studies using multiple simple sine-wave gratings with exogenous cueing show attentional benefits for contrast sensitivity in contrast increment or decrement judgment tasks (Foley & Schwartz, 1998; Solomon, Lavie, & Morgan, 1997), orientation detection tasks (Lu & Doshier, 1998) and

divided attention tasks (Lee, Koch, & Braun, 1997; Lee, Itti, Koch, & Braun, 1999). Behavioral studies also suggest that attention modulates motion perception. This is especially true in the case of ambiguous motion, i.e. motion in which different percepts can be experienced depending on the focus of attention. For example, Watanabe and Shimojo (1998) report that attention results in an increase in the percept of motion continuing in one direction rather than changes in direction. Similarly, von Grünau, Bertone and Pakneshan (1998) had participants attend to one of two component motion directions within a plaid stimulus. The resulting motion aftereffect suggests that the dominance of the attended component is increased.

Carrasco, Penpeci-Talgar and Eckstein (2000) studied the impact of spatial covert attention on contrast sensitivity. They used a simple visual stimulus, similar to the first-order contrast stimulus described previously. Static sine-wave gratings of different orientations were used as targets and they tested a wide range of spatial frequencies. A small circle was used as an exogenous attentional cue. In different experiments, contrast sensitivity was assessed through either orientation discrimination, detection or localization tasks. A single stimulus was presented at one of eight pre-determined locations in the experimental display. The attentional effect was measured in comparison to neutral trials in which the cue did not reveal the target location in advance.

Half the trials were cued and half were neutral. In this study, the attentional cue always accurately predicted the location of the target (100% cue validity). The results show an increase in contrast sensitivity for cued trials compared to neutral trials. This suggests that attention increases sensitivity to contrast and the authors suggest that this is likely due to the enhancement of processing at the cued location. However since the impact of inhibition was not assessed, the underlying mechanisms remain unclear.

The findings of Carrasco et al. (2000) are interesting because evidence of an attentional effect on contrast sensitivity suggests that, on a functional level, the sensitivity to targets that are near threshold can be modified by exogenous attentional cueing. While the finding that this can occur with exogenous cueing is interesting, an investigation of the impact of endogenous cueing on contrast sensitivity has even more value in terms of functional vision, as it implies the possibility of training. The findings of Ball, Beard, Roenker, Miller and Griggs (1988) also suggest that training can improve perceptual functions. They report improvements an enlargement of the useful field of view in older participants following training.

5.3 Conclusions

Attention can modulate contrast sensitivity, as observed by lowered contrast thresholds, improved judgments on whether a target has a contrast increment or decrement, improved orientation discrimination and increased sensitivity to motion direction in ambiguous targets. The studies reported here have not, however, investigated the impact of attention on contrast sensitivity for different types of attentional cueing (exogenous and endogenous). Furthermore, mostly young participants and simple targets were tested. To develop a better understanding of the impact of attention on contrast sensitivity, it will be necessary to look at the impact of attention on complex targets, older participants and to study the underlying mechanisms that govern attentional processing.

Chapter 6: Impact of normal aging on visual attention

The impact of normal aging on attention is not yet fully understood. Contradictory reports have been published and there is no consensus at this time.

6.1 Effect of age on attention

Some aspects of attentional processing appear to be spared in older individuals. For example, Tellinghuisen, Zimba and Robin (1996) report normal visuo-spatial function in aged individuals for speeded two-choice responses that involved making line-orientation or lexical decisions. However, other reports suggest deficits in attentional processing associated with age. Such deficits have been reported in the ability to shift attention (Madden, Connelly, & Pierce, 1994), perform visual search tasks (Greenwood, Parasuraman, & Alexander, 1997) and on tasks that require divided (Ball et al., 1988) or selective (Brink & McDowd, 1999) attention.

Interestingly, however, age-related attentional deficits appear to be associated with complex processing. For example, the deficits in shifting attention in older individuals reported by Madden et al. (1994) were observed mainly when distractor items had to be processed. When these items could be ignored, no age-related attentional differences were observed. Similarly, the

age-related attentional deficits reported by Greenwood et al. (1997) in visual search were observed for targets composed of a conjunction of features and not for target composed of a single feature. This suggests that age-related attentional deficits may occur for complex stimuli and not, or at least to a lesser degree for simple stimuli.

6.2 Attentional training

It is crucial to better understand attentional deficits in the aged population, as they may have serious implications in demanding yet common tasks of daily living and thus on quality of life. Driving is a striking example of a complex task performed by an increasing number of older individuals. There is no doubt that an assessment of visual attention should be included in the overall assessment of older drivers when determining driving ability.

Furthermore, some evidence shows that training can improve performance in older individuals (Ball et al., 1988) as well as in stroke patients (Mazer, Sofer, Korner-Bitensky, & Gelinas, 2001). Significant improvements in the time needed to perform daily tasks such as reading the ingredients on cans of food, reading the instructions on medicine bottles, finding a phone number in the phone book and locating items on a crowded shelf, were observed following processing speed training (Edwards, Wadley, Myers,

Roenker, Cissell, & Ball, 2002). This type of training was also found to improve performance on the Useful Field of View (UFOV) test (Roenker, Cissell, Ball, Wadley, & Edwards, 2003).

It may therefore be possible, at least in some individuals, to use attention to compensate for other visual deficits. This is consistent with the physiological substrates of visual attention and with the changes the aging brain undergoes. Indeed, attention is a distributed mechanism, which operates from primitive to cortical structures. Similarly, diffuse, non-specific changes are the landmark of the normal aging brain.

6.3 Conclusions

Age-related deficits in visual attention have been reported. However, these deficits appear to be associated with complex stimuli that require a higher level of processing. Evidence suggests that training can improve attentional skills.

6.4 Overall summary

Independent relationships have been reported between contrast sensitivity, visual attention and normal aging. In general, it appears that age-related deficits in both contrast sensitivity and visual attention are associated

with stimuli or tasks that require complex processing. The interaction between contrast sensitivity and visual attention in the normal aging population has not been investigated. The present research is therefore an investigation of the relationship between visual attention and contrast sensitivity in normal aging.

Chapter 7: The present research

Although previous studies have shown that attention can improve contrast sensitivity and that there is a decrease in contrast sensitivity with increasing age, little is known about the interactions between these processes. The purpose of the present research is to investigate the impact of visual attention on contrast sensitivity in normal aging. More specifically, the purpose of the present research is to determine whether age-related differences are more readily observed under conditions that impose a heavy processing load, compared to conditions that impose a light processing load.

The results obtained by Habak and Faubert (2000) provide support for the hypothesis that an increased processing load is likely to reveal perceptual age-related differences. They report larger age-related differences in contrast thresholds for complex second-order stimuli compared to simple first-order stimuli. Complex stimuli require more processing than simple stimuli, as they may involve additional processing steps. As reviewed in chapter 3, physiological changes in the aging brain are thought to be widespread and non-specific and may have a small effect at each stage of processing. Therefore, the more steps involved in the processing of a stimulus, the greater the impact of normal aging should be. Although the results obtained by Habak and Faubert (2000) support this approach, they did not test for the effect of attention.

7.1 Specific goals

The first goal is to confirm the impact of aging on contrast sensitivity as suggested by Habak and Faubert (2000). The second goal is to determine whether attention can modulate contrast sensitivity. The third goal is to determine whether age-related differences in the effect of attention on contrast sensitivity exist. Finally, the fourth goal is to determine whether these effects vary with processing load. Processing load was manipulated by varying the type of attentional cue (exogenous and endogenous), the array size (single and multiple target presentation), the cue validity (75% and 100%), the drifting speed (static and drifting) and the contrast type (first- and second-order).

7.2 Assumptions

In the present research, three assumptions are made: 1) changes in the aging brain are widespread and non-specific; 2) the deficits caused by these non-specific age-related changes are more likely to be observed under conditions that impose a heavy processing load; and 3) attention is a process distributed along a continuum and attentional resources are allocated based on processing complexity.

7.3 Hypotheses

Based on the literature, the following hypotheses were formulated: 1) if more processing steps are required for complex second-order stimuli than for simple first-order stimuli, then larger perceptual age-related differences should be observed for second-order stimuli; 2) if the larger perceptual age-related deficits for second-order stimuli are also present in the attentional realm, then a larger difference should be observed between young and older participants for second-order stimuli compared to first-order stimuli under attentional conditions; 3) if the perceptual and attentional age-related differences are due to processing load, then larger age-related differences should be observed for endogenous compared to exogenous attention, multiple compared to single stimulus presentation, dynamic compared to static gratings, 75% cue validity compared to 100% cue validity and for second- compared to first-order stimuli.

7.4 Theory-based predictions

One goal of this research is to confirm whether larger perceptual age-related differences exist in contrast sensitivity, or in other words, the replication of the results obtained by Habak and Faubert (2000). It will also allow for the performance of young and older participants to be equated in terms of the perceptual task, by assessing the contrast thresholds needed for an

arbitrarily determined performance accuracy of 75%. Based on previous studies, it is expected that older participants will have higher contrast thresholds than young participants for both first- and second-order stimuli. In addition, the difference in contrast thresholds between the young and older participants is expected to be larger for second-order stimuli than for first-order stimuli. This is assumed to occur because there are more processing steps involved for second-order stimuli than for first-order stimuli. Furthermore, processing load is assumed to be heavier under endogenous, compared to exogenous attention, dynamic compared to static gratings, multiple compared to single gratings, for 75% compared to 100% cue validity and for second- compared to first-order stimuli. These predictions are illustrated in Table 7.1.

Once all participants are perceptually equated, attention will be introduced. The main goal of this research is to determine the impact of attention on contrast sensitivity in normal aging. On the one hand, it is possible that attentional age-related deficits exist in addition to the perceptual deficits (Table 7.2). On the other hand however, attention may compensate for other deficits in the perception of contrast sensitivity in older individuals (Table 7.3). As illustrated in Tables 7.2 and 7.3, greater attentional age-related differences were expected under conditions requiring heavier processing load.

7.5 Experimental organization

The organization of the experiments included in this research is presented in Figures 7.1 (exogenous attention) and 7.2 (endogenous attention). The baseline experiment was always conducted first, to determine the contrast thresholds for 75% performance accuracy. The subsequent sixteen experiments were conducted in random order, with blocking on each of the variables. The shaded boxes in Figures 7.1 and 7.2 illustrate the blocking scheme. Once the baseline experiment was completed, the participants were first tested under either exogenous or endogenous attention. Randomization between each of the blocks was then performed. A more detailed description of the randomization process is provided in section 8.5 of chapter 8.

Table 7.1. Illustration of the perceptual differences in contrast thresholds for 75% performance accuracy for young and older participants for first-and second-order stimuli. (Δ : difference)

	Static				Dynamic			
	First-order (Light load)		Second-order (Heavy load)		First-order (Light load)		Second-order (Heavy load)	
	Young	Older	Young	Older	Young	Older	Young	Older
Contrast threshold (%) ¹	3	3	6	11.3	0.5	0.8	10.0	23.3
Age-related contrast Δ (%)	0		5.3		0.3		13.3	
Performance accuracy (%)	75	75	75	75	75	75	75	75

¹ Based on the results obtained by Habak and Faubert (2000)

Table 7.2. Predictions for additional age-related attentional deficits in contrast sensitivity.

	Static				Dynamic			
	Light load		Heavy load		Light load		Heavy load	
	Young	Older	Young	Older	Young	Older	Young	Older
Contrast threshold (%)	3	3	6	11.3	0.5	0.8	10.0	23.3
Performance on neutral (%)	75	75	75	75	75	75	75	75
Performance with attention (%)	85	85	85	80	85	83	85	78
Performance difference (%)	10	10	10	5	10	8	10	3
Age-related difference (%)	0		5		2		7	

Table 7.3. Predictions for compensatory age-related mechanisms in attention for contrast sensitivity.

	Static				Dynamic			
	Light load		Heavy load		Light load		Heavy load	
	Young	Older	Young	Older	Young	Older	Young	Older
Contrast threshold (%)	3	3	6	11.3	0.5	0.8	10.0	23.3
Performance on neutral (%)	75	75	75	75	75	75	75	75
Performance with attention (%)	85	85	85	85	85	85	85	85
Performance difference (%)	10	10	10	10	10	10	10	10
Age-related difference (%)	0		0		0		0

Figure 7.1. Diagram of all experiments conducted under exogenous cueing. (FO: first-order; SO: second-order)

Figure 7.2.: Diagram of all experiments conducted under endogenous cueing. (FO: first-order; SO: second-order)

Chapter 8: General Methods

This chapter describes the general methods used in this research. A description of the participants, apparatus, stimuli, data collection, testing order and statistical analyses are included.

8.1 Participants

Fourteen participants were included in this research, seven young adults (Mean: 21 years of age; SD: 4.9; five females) and seven older adults (Mean: 71.9 years of age; SD: 6.8; four females). Participants were recruited among the students and staff of the Ottawa Hospital-General Campus. Recruitment advertisements were also posted in the volunteers' lounge at the Ottawa Hospital-General Campus and at the Children's Hospital of Eastern Ontario. The research followed the tenets of the Declaration of Helsinki and was approved by the research ethics committee of the Ottawa Hospital. All participants provided informed consent.

All participants had healthy eyes and normal or corrected-to-normal vision. In the young group, five of the seven participants were experienced psychophysical observers and two of the seven older participants had previously been involved in psychophysical research. All participants were,

however, naive to the purpose of the research. The same participants were tested in all experiments.

8.2 Apparatus

Stimuli were generated by a Power Macintosh 7100/80AV and were presented on a 19-inch Silicon Graphics monitor. The monitor had a refresh rate of 67 Hz and a resolution of 640 X 480 pixels. All stimuli were created using the Pixx© software program. Participants were comfortably seated with their head positioned in a chin- and forehead-rest. Stimuli were viewed binocularly in a dimly lit room, from a distance of 47.5 centimeters.

8.3 Stimuli

The stimuli used in this research were static and dynamic spatial modulations of either luminance or contrast subtending $4^\circ \times 4^\circ$ of visual angle. The basic stimulus consisted of a reddish hard-edged square patch containing a sine-wave grating of one cycle per degree (cpd), on which a two-dimensional gray-scale static random noise field was superimposed. Each noise element was square and subtended 2.2 arcmin. Examples of first- and second-order stimuli are presented in Figure 8.1. The position of the stimuli was different

depending on the experiment and will be discussed later, in the appropriate chapters.

A reddish stimulus was chosen because the absorption of wavelengths beyond 600 nm has been shown to be similar in young and older adults (Weale, 1963). Furthermore, there is a sharp peak in the spectral components of the screen at 620 nm that is not filtered by the optics of the eye (Faubert, 1994; Faubert, Diaconu, Ptito, & Ptito, 1999). The blue and green guns were therefore set to a minimal value while the red gun was set to its maximum value. The rest of the screen was set at the mean luminance of 10.8 cd/m².

8.3.1 First-order stimuli

In this research, simple first-order stimuli and complex second-order stimuli were used. Stimuli were composed of a luminance-defined 1 cpd sine-modulated envelope and of a static gray-scale noise carrier. The envelope and the carrier were added to create first-order stimuli (Figure 8.1, panel a). At any given point, the luminance profile was defined as:

$$L(x, y) = L_{\text{mean}} [(1 + m_{\text{env}} * \sin 2\pi xf) + (1 + 0.5 m_{\text{car}} * R(x, y))]$$

where L_{mean} is the mean luminance of the display, m_{env} is the modulation depth of the envelope, f is the spatial frequency of the envelope and m_{car} is the contrast of the carrier. $R(x, y)$ is the static noise carrier consisting of dots

whose individual luminances were randomly assigned as a function of $\sin(x)$, where (x) ranged from 0 to 2π . Grey-scale noise elements were randomly assigned various intensity levels along a sine function rather than dark or light polarities. The amplitude of the luminance modulation (Michelson contrast) varied between 0 and 0.55 and the mean contrast or modulation depth was defined as:

$$\text{Modulation depth} = (L_{\max} - L_{\min}) / (L_{\max} + L_{\min})$$

where $L_{\max}$ is the maximum luminance and $L_{\min}$ is the minimum luminance averaged over adjacent noise elements.

8.3.2 Second-order stimuli

Complex second-order stimuli were composed of a contrast-defined 1 cpd sine-modulated envelope and of a static gray-scale noise carrier. The envelope and the carrier were multiplied to create second-order stimuli (Figure 8.1, panel b). At any given point, the luminance profile was defined as:

$$L(x, y) = L_{\text{mean}} [(1 + m_{\text{env}} * \sin 2\pi x f) * (1 + 0.5 m_{\text{car}} * R(x, y))]$$

where the terms are the same as those described for first-order stimuli, but where the envelope and the carrier were multiplied rather than added. The amplitude of the contrast modulation varied between 0 and 1 and the mean contrast or modulation depth was defined as:

$$\text{Modulation depth} = (L_{\max} - L_{\min}) / (L_{\max} + L_{\min})$$

where $L_{\max}$ is the maximum luminance and $L_{\min}$ is the minimum luminance of neighbouring noise elements in the high contrast areas of the stimulus.

Accordingly, the contrast between adjacent noise elements of opposite polarity was modulated across the stimulus between 0 and a maximum value.

8.3.3 Static and drifting stimuli

In different experiments, static and dynamic stimuli were presented.

Dynamic stimuli drifted at a rate of 4Hz to the right or left for vertically oriented gratings and upwards or downwards for horizontally oriented gratings, as indicated by the arrows in Figure 10.1. These two levels of drifting speed were selected based on a previous study (Habak & Faubert, 2000) showing that age-related differences were observed under these conditions.

8.3.4 Attentional cues

All experiments were conducted under both exogenous and endogenous cueing conditions. The exogenous cue was designed to capture attention automatically. It consisted of a black circle subtending 0.6 degrees of visual angle. This cue was flashed for 100 ms prior to the onset of the target. An example of the exogenous attentional cue used in this research is presented in

Figure 10.1 (panel A). In the neutral trials, the exogenous cue was presented at fixation. In the valid and invalid trials, it was presented at 10 degrees of visual angle from fixation (from fixation to the center of the cue), near the most distant corner from fixation of the grating.

The endogenous cue consisted of a centrally located directional arrow, pointing towards one of four possible sine-wave grating locations. An example of the endogenous attentional cue used in this research is presented in Figure 10.1 (panel B). Participants were instructed to attend to the location indicated by the directional arrow, while maintaining central fixation. Participants initiated each trial when they were confident that their attention was focused on the required area of the visual field. Trials were initiated by depressing the spacebar key on the computer keyboard.

Finally, the report signal was identical to the attentional cue, but was presented immediately after the sine-wave gratings. The report cue remained on the screen until the participants gave a response.

8.4 Data collection

All experiments were conducted over as many one-hour sessions as necessary to complete all experimental conditions. Participants were encouraged to rest at any time during testing if they experienced fatigue. The

first session was devoted exclusively to practice trials and to the baseline experiment. The overall testing time was different for each participant and was dependent upon the number and length of rest periods necessary, as well as on the number of practice trials needed.

Formal practice trials were conducted prior to the baseline experiment, prior to the exogenous block of experiments and prior to the endogenous block of experiments. To familiarize the participants with the task and stimuli used in the baseline experiment, four blocks of 60 practice trials were performed. Each block tested a different condition composed of the combinations between array size (single and multiple grating presentation) and contrast type (first- and second-order stimuli). If participants felt they needed more practice, then one or more of these blocks were conducted a second time. Practice trials were also conducted prior to the exogenous and endogenous blocks. Four conditions were selected to provide an example of each of the stimulus configurations. These conditions were selected pseudo-randomly to expose each participant to all stimuli, stimulus configurations and cue validity levels. The blocks in which cue validity was set at 100% contained 96 trials, while those in which cue validity was set at 75% contained 80 trials.

Prior to each experiment, participants received detailed instructions as to the task they were about to perform. Participants responded verbally and the

experimenter entered the data by pressing one of two predetermined keys on the computer keyboard. This was done to equate task difficulty between the two age groups, as there may be differences between young and older participants in manually entering data.

8.5 Testing order

While the baseline experiment was always conducted first, the order of testing for the subsequent sixteen experiments was determined pseudo-randomly for each participant. To achieve randomization, each level of each variable was given a unique number. A list of random numbers was then produced through an automated random number generator program. Each number on this list sequentially determined which level of each variable would be tested first. The exogenous and endogenous experiments were conducted in separate blocks, in random order. The order of testing for all experiments within the exogenous and endogenous conditions was randomly determined. First- and second-order stimuli were always tested separately and the order of testing was randomly determined.

More concretely, for each participant, the baseline experiment was conducted first. Then, it was randomly determined whether this participant would undergo exogenous or endogenous attentional conditions. If exogenous

attention was selected, then further randomization determined whether single or multiple gratings would be tested first. If single grating was selected, further randomization determined whether static or dynamic gratings would be tested first. If static gratings were selected, then it was randomly determined whether cue validity would be set at 75% or at 100%. Finally, if 100% was selected, random determination of first- and second-order stimuli was performed.

Therefore, under these hypothetical random determinations, this participant would first be tested on the baseline experiment. The following experiment would have been conducted: exogenous cue with 100% validity tested with a single static first-order grating. The third condition tested would have been exogenous cue with 100% validity tested with a single static second-order grating. The fourth tested condition would have been exogenous cue with 100% validity tested with a single static grating and first-or second-order stimuli would have been randomly determined. This process went on until all conditions were tested.

8.6 Statistical analyses

8.6.1 Investigational data analysis

An analysis of variance (ANOVA) was performed on the results obtained in each experiment. Significant results were based on an alpha of .05. All

analyses were performed with the SigmaStat software and the results were graphed with the SigmaPlot software. Significant main effects in which more than two levels of one variable were included were followed up with the Tukey test, to determine which levels were significantly different from each other. Significant two-way interactions were followed up with simple effect analyses, to determine the effect of one variable at each level of the other. Significant simple effects in which more than two levels of one variable were included were also followed up with the Tukey test, to determine which levels of the variable significantly differed from the others.

8.6.2 Neutral trials analysis

The goal of the baseline experiment was to equate the performance of all participants on a contrast sensitivity task. This was done to rule out the possibility that any subsequently observed attentional effects were in reality caused by differences in perception between young and older participants. One problem with the baseline experiment, however, was that the stimulus configuration and the task were slightly different than in the subsequent sixteen experiments. As a control for these differences, it was necessary to determine whether the participants remained perceptually equal under each experimental condition.

This verification was performed through an analysis of the neutral trials in each experiment, which is presented at the end of chapters 10, 11, 13 and 14. In the baseline experiment, no attentional manipulations were performed. In all other experiments, attention was manipulated either exogenously or endogenously. However, the neutral trials were not influenced by attention. Therefore, performance on the neutral trials was expected to be similar to the performance observed in the baseline experiment. Although overall performance on the neutral trials could be either slightly better or worse in both age groups compared to the baseline experiment, no difference between the two age groups should be observed. Overall increases or decreases in performance could be explained by the differences in the stimulus configuration and task between the baseline experiment and each of the subsequent sixteen experiments. However, a significant difference between the two age groups on neutral trials may suggest that the young and older participants were no longer perceptually equated. The summary tables for all of the statistical analyses are included in Appendix A.

8.6.3 Family-wise error rate correction

Although many variables were included in this research, no adjustments for multiple comparisons were performed. This is justified by the relatively

low impact that making a Type I error would have compared to making a Type II error. In other words, it would be more detrimental to the goals of this research to find a non-existing effect, than to have an existing effect go undetected. In addition, these adjustments test the universal null hypothesis, that is that all groups are similar on all variables (Perneger, 1998; Savitz & Olshan, 1995). As is often the case, the universal null hypothesis is of no genuine interest in this research. Furthermore, adjustments for multiple comparisons imply that any given comparison is evaluated differently, depending on the number of tests performed. Guarding against spurious results with Bonferroni-like adjustments may prevent one from detecting real differences in the data.

Figure 8.1. Illustration of first-order (panel a) and second-order (panel b) stimuli (adapted from Habak & Faubert, 2000). The stimuli used in the present research differed in two respects: 1) the sine-wave grating was presented within a square patch and 2) the stimuli were reddish.

Chapter 9: Baseline experiment

The goal of the baseline experiment was two-fold: 1) to determine whether larger age-related perceptual differences in contrast thresholds are observed for complex second-order stimuli compared to simple first-order stimuli. If so, this provides support for the results obtained by Habak and Faubert (2000); 2) to determine the individual contrast thresholds that were used in all subsequent experiments. This was critical to ensure that all participants were perceptually equal on all targets when attention was introduced in the experimental setting.

9.1 Design

In this experiment, participants performed a two-interval forced choice orientation discrimination task. The independent variables were age (young and older), contrast type (first- and second-order) and drifting speed (static or dynamic). The dependent variable was the percent contrast for a 75% accuracy performance level on an orientation discrimination task. The baseline experiment was always conducted first.

9.2 Procedure

Participants were asked to fixate on a centrally located dot during stimulus presentation. Two sine-wave gratings, separated by an inter-stimulus interval of 60 ms, were presented in the same location for 100 ms each, either above or below fixation. One sine-wave grating was vertically oriented while the other was horizontally oriented. Participants were asked to report whether the vertical grating was presented first or second. The order of stimulus presentation was randomized. Participants responded verbally on each trial and the experimenter recorded the response. The dimensions of the stimuli are illustrated in Figure 9.1.

A parameter estimation technique (PEST) (Taylor & Creelman, 1967) was used to determine the contrast thresholds required for 75% performance accuracy. PEST is an adaptive staircase method, which allows for the determination of a dependent variable at any level of an independent variable. In this experiment, the contrast levels were manipulated until each participant could accurately discriminate the orientation of the sine-wave gratings on 75% of the trials. When correct responses were recorded, PEST reduced the contrast of the sine-wave grating of the subsequent pair of stimuli. Conversely, incorrect responses resulted in an increase in contrast on the following pair of stimuli. This procedure was repeated until the pre-determined performance

level of 75% was reached. After a pre-specified number of reversals, the contrast threshold was determined as the average of the last two reversals. The number of trials was different each time and was dependent on how consistent the responses were.

Contrast levels were assessed for each participant individually and were used in all subsequent experiments. This was done in four separate conditions, which combined static, dynamic, first- and second-order stimuli. The four conditions were tested in random order. An illustration of a trial is presented in Figure 9.2.

9.3 Results

The contrast levels for each participant under each condition are shown in Tables 9.1 (young group) and 9.2 (older group). These contrast levels were used in all subsequent experiments. The mean results for each group are presented for static and dynamic gratings in Figure 9.3.

An analysis of variance (ANOVA) was performed on the contrast thresholds obtained in this experiment. Significant main effects of contrast type and age were found (Figure 9.4). The contrast thresholds were significantly higher for second-order stimuli (Mean: 37.9; SD: 22.8) than for first-order stimuli (Mean: 3.76; SD: 2.33), consistent with the idea that second-order

stimuli require more complex processing than first-order stimuli. Higher contrast levels were also observed in the older group (Mean: 30.1; SD: 28.9) compared to the young group (Mean: 11.6; SD: 11.0). There were no significant differences between the results for static and dynamic gratings; that is, the speed at which the sine-wave grating drifted did not significantly influence the contrast thresholds.

The interaction between contrast type and age was significant (Figure 9.5). Young and older participants had similar performance when first-order stimuli were presented. However, when the more complex second-order stimuli were used, the older group needed higher contrast levels than the young group for similar performance. No other significant interactions were observed.

9.4 Discussion

Significant differences were observed between the young and older participants for mean contrast thresholds. There were also differences in contrast thresholds for contrast type, in which higher contrast levels were required for second-order stimuli. This is consistent with the hypothesis that second-order stimuli are more complex and may require more processing steps. Furthermore, age-related differences were observed such that a larger increment in contrast threshold for second- compared to first-order stimuli was

observed in the older group. This increment was smaller in the young group. These results are consistent with the findings reported by Habak and Faubert (2000).

The study of age-related attentional differences is complicated by age-related sensory changes. With increasing age, pupils tend to be smaller (miosis) and cataracts are more commonly observed (lens opacification). Factors such as pupil miosis and lens opacification may reduce retinal light input, resulting in impaired sensory processing. Such sensory degradation can be a confounding factor if it is not controlled for carefully. The differences observed between the age groups reinforce the necessity to equate perceptual performance when testing young and older participants. By using individual contrast levels in all of the following experiments, age differences in contrast levels were controlled for.

Figure 9.1. The dimensions of all stimuli in the baseline experiment are presented. The stimuli could be presented either above (panel A) or below (panel B) fixation.

Figure 9.2. Illustration of the sequence of events used in the baseline experiment.

Table 9.1. Individual contrast levels (%) for each participant in the young group are presented. The mean and standard deviation are presented at the bottom of the table.

Participants	Age	Sex	First-order stimuli		Second-order stimuli	
			Static	Dynamic	Static	Dynamic
ab	25	F	3.0	2.9	19.5	23.3
ad	21	M	2.4	2.2	23.4	45.3
an	17	F	2.2	2.1	11.5	22.0
hm	17	M	3.0	1.7	12.9	15.6
ks	20	F	2.5	2.3	23.1	20.9
lr	30	F	2.0	3.7	18.9	24.7
sh	17	F	1.9	1.8	17.8	12.7
Mean	21		2.4	2.4	18.2	23.5
SD	4.9		0.4	0.7	4.6	10.5

Table 9.2. Individual contrast levels (%) for each participant in the older group are presented. The mean and standard deviation are presented at the bottom of the table.

Participants	Age	Sex	First-order stimuli		Second-order stimuli	
			Static	Dynamic	Static	Dynamic
bp	68	M	4.3	4.0	64.8	64.1
cn	77	F	6.5	5.3	83.8	90.5
jn	84	M	3.8	3.9	44.7	52.3
js	67	F	2.8	9.4	55.5	60.0
ky	74	M	4.6	4.1	40.7	43.7
ma	66	F	5.4	12.0	28.3	77.7
ph	67	F	2.6	2.9	32.3	31.8
Mean	71.9		4.3	5.9	50.0	60.0
SD	6.8		1.4	3.4	19.5	19.9

Figure 9.3. Bar graphs showing the mean results obtained in the baseline experiment for dynamic and static gratings for first- and second-order stimuli in each age group.

Figure 9.4. The main effects of contrast type, age and drifting speed obtained in the baseline experiment are presented (* statistically significant effects in this and all subsequent graphs).

Figure 9.5. The two-way interaction between contrast type and age in the baseline experiment is presented.

Chapter 10: Exogenous cueing with static gratings

The four experiments included in this chapter test the impact of exogenous attention on contrast sensitivity for static gratings in young and older participants, under conditions that impose different processing loads. The individual contrast thresholds obtained for each target in the baseline experiment were used in all the experiments described in this chapter. Participants were tested on an orientation discrimination task on which they had to report whether the grating next to the report cue was horizontally or vertically oriented. Within each experiment, participants were tested on simple, first-order stimuli and complex, second-order stimuli and this in random order. In addition, array size (one or four gratings) and cue validity (100% or 75%) were used in combination to manipulate processing complexity across experiments. Processing load was lightest in Experiment I and heaviest in Experiment IV. Orientation discrimination was assumed to be more difficult for multiple compared to single grating presentation. Similarly, orientation discrimination was assumed to be more complex when cue validity is set at 75% compared to 100%. In Experiment I, a single grating was presented at one of four possible locations and cue validity was set at 100%. In Experiment II, a single grating was presented at one of four possible locations and cue validity was set at 75%. In Experiment III, multiple gratings were presented and cue

validity was set at 100%. Finally, in Experiment IV, multiple gratings were presented and cue validity was set at 75%.

10.1 Design

A mixed within-subject design was used for all the experiments described in chapters 10, 11, 13 and 14. The independent and dependent variables were the same in all experiments. The following independent variables were manipulated within each experiment: age (young and older) and attention (neutral, valid and invalid trials), while the following independent variables were manipulated between experiments: type of attention (exogenous and endogenous), array size (single and multiple), cue validity (75% and 100%), drifting speed (static and dynamic) and contrast type (first- and second-order). The dependent variable was the percent accuracy on an orientation discrimination task.

10.2 Procedure

The same participants tested in the baseline experiment were tested under all the experiments described in chapters 10, 11, 13 and 14. Participants performed a two-alternative forced-choice task, in which they were asked to discriminate between horizontal and vertical sine-wave gratings. Participants

initiated each trial by depressing the space bar on the computer keyboard. When cue validity was set at 100%, 80 trials were conducted in each session. Forty were neutral trials and 40 were valid trials. When cue validity was set 75%, 96 trials were conducted in each session. Forty-eight trials were neutral trials, thirty-six were valid trials and twelve were invalid trials. Within each experiment, participants were tested with first- and second-order contrast stimuli, in separate blocks.

The dimensions of all stimuli used in the experiment reported in chapters 10 and 11 (exogenous) and 13 and 14 (endogenous) are presented in Figure 10.1. Examples of the experimental conditions under exogenous cueing are shown for neutral (Figure 10.2), valid (Figure 10.3) and invalid (Figure 10.4) trials. In the neutral trials, the cue was presented centrally while the target stimulus could be presented in one of four locations

Figure 10.1. Illustration of the dimension of all stimuli in the exogenous (panel A) and endogenous (panel B) conditions. The exogenous cue consisted of a peripheral circle while the endogenous cue consisted of a central arrowhead. Endogenous cues will be discussed fully in Chapter 13. The bi-directional arrows indicate motion direction for dynamic gratings.

Figure 10.2. Illustration of the basic sequence of events used in the neutral trials under exogenous attentional cueing.

Figure 10.3. Illustration of the basic sequence of events used in the valid trials under exogenous attentional cueing.

Figure 10.4. Illustration of the basic sequence of events used in the invalid trials under exogenous attentional cueing.

10.3 Experiment I

10.3.1 Goals and Methods

The goal of this experiment was to investigate the impact of exogenous attention on contrast sensitivity in normal aging, under conditions imposing the lightest processing load of the four experiments conducted in this chapter. Processing complexity was minimized by presenting a single static grating at one of four possible locations (Figure 10.1) and by setting cue validity at 100%. These conditions are similar to those used by Carrasco et al. (2000). Based on the literature, the orientation discrimination task should require less processing when a single grating is used compared to multiple gratings. Similarly, less processing is required for 100% than 75% cue validity. Attentional and age-related differences in the effect of attention on contrast sensitivity were assumed to be more readily observed under heavy processing load and were therefore not expected in this experiment. However, should any effects be observed, it would be likely for complex, second-order stimuli.

10.3.2 Results

An ANOVA was performed on the data obtained in this experiment. The main effects and two-way interactions are presented in Figure 10.4, which is divided into six panels. Panels A (attention), B (age) and C (contrast type)

illustrate the main effects, while panels D (attention X age), E (attention X contrast type) and F (age X contrast type) illustrate the two-way interactions. This presentation format is consistent throughout the manuscript. On all graphs, the horizontal line shows the 75% performance level assessed in the baseline experiment. Each graph is labeled with the main effect or two-way interaction it illustrates and an asterisk near the graph label highlights significant effects. Although none of the three-way interactions were significant, these graphs are presented in Appendix B.

Main effects: The main effect of attention was not significant, indicating similar performance for neutral and valid trials (Figure 10.5, panel A). The main effect of age was not significant, indicating that the young and older groups performed similarly (Figure 10.5, panel B). The main effect contrast type was not significant, indicating no differences in performance between the first- and second-order stimuli (Figure 10.5, panel C).

Interactions: The interaction between age and attention was not significant, indicating that the effect of attention was similar in both age groups (Figure 10.5, panel D). The interaction between contrast type and attention was not significant, indicating that the effect of attention was similar for both first- and second-order stimuli (Figure 10.5, panel E). The interaction between contrast type and age was not significant, indicating that the effect of age was

similar for first- and second-order stimuli (Figure 10.5, panel F). The three-way interaction between age, attention and contrast type was not significant.

10.3.3 Discussion

The results of this experiment suggest, unlike what was reported by Carrasco et al. (2000), that exogenous attention may not influence contrast sensitivity under conditions that impose a light processing load. Under these conditions, perception may be mediated through sensory processes alone. It is also possible that the grating grabs attention automatically, such that the cue does not further enhance performance. The lack of an attentional effect in this experiment is consistent with the theory that attention is a process distributed along a continuum, whose impact is mainly observed under heavier processing loads. The lack of an attentional effect also ruled out the possibility of observing age-related differences in the effect of attention on contrast sensitivity.

Figure 10.5. Main effects and two-way interactions for a single static grating with exogenous cue at 100% (EI).

10.4 Experiment II

10.4.1 Goals and Methods

The goal of this experiment was to investigate the impact of exogenous attention on contrast sensitivity in normal aging, under conditions imposing a heavier processing load than those used in Experiment I of this chapter. The increase in processing load was achieved by reducing cue validity from 100% to 75% such that on 25% of the cued trials attention was shifted onto a stimulus other than the target. As in the previous experiment, a single static grating was presented at one of four possible locations. Although presenting a single grating requires less processing than multiple gratings, more processing is required when cue validity is set at 75% as the cue does not always accurately predict the location of the target. The increase in processing load associated with the reduction of cue validity may result in an attentional effect on contrast sensitivity. If an attentional effect is present, the increase in processing load may in addition reveal age-related attentional differences.

10.4.2 Results

Main effects: The main effect of attention was not significant, indicating similar performance for neutral, valid and invalid trials (Figure 10.6, panel A). The main effect of age was not significant, indicating that the young

and older groups performed similarly (Figure 10.6, panel B). The main effect of contrast type was not significant, indicating no differences in performance between the first- and second-order stimuli (Figure 10.6, panel C).

Interactions: The interaction between age and attention was not significant, indicating that the effect of attention was similar in both age groups (Figure 10.6, panel D). The interaction between contrast type and attention was not significant, indicating that the effect of attention was similar for first- and second-order stimuli (Figure 10.6, panel E). The interaction between contrast type and age was not significant, indicating that the effect of age was similar for first- and second-order stimuli (Figure 10.6, panel F). The three-way interaction between age, attention and contrast type was not significant.

10.4.3 Discussion

As in the previous experiment, the results suggest that exogenous attention may not influence contrast sensitivity under conditions requiring slightly heavier processing load. Under these conditions, perception may be mediated through sensory processes alone or attention may be grabbed automatically by the stimulus, such that the cue does not further enhance performance. The lack of an attentional effect in this experiment is consistent with the theory that attention is a process distributed along a continuum, whose

impact is observed mainly under heavier processing load. The lack of an attentional effect also ruled out the possibility of observing age-related differences in the effect of attention on contrast sensitivity.

Figure 10.6. Main effects and two-way interactions for a single static grating with exogenous cue at 75% (EI).

10.5 Experiment III

10.5.1 Goals and Methods

The goal of this experiment was to investigate the impact of exogenous attention on contrast sensitivity in normal aging, under conditions imposing a heavier processing load than those used in Experiments I and II of the present chapter. The increase in processing complexity was achieved by presenting four stimuli instead of a single stimulus at one of four locations. Cue validity was set at 100%, such that the cue always predicted the location of the target accurately. The possibility of observing an attentional effect on contrast sensitivity, as well as age-related differences was higher in this experiment than in the previous experiments.

10.5.2 Results

Main effects: A significant main effect of attention was found, indicating that performance was better in the valid trials (Mean: 79.76; SD: 11.49) than in the neutral trials (Mean: 68.23; SD: 7.75) (Figure 10.7, panel A). A main effect of age was also found, indicating that overall performance was significantly better in the young group (Mean: 77.01; SD: 11.93) than in the older group (Mean: 70.98; SD: 10.00) (Figure 10.7, panel B). No main effect

of contrast type was observed, indicating that performance was similar for first- and second-order stimuli (Figure 10.7, panel C).

Interactions: A significant interaction between age and attention was found (Figure 10.7, panel D). A simple effect analysis revealed that the effect of attention was significant in the young group, but not in the older group. Performance in the young group was better on the valid trials (Mean: 85.57; SD: 8.78) compared to the neutral trials (Mean: 68.45; SD: 7.79). The interaction between contrast type and attention was not significant, indicating that the effect of attention was similar for first- and second-order stimuli (Figure 10.7, panel E). A significant interaction between contrast type and age was observed (Figure 10.7, panel F). A simple effect analysis revealed that the effect of age was present when second-order stimuli were used, but not when first-order stimuli were used. When second-order stimuli were used, performance was better in the young group (Mean: 80.06; SD: 11.49) than in the older group (Mean: 66.07; SD: 10.16). The three-way interaction was not significant.

10.5.3 Discussion

In this experiment, the presentation of multiple stimuli increased the processing load compared to the conditions used in Experiments I and II.

Under these conditions, the results suggest that exogenous attention improves contrast sensitivity. This attentional effect, however, was only present in the young group, while the older group did not benefit from attention. Although an age-related difference was observed for second-order stimuli and not for first-order stimuli, this effect may be driven by differences between the baseline experiment and this experiment, as revealed by an analysis of the neutral trials presented in section 10.7.

Figure 10.7. Main effects and two-way interactions for multiple static gratings with exogenous cue at 100% (EIII).

10.6 Experiment IV

10.6.1 Goals and Methods

The goal of this experiment was to investigate the impact of exogenous attention on contrast sensitivity in normal aging, under conditions imposing the heaviest processing load of the four experiments included in this chapter. The increase in processing complexity was achieved by presenting four stimuli and by setting cue validity at 75%. The possibility of observing an attentional effect on contrast sensitivity, as well as age-related differences was greater in this experiment than in the previous experiments.

10.6.2 Results

Main effects: A significant main effect of attention was observed, indicating that exogenous attention improves contrast sensitivity (Figure 10.8, panel A). The Tukey test revealed that all three trial types were significantly different from each other. Performance on the valid trials (Mean: 81.59; SD: 10.00) was better than that on both the neutral (Mean: 66.52; SD: 11.35) and invalid (Mean: 55.36; SD: 24.40) trials. Performance was also significantly worse for the invalid trials than for the neutral trials. No main effect of age was observed, indicating that the young and older groups had similar performance (Figure 10.8, panel B). A main effect of contrast type was observed, indicating

that performance was significantly better for second-order stimuli (Mean: 74.12; SD: 14.50) than for first-order stimuli (Mean: 61.52; SD: 22.09) (Figure 10.8, panel C).

Interactions: The interaction between age and attention was not significant, indicating that the effect of attention was similar for young and older participants (Figure 10.8, panel D). A statistically significant interaction between contrast type and attention was observed (Figure 10.8, panel E). The simple effect analysis revealed a significant effect of attention when both first- and second-order stimuli were used. The effect of attention was, however, different in the two types of stimuli. A Tukey test performed within each simple analysis revealed that for first-order stimuli, all trial types are significantly different from each other. When second-order stimuli were used, performance was better on the valid trials (Mean: 82.37; SD: 11.54) than on the invalid trials (Mean: 69.64; SD: 15.28), but none of the other comparisons were significant.

The interaction between contrast type and age was also statistically significant (Figure 10.8, panel F). The simple effect analysis revealed that when simple first-order stimuli were used, no age-related differences in contrast sensitivity were observed. When complex second-order stimuli were used however, performance was better in the young group (Mean: 80.24; SD:

12.67) compared to the older group (Mean: 68.01; SD: 13.86). The three-way interaction was not significant.

10.6.3 Discussion

The results of this experiment suggest that exogenous attention improves contrast sensitivity under conditions imposing heavy processing load. The attentional effect was mediated through both enhancement and inhibition. Although the interaction between age and attention did not reach significance, the trend suggests that the attentional effect was stronger in the young group. Although the interaction between contrast type and age was significant, it may have been driven by differences between the baseline experiment and this experiment, as revealed by an analysis of the neutral trials presented in section 10.7. The interaction between contrast type and attention suggests that the invalid trials had a larger effect on first-order stimuli than on second-order stimuli.

Figure 10.8. Main effects and two-way interactions for multiple static gratings with exogenous cue at 75% (EIV).

10.7 Neutral trials analysis

An ANOVA was performed on the results obtained from the neutral trials in each of the experiments included in this chapter. The results are presented in Figure 10.9. In theory, no significant effects should be observed in the neutral trial analyses, as performance was equated between the young and older groups on each target in the baseline experiment. However, due to differences in the experimental paradigm between the baseline and all other experiments, some differences may have occurred. It is important to take these differences into consideration when interpreting the overall results.

In the four experiments included in this chapter, no difference in overall performance was observed between the young and older groups on the neutral trials. This suggests that the two groups performed similarly when attention was not involved. When multiple stimuli were presented and cue validity was set at 75%, a main effect of contrast type was observed (Experiment IV). This effect did not have an impact on the interaction between attention and contrast type in Experiment IV. In the two experiments in which multiple gratings were presented, a significant interaction between age and contrast type was observed (Experiments III and IV). These interactions in the neutral trials suggest that the significant interactions between contrast type and age observed in Experiments III and IV may not be due to attention, but rather associated with

differences in configuration in the baseline experiment. When a single grating was presented, no statistically significant effects were observed for the neutral trials.

10.8 Summary of Chapter 10

The goal of the experiments included in this chapter was to assess the impact of exogenous attention on contrast sensitivity in normal aging. Static gratings were used and the processing load was gradually increased from Experiment I to Experiment IV, by changing the levels of cue validity (100% and 75%) and array size (single and multiple gratings). Based on the literature, processing load is heavier when multiple gratings are presented compared to when a single grating is used. Similarly, processing load is heavier when the cue does not always accurately predict the location of the target (75% cue validity). Furthermore, in each experiment, two types of contrast were tested: simple first-order contrast and complex second-order contrast.

The results show no attentional effect when a single static grating was presented, independent of the level of cue validity. These results are inconsistent with those of Carrasco et al. (2000), who report an attentional effect on contrast sensitivity when a single grating was presented. The results obtained in the present research suggest that under light processing load

conditions, attention does not improve performance. Under these conditions, adequate performance appears to be achieved by sensory processing alone. This can be thought of as a ceiling effect, where adding attention does not further improve performance. It is also possible that the grating itself acted as an attentional cue when only one grating was presented at one of four locations. The grating may have captured attention automatically, thus explaining why adding an attentional cue has no effect.

When multiple static gratings were presented, exogenous attention significantly improved contrast sensitivity, under both levels of cue validity. This attentional effect was mediated through enhancement and inhibition. The benefit of exogenous attention on contrast sensitivity was only observed in the young group. Although the interaction between age and attention did not reach statistical significance in Experiment IV, a trend in the results nonetheless suggests that the effect of exogenous attention is stronger in the young group.

Figure 10.9. Neutral trial analyses are presented for Experiments I-IV, for static gratings under exogenous attention.

Chapter 11: Exogenous cueing with dynamic gratings

In chapter 10, the effect of exogenous attention on contrast sensitivity was tested with static gratings. In theory, the processing load imposed by static gratings is lighter than that imposed by dynamic gratings, although similar thresholds were obtained for static and dynamic gratings in the baseline experiment. As expressed earlier, attentional age-related differences are more likely to be revealed when heavier processing load is imposed. The widespread non-specific changes in the aging brain are more likely to be measured when they affect a large number of processing steps.

The four experiments included in this chapter tested the impact of exogenous attention on contrast sensitivity for dynamic gratings in young and older participants, under conditions that require various levels of processing. The individual contrast thresholds obtained for each target in the baseline experiment were used in all the experiments described in this chapter. Array size (one or four gratings) and cue validity (100% or 75%) were used in combination to manipulate the processing load across experiments. Within each experiment, participants were tested with simple, first-order stimuli and complex, second-order stimuli, in separate blocks. The processing load was lightest in Experiment I and heaviest in Experiment IV. Orientation discrimination was assumed to be more complex for multiple, compared to

single grating presentation. Similarly, orientation discrimination was assumed to be more complex when cue validity was set at 75% compared to 100%. In experiment I, a single grating was presented at one of four possible locations and cue validity was set at 100%. In experiment II, a single grating was presented at one of four possible locations and cue validity is set at 75%. In experiment III, multiple gratings were presented and cue validity was set at 100%. Finally, in experiment IV, multiple gratings were presented and cue validity was set at 75%.

11.1 Experiment I

11.1.1 Goals and Methods

The goal of this experiment was to investigate the impact of exogenous attention on contrast sensitivity in normal aging, under conditions requiring the least amount of processing of the four experiments tested in this chapter.

Processing complexity was minimized by presenting a single dynamic grating at one of four possible locations and by setting cue validity at 100%. Based on the literature, the orientation discrimination task should require less processing when a single grating is used, compared to multiple gratings. Similarly, less processing is required for 100% compared to 75% cue validity. An attentional effect on contrast sensitivity, as well as age-related differences, which are more readily observed when complex processing is required, were therefore not expected.

11.1.2 Results

Main effects: No main effect of attention was observed, indicating that performance was similar for neutral and valid trials (Figure 11.1, panel A). The main effect of age was not significant, indicating that performance was similar for young and older participants (Figure 11.1, panel B). A statistically significant main effect of contrast type was observed, in which performance

was better for first-order stimuli (Mean: 78.01; SD: 13.65) compared to second-order stimuli (Mean: 58.13; SD: 18.64) (Figure 11.1, panel C).

Interactions: The interaction between age and attention was not significant, indicating that the effect of attention was similar in both age groups (Figure 11.1, panel D). The interaction between contrast type and attention was not significant, indicating that the effect of attention was similar for both first- and second-order stimuli (Figure 11.1, panel E). The interaction between contrast type and age was not significant, indicating that the effect of age was similar for first- and second order stimuli (Figure 11.1, panel F). The three-way interaction was not significant.

11.1.3 Discussion

The results of this experiment suggest that exogenous attention may not influence contrast sensitivity under conditions that impose a light processing load, even though dynamic gratings were used. Under these conditions, perception may be mediated through sensory processes alone. It is also possible that the grating grabs attention automatically, such that the cue does not further enhance performance. This is consistent with the hypothesis that attention is a process distributed along a continuum, whose impact is observed mainly under heavier processing load. The lack of an attentional effect on

contrast sensitivity ruled out the possibility of observing attentional age-related differences. Although the results suggest better overall performance for first-order stimuli compared to second-order stimuli, this effect may be driven by differences between the baseline experiment and this experiment, as revealed by an analysis of the neutral trials presented in section 11.5.

Figure 11.1. Main effects and two-way interactions for a single dynamic grating with exogenous cue at 100% (EI).

11.2 Experiment II

11.2.1 Goals and Methods

The goal of this experiment was to investigate the impact of exogenous attention on contrast sensitivity in normal aging, under conditions that impose a heavier processing load than those used in Experiment I of this chapter. The increase in processing complexity was achieved by reducing cue validity from 100% to 75%. As in the previous experiment, a single dynamic grating was presented at one of four possible locations. Although presenting a single grating requires less processing than multiple gratings, more processing is required when cue validity is set at 75%, as the cue does not always accurately predict the location of the target. The possibility of observing an effect of attention on contrast sensitivity, as well as age-related differences was greater in this experiment than in the previous experiment.

11.2.2 Results

Main effects: A significant main effect of attention was observed (Figure 11.2, panel A). The Tukey test revealed that performance was significantly worse on the invalid trials (Mean: 60.71; SD: 19.16) than on the valid trials (Mean: 71.09; SD: 14.02). No significant difference was observed between the valid and neutral trials, or between the invalid and neutral trials.

No main effect of age was found, indicating that the young and older participants had similar performance (Figure 11.2, panel B). A significant main effect of contrast type was observed, in which performance was significantly worse for second-order stimuli (Mean: 60.64; SD: 15.22) than for first-order stimuli (Mean: 73.54; SD: 15.92) (Figure 11.2, panel C).

Interactions: The interaction between age and attention was not significant, indicating that the effect of attention was similar in young and older participants (Figure 11.2, panel D). The interaction between contrast type and attention was not statistically significant, indicating that the effect of attention was similar for first- and second-order stimuli (Figure 11.2, panel E). A significant interaction between contrast type and age was found (Figure 11.2, panel F). A simple effect analysis revealed that the effect of age was marginally significant when first-order stimuli were used and not significant when second-order stimuli were used. The three-way interaction was not significant.

11.2.3 Discussion

The results of this experiment suggest that exogenous attention improves contrast sensitivity and that both enhancement and inhibition were involved, although neither reached statistical significance. When a single dynamic

grating was used, marginally significant age-related differences were observed for simple first-order stimuli, but not for complex second-order stimuli. This is inconsistent with the theory that age-related differences may be more readily observed under heavier processing load. When static gratings were used (chapter 10, EII), no attentional effect was observed on contrast sensitivity. This supports the idea that dynamic gratings impose a heavier processing load than static gratings.

Figure 11.2. Main effects and two-way interactions for a single dynamic grating with exogenous cue at 75% (EI).

11.3 Experiment III

11.3.1 Goals and Methods

The goal of this experiment was to investigate the impact of exogenous attention on contrast sensitivity in normal aging, under conditions imposing a heavier processing load than those used in Experiments I and II of this chapter. The increase in processing complexity was achieved by presenting four dynamic stimuli instead of a single stimulus. In this experiment, cue validity was set at 100%, such that the cue always predicted the location of the target accurately. The possibility of observing an effect of attention on contrast sensitivity, as well as age-related differences was higher in this experiment than in the previous experiments.

11.3.2 Results

Main effects: A significant main effect of attention was found, indicating that attention improves performance on an orientation discrimination task (Figure 11.3, panel A). Performance was better for the valid trials (Mean: 82.85; SD: 11.83) compared to the neutral trials (Mean: 69.27; SD: 9.32). A main effect of age was also found, in which performance was significantly better in the young group (Mean: 80.39; SD: 12.69) compared to the older group (Mean: 71.73; SD: 11.07) (Figure 11.3, panel B).

No main effect of contrast type was observed, indicating that performance was similar for first- and second-order stimuli (Figure 11.3, panel C).

Interactions: A significant interaction between age and attention was found (Figure 11.3, panel D). A simple effect analysis revealed that attention had a significant impact in the young group, but not in the older group. The interaction between contrast type and attention was not significant, indicating that the impact of performance was similar for both first- and second-order stimuli (Figure 11.3, panel E). The interaction between contrast type and age was not significant, indicating that the effect of age was similar for first- and second-order stimuli (Figure 11.3, panel F). The three-way interaction was not significant.

11.3.3 Discussion

The results of this experiment suggest that exogenous attention improves contrast sensitivity under increased processing load. This attentional effect, however, was present only in the young group, suggesting that older individuals did not benefit from the attentional cue. The effect of attention was similar for first- and second-order stimuli. Furthermore, no age-related differences were observed between first- and second-order stimuli.

Figure 11.3. Main effects and two-way interactions for multiple dynamic gratings with exogenous cue at 100% (EIII).

11.4 Experiment IV

11.4.1 Goals and Methods

The goal of this experiment was to investigate the impact of exogenous attention on contrast sensitivity in normal aging, under conditions imposing the heaviest processing load of the four experiments included in this chapter. The increase in processing complexity was achieved by presenting four dynamic stimuli and by setting cue validity at 75%.

11.4.2 Results

Main effects: A significant main effect of attention was observed (Figure 11.4, panel A). The results of the Tukey test revealed that performance on the valid trials (Mean: 78.53; SD: 15.89) was significantly better than on the invalid trials (Mean: 63.84; SD: 18.43) and that performance on the invalid trials was worse than on the neutral trials (Mean: 70.19; SD: 14.08). No difference was observed between the valid and neutral trials. A significant main effect of age was also observed, in which the young participants (Mean: 72.29; SD: 19.96) showed better performance than the older participants (Mean: 63.47; SD: 14.20) (Figure 11.4, panel B). No main effect of contrast type was observed, indicating that overall performance was similar for first- and second-order stimuli (Figure 11.4, panel C).

Interactions: A statistically significant interaction between age and attention was observed (Figure 11.4, panel D). A simple effect analysis revealed that attention had a significant effect in both the young and older groups. However, the attentional effect was stronger in the young group, as revealed by a post-hoc comparison (Tukey). In the young group, performance was better on both the valid (Mean: 87.05; SD: 11.88) and neutral (Mean: 76.25; SD: 15.37) trials, compared to the invalid trials (Mean: 53.57; SD: 15.83). In the older group, only the performance on valid trials (Mean: 70.02; SD: 15.06) was better than performance on invalid trials (Mean: 56.25; SD: 14.50). The invalid trials did not differ from the neutral trials.

The interaction between contrast type and attention was not significant, indicating that attention had a similar effect on first- and second-order stimuli (Figure 11.4, panel E). The interaction between contrast type and age was not significant, indicating that the effect of age was similar for first- and second-order stimuli (Figure 11.4, panel F). The three-way interaction was not significant.

11.4.3 Discussion

The results of this experiment suggest that exogenous attention improves contrast sensitivity under conditions imposing a heavy processing

load. This effect was mediated through inhibition. The effect of attention was present only in the young group, suggesting that older individuals may not benefit from exogenous attention. The lack of an attentional benefit in the older group did not seem to be driven by differences between the baseline experiment and this experiment, as revealed by an analysis of the neutral trials presented in section 11.5.

Figure 11.4. Main effects and two-way interactions for multiple dynamic gratings with exogenous cue at 75% (EIV).

11.5 Neutral trials analysis

An ANOVA was performed on the results obtained on the neutral trials in each of the experiments included in this chapter. The results are presented in Figure 11.5. The results show that only two effects were observed. First, a main effect of contrast type was observed when a single grating was presented and cue validity was set at 100% (Experiment I), with better performance for first-order stimuli. This effect appears to be responsible for the significant main effect of contrast type observed in Experiment I. Second, a main effect of age was observed when multiple gratings were presented with cue validity set at 75% (Experiment IV), with better performance in the young group. This effect does not seem to be responsible for the significant interaction between age and attention observed in Experiment IV. Under all other conditions, no differences were observed in the neutral trials.

11.6 Summary of Chapter 11

As in the previous chapter, the goal of the experiments included in this chapter was to assess the impact of exogenous attention on contrast sensitivity in normal aging. In this chapter, however, dynamic gratings were used. The processing load was gradually increased from Experiment I to Experiment IV, by changing the levels of cue validity (100% and 75%) and array size (single

and multiple gratings). Based on the literature, processing load is heavier when multiple gratings are presented compared to when a single grating is used. Similarly, processing load is heavier when the cue does not always accurately predict the location of the target (75% cue validity). Furthermore, two types of contrast were tested: simple first-order contrast and complex second-order contrast.

The results show that exogenous attention did not improve contrast sensitivity when a single dynamic grating was presented under the lightest processing load. When a single dynamic target was presented in combination with a cue that always accurately predicted the location of the target (100% cue validity), no attentional effect was observed. Under these conditions, adequate performance was achieved by sensory processing alone. This can be thought of as a ceiling effect, where adding attention does not further improve performance. It is also possible that the grating itself acted as an attentional cue when only one grating is presented at one of four locations. The grating may have captured attention automatically, thus explaining why adding an attentional cue had no effect.

Unlike what was observed with static gratings, when a single dynamic grating was used, increasing the processing load by reducing the level of cue validity from 100% to 75%, did reveal an attentional effect. Thus, motion

appears to have increased the processing load enough for an attentional effect to be observed.

When multiple dynamic gratings were presented, exogenous attention improved contrast sensitivity, under both levels of cue validity. This attentional effect was mediated through inhibition alone. The effect of attention was only observed in the young group, suggesting that older individuals may not benefit from exogenous attention in a contrast sensitivity task.

Finally, the type of contrast used revealed age-related differences when a single dynamic grating was presented under 75% cue validity. Under these conditions, age-related differences were observed between simple first-order stimuli and complex second-order stimuli, in which the young group showed deficits in performance for first-order stimuli. This is inconsistent with the idea that age-related differences may be more readily observed when complex second-order stimuli are used.

Figure 11.5. Neutral trial analyses are presented for Experiments I-IV, for dynamic gratings under exogenous attention.

Chapter 12: Summary of results under exogenous attention

The goal of the experiments included in chapters 10 and 11 was to assess the impact of exogenous attention on contrast sensitivity in normal aging. Static (chapter 10) and dynamic (chapter 11) gratings were used. In each chapter, the processing load was gradually increased from Experiment I to Experiment IV, by changing the levels of cue validity (100% and 75%) and array size (single and multiple gratings). Based on the literature, processing load is heavier when multiple grating are presented compared to when a single grating is used. Similarly, processing load is heavier when the cue does not always accurately predict the location of the target (75% cue validity). Furthermore, two types of contrast were tested: simple first-order contrast and complex second-order contrast. The results obtained under exogenous attentional conditions are presented in Tables 12.1 (static gratings) and 12.2 (dynamic gratings).

12.1 The effect of exogenous attention

Taken together, the results suggest that under light processing load, exogenous attention does not influence contrast sensitivity. When a single stimulus was presented and the cue always accurately indicated the location of the target (100% cue validity), no attentional effect was observed, regardless of

whether the grating was static or dynamic. Under these conditions, it is possible that the grating itself acts as an attentional cue. If this is the case, the exogenous cue has no additional effect on performance. Within the framework of the feature integration theory, it is possible that the grating acts as a pop-out, automatically grabbing attention.

In this research, one assumption was that attention may be distributed along a continuum rather than being an all-or-nothing process. Attentional effects are more likely to be observed under conditions requiring complex processing. Based on the literature, processing dynamic gratings imposes a heavier load on the visual system than does the processing of static gratings. Consistent with this, the results show an effect of exogenous attention on contrast sensitivity when a single dynamic grating was presented, when the cue did not predict the location of the target on all trials (75% cue validity). This attentional effect was not observed when a single static grating was presented at 75% cue validity. This is also consistent with the theory that attention is distributed along a continuum. Although the processing load was relatively light when only one grating was presented, it was made heavier by introducing motion in the grating and by reducing the level of cue validity. These conditions made it more difficult to perform the task and the benefits of attention were present.

When multiple gratings were presented, thus increasing the processing load, exogenous attention improved contrast sensitivity. This was true for static and dynamic gratings and for both levels of cue validity. The attentional effect appears to be mediated through different mechanisms for static and dynamic gratings. When static gratings were used the attentional effect was mediated through enhancement and inhibition, while only inhibition was involved when dynamic gratings were used.

12.2 Age-related differences in the effect of exogenous attention

Overall, when a single stimulus was presented, no effect of exogenous attention was observed, except when a single dynamic grating was presented under 75% cue validity. Even in the case of this exception, no age-related differences were found. When, however, multiple gratings were presented, attentional effects were present and age-related differences were observed for both static and dynamic gratings. Overall, performance was better in the young group compared to the older group. Although statistical significance was not reached in one condition, the trend in the results was consistent with greater benefits of exogenous attention in young individuals. These results suggest deficits in exogenous attentional processing in older individuals.

Finally, although some age-related differences were observed for contrast type, these were inconsistent with the expectations. Performance was better in the young group for simple first-order stimuli, while the young and older groups had similar performance on for complex second-order stimuli. It was expected that age-related deficits would be observed when complex second-order stimuli were used.

Table 12.1. Summary of the results obtained in the experiments in which exogenous cueing was used with static gratings. * significant result; * significant result but the interpretation needs to take into account the differences between the neutral trials in these conditions and the baseline

EXOGENOUS STATIC	1 grating			4 gratings	
	100%	75%	100%	100%	75%
Attention	ns	ns	*	*	*
Age	ns	ns	*	*	ns
Contrast type (CT)	ns	ns	ns	ns	*
Age X Attention	ns	ns	*	*	ns
CT X Attention	ns	ns	ns	ns	*
CT X Age	ns	ns	*	*	*

Table 12.2. Summary of the results obtained in the experiments in which exogenous cueing was used with dynamic gratings. * significant result; * significant result but the interpretation needs to take into account the differences between the neutral trials in these conditions and the baseline

EXOGENOUS DYNAMIC	1 grating			4 gratings	
	100%	75%	100%	100%	75%
Attention	ns	*	*	*	*
Age	ns	ns	*	*	*
Contrast type (CT)	*	*	ns	ns	ns
Age X Attention	ns	ns	*	*	*
CT X Attention	ns	ns	ns	ns	ns
CT X Age	ns	*	ns	ns	ns

Chapter 13: Endogenous cueing with static gratings

The four experiments included in this chapter tested the impact of endogenous attention on contrast sensitivity for static gratings in young and older participants, under conditions that require various levels of processing. In theory, the processing load was heavier under endogenous than under exogenous attentional conditions and attentional effects on contrast sensitivity, as well as age-related differences may therefore be more readily observed under endogenous cueing conditions. The results obtained under exogenous conditions (chapters 10 and 11), show that when multiple gratings were presented, attention improved contrast sensitivity and this effect was present only in the young group.

The endogenous cue and stimulus dimensions are illustrated in panel B of Figure 10.1. The individual contrast thresholds obtained for each target in the baseline experiment were used in all the experiments described in the present chapter and in chapter 14. Processing complexity was lowest in Experiment I and highest in Experiment IV and array size (one or four gratings) and cue validity (100% or 75%) were used in combination to manipulate processing complexity across experiments. Within each experiment, participants were tested on simple first-order stimuli and complex second-order stimuli. In addition, orientation discrimination was assumed to be

more complex for multiple compared to single grating presentation. Similarly, orientation discrimination was assumed to be more complex when cue validity was set at 75% compared to 100%. In Experiment I, a single grating was presented at one of four possible locations and cue validity was set at 100%. In Experiment II, a single grating was presented at one of four possible locations and cue validity was set at 75%. In Experiment III, multiple gratings were presented and cue validity was set at 100%. Finally, in Experiment IV, multiple gratings were presented and cue validity was set at 75%.

Figure 13.1. Illustration of the basic sequence of events used in the neutral trials under endogenous attention.

Figure 13.2. Illustration of the basic sequence of events used in the valid trials under endogenous attentional cueing.

Figure 13.3. Illustration of the basic sequence of events used in the invalid trials under endogenous attention.

13.1. Experiment I

13.1.1 Goals and Methods

The goal of this experiment was to investigate the impact of endogenous attention on contrast sensitivity in normal aging, under conditions requiring the least amount of processing of the four experiments tested in this chapter.

Processing complexity was minimized by presenting a single static grating at one of four possible locations and by setting cue validity at 100%. An effect of attention on contrast sensitivity, as well as age-related differences were therefore not expected in this experiment. Under the same conditions using an exogenous attentional cue, these effects were not observed. However, because it is assumed that endogenous attention imposes a heavier processing load than exogenous attention, age-related differences may be observed in this experiment.

13.1.2 Results

Main effects: No main effect of attention was observed, indicating that performance was similar for neutral and valid trials (Figure 13.4, panel A). The main effect of age was not statistically significant, indicating that the young and older groups performed similarly (Figure 13.4, panel B). No main effect of contrast type was observed, indicating that performance was similar for both first- and second-order stimuli (Figure 13.4, panel C).

Interactions: The interaction between age and attention was not significant, indicating that the effect of attention was similar for young and older participants (Figure 13.4, panel D). The interaction between contrast type and attention was not significant, indicating that the effect of attention was similar for first- and second-order stimuli (Figure 13.4, panel E). The interaction between contrast type and age was not significant, indicating that the effect of age was similar for first- and second-order stimuli (Figure 13.4, panel F). The three-way interaction was not significant.

13.1.3 Discussion

The results of this experiment suggest that, similar to what was observed under exogenous conditions, endogenous attention did not improve contrast sensitivity when a single static grating was presented and cue validity was set at 100%. Under these conditions, perception may be mediated through sensory processes alone. It is also possible that the grating grabs attention automatically, such that the cue does not further enhance performance. The lack of an attentional effect in this experiment is consistent with the theory that attention is a process distributed along a continuum, whose impact is mainly observed under heavier processing loads. The lack of an attentional effect also

ruled out the possibility of observing age-related differences in the effect of attention on contrast sensitivity.

Figure 13.4. Main effects and two-way interactions for a single static grating with endogenous cue at 100% (EI).

13.2 Experiment II

13.2.1 Goals and Methods

The goal of this experiment was to investigate the impact of endogenous attention on contrast sensitivity in normal aging, under conditions imposing a heavier processing load than those used in Experiment I of this chapter. The increase in processing complexity was achieved by reducing cue validity from 100% to 75%. As in the previous experiment, a single static grating was presented at one of four possible locations. The possibility of observing an effect of attention on contrast sensitivity, as well as age-related differences was higher in this experiment than in the previous experiment. Under these conditions, no effect of exogenous attention on contrast sensitivity was observed, nor were any age-related differences. However, because it is assumed that endogenous attention imposes a heavier processing load than exogenous attention, an attentional effect as well as age-related differences may be observed in this experiment.

13.2.2 Results

Main effects: The main effect of attention was not significant, indicating that performance was similar for neutral, valid and invalid trials (Figure 13.5, panel A). A significant main effect of age was observed,

indicating that performance in the older group (Mean: 73.71; SD: 14.85) was better than in the young group (Mean: 65.19; SD: 11.47) (Figure 13.5, panel B). The main effect of contrast type was not significant, indicating that performance was similar for first- and second-order stimuli (Figure 13.5, panel C).

Interactions: The interaction between age and attention was not significant, indicating that the effect of attention was similar for young and older participants (Figure 13.5, panel D). The interaction between contrast type and attention was not significant, indicating that the effect of attention was similar for first- and second-order stimuli (Figure 13.5, panel E). The interaction between contrast type and age was not significant, indicating that the effect of age was similar for first- and second-order stimuli (Figure 13.5, panel F). The three-way interaction was not significant.

13.2.3 Discussion

The results of this experiment suggest that, similar to what was observed under exogenous conditions, endogenous attention did not improve contrast sensitivity when a single static grating was presented and cue validity was set at 75%. Although overall performance was better in the older group, this effect may be driven by differences between the baseline experiment and this

experiment, as revealed by an analysis of the neutral trials presented in section

13.5. Overall performance was similar for first- and second-order stimuli.

Figure 13.5. Main effects and two-way interactions for a single static grating with endogenous cue at 75% (EI).

13.3 Experiment III

13.3.1 Goals and Methods

The goal of this experiment was to investigate the impact of endogenous attention on contrast sensitivity in normal aging, under conditions imposing a heavier processing load than those used in Experiments I and II of this chapter. The increase in processing complexity was achieved by presenting four stimuli instead of a single stimulus. In this experiment, cue validity was set at 100%, such that the cue always predicted the location of the target accurately. The possibility that attention may improve contrast sensitivity and that age-related differences may be present, was higher in this experiment than in the previous experiments. Exogenous attention significantly improved contrast sensitivity under similar conditions and this effect was observed in the young, but not the older group. In the present experiment, because it is assumed that endogenous attention imposes a heavier processing load than exogenous attention, endogenous attention is expected to improve contrast sensitivity and this effect is expected to be stronger in the young group.

13.3.2 Results

Main effects: A significant main effect of attention was found, in which performance was better on valid trials (Mean: 88.06; SD: 7.88) than on neutral

trials (Mean: 70.83; SD: 9.18). This indicates that attention improves the ability to perceive contrast (Figure 13.6, panel A). No main effect of age was found, indicating that performance was similar in the young and older groups (Figure 13.6, panel B). No main effect of contrast type was observed, indicating that performance was similar for first- and second-order stimuli (Figure 13.6, panel C).

Interactions: The interaction between age and attention was not significant, indicating that the effect of attention was similar for young and older participants (Figure 13.6, panel D). The interaction between contrast type and attention was not significant, indicating that the effect of attention was similar for first- and second-order stimuli (Figure 13.6, panel E). The interaction between contrast type and age was not significant, indicating that the effect of age was similar for first- and second-order stimuli (Figure 13.6, panel F). The three-way interaction was not significant.

13.3.3 Discussion

Similar to what was observed under exogenous attention, the results obtained in this experiment show that endogenous attention significantly improves contrast sensitivity when multiple static gratings are presented and cue validity is set at 100%. However, an important difference between

exogenous and endogenous attention is that while the effect of exogenous attention was limited to the young group, the effect of endogenous attention was similar in both age groups. In this experiment, no significant effect of contrast type was observed.

Figure 13.6. Main effects and two-way interactions for multiple static gratings with endogenous cue at 100% (EIII).

13.4 Experiment IV

13.4.1 Goals and Methods

The goal of this experiment was to investigate the impact of endogenous attention on contrast sensitivity in normal aging, under conditions imposing the highest processing load of the four experiments included in this chapter. The increase in processing complexity was achieved by presenting four stimuli and by setting cue validity at 75%. Under the same conditions, exogenous attention significantly improved contrast sensitivity and a trend showed that this effect was stronger in the young group. In the present experiment, because it was assumed that endogenous attention imposes a heavier processing load than exogenous attention, endogenous attention was expected to improve contrast sensitivity. This effect was expected to be stronger in the young group.

13.4.2 Results

Main effects: A significant main effect of attention was observed, indicating that attention improved performance on a contrast sensitivity task (Figure 13.7, panel A). The Tukey post-hoc comparison test revealed that all three attentional conditions differed from each other. Performance was better on the valid trials (Mean: 84.04; SD: 9.37) than on the neutral (Mean: 65.27;

SD: 11.53) and invalid (Mean: 37.50; SD: 21.78) trials. Performance was worse on the invalid trials than on the neutral trials. No main effect of age was observed, indicating that performance was similar for the young and older groups (Figure 13.7, panel B). A main effect of contrast type was observed, indicating that performance was better when second-order stimuli (Mean: 66.82; SD: 20.43) were used in comparison to first-order stimuli (Mean: 57.72; SD: 27.33) (Figure 13.7, panel C).

Interactions: The interaction between age and attention was not significant, indicating that the impact of attention was similar for both age groups (Figure 13.7, panel D). A statistically significant interaction between contrast type and attention was observed (Figure 13.7, panel E). A simple effect analysis revealed that attention had a statistically significant effect when both first- and second-order stimuli were used. Furthermore, Tukey tests revealed that all three attentional conditions were different from each other when both the first- and second-order stimuli were used. The interaction between contrast type and age was significant (Figure 13.7, panel F). A simple effect analysis revealed that the effect of age was not significant when first- and second-order stimuli were used. However, the analysis almost reached statistical significance ($p = 0.06$) when second-order stimuli were used,

suggesting a trend for better performance in the young group (Mean: 72.77; SD: 17.22) compared to the older group (Mean: 60.86; SD: 22.01).

13.4.3 Discussion

Similar to what was observed under exogenous attention, the results obtained in this experiment show that endogenous attention significantly improves contrast sensitivity when multiple static gratings are presented and cue validity is set at 100%. However, an important difference between exogenous and endogenous attention is that while the effect of exogenous attention was limited to the young group, the effect of endogenous attention was similar in both age groups. In this experiment, no significant effect of contrast type was observed.

Figure 13.7. Main effects and two-way interactions for multiple static gratings with endogenous cue at 75% (EIV).

13.5 Neutral trials analysis

An ANOVA was performed on the results obtained on the neutral trials in each experiment included in this chapter. The results are presented in Figure 13.8. The only significant effect observed was a main effect of age when a single grating was presented and cue validity was set at 75% (Experiment II). This effect appears to be responsible for the significant main effect of age observed in Experiment II. Under all other conditions, no differences were observed in the neutral trials.

13.6 Summary of Chapter 13

The goal of the experiments included in this chapter was to assess the impact of endogenous attention on contrast sensitivity in normal aging. Static gratings were used and the processing load was gradually increased from Experiment I to Experiment IV, by changing the levels of cue validity (100% and 75%) and array size (single and multiple gratings). Based on the literature, processing load is heavier when multiple gratings are presented compared to when a single grating is used. Similarly, processing load is heavier when the cue does not always accurately predict the location of the target (75% cue

validity). Furthermore, in each experiment, two types of contrast were tested: simple first-order contrast and complex second-order contrast.

When a single static grating was presented, no attentional effect was observed, independent of the level of cue validity. This finding is similar to what was observed under exogenous attentional conditions. Under these conditions, attention did not appear to improve performance on a contrast sensitivity task. Performance was achieved by sensory processing alone. This can be thought of as a ceiling effect, where adding attention does not further improve performance. It is also possible that the grating acts as an attentional cue by capturing attention automatically.

When multiple static gratings were presented, endogenous attention improved contrast sensitivity under both levels of cue validity. This finding is similar to what was observed with exogenous attentional cues. However, unlike what was observed with exogenous attentional cues, no age-related differences in the effect of attention on contrast sensitivity were observed when endogenous attentional cues were used. This suggests that older individuals may be able to use endogenous attention as efficiently as young individuals.

Figure 13.8. Neutral trial analyses are presented for Experiments I-IV, for static gratings under endogenous attention.

Chapter 14: Endogenous cueing with dynamic gratings

In chapter 13, the effect of endogenous attention on contrast sensitivity was tested with static gratings. In theory, the processing load imposed by static gratings is lighter than that imposed by dynamic gratings. As expressed earlier, attentional effects and age-related attentional differences are more likely to be observed when heavier processing load is imposed. It is therefore expected that these effects should be stronger when dynamic gratings are used. The results obtained under exogenous attentional conditions are in line with this assertion, in that the only condition in which attention improved contrast sensitivity when a single grating was presented was when dynamic gratings were used.

The four experiments included in this chapter tested the impact of endogenous attention on contrast sensitivity for dynamic gratings in young and older participants, under conditions that required various levels of processing. The individual contrast thresholds obtained for each target in the baseline experiment were used in all the experiments described in this chapter. Within each experiment, participants were tested on simple first-order stimuli and complex second-order stimuli. In addition, array size (one or four gratings) and cue validity (100% or 75%) were used in combination to manipulate processing complexity across experiments. Processing load was lightest in Experiment I and heaviest in Experiment IV. Orientation discrimination was

assumed to be more complex for multiple than for single grating presentation. Similarly, orientation discrimination was assumed to be more complex when cue validity was set at 75% compared to 100%. In Experiment I, a single grating was presented at one of four possible locations and cue validity was set at 100%. In Experiment II, a single grating was presented at one of four possible locations and cue validity was set at 75%. In Experiment III, multiple gratings were presented and cue validity was set at 100%. Finally, in Experiment IV, multiple gratings were presented and cue validity was set at 75%.

14.1 Experiment I

14.1.1 Goals and Methods

The goal of this experiment was to investigate the impact of endogenous attention on contrast sensitivity in normal aging, under conditions imposing the lightest processing load of the four experiments tested in this chapter. Processing complexity was minimized by presenting a single dynamic grating at one of four possible locations and by setting cue validity at 100%. Based on the literature, the orientation discrimination task should require less processing when a single grating is used, compared to multiple gratings. Similarly, less processing is required for 100%, compared to 75% cue validity. Attentional effects on contrast sensitivity as well as age-related attentional differences in the effect of attention on contrast sensitivity were more readily observed under heavier processing load and were therefore not expected in this experiment. Consistently, no effect of exogenous attention and no age-related differences were observed. Similarly, none of these effects were observed under endogenous cueing with static gratings under the conditions tested in this experiment.

14.1.2 Results

Main effects: No main effect of attention was observed, indicating that attention did not influence the perception of contrast (Figure 14.1, panel A). A statistically significant main effect of age was observed, indicating that performance was better in the older group (Mean: 78.38; SD: 13.73) than in the young group (Mean: 66.73; SD: 14.84) (Figure 14.1, panel B). No main effect of contrast type was observed, indicating that performance was similar for first- and second-order stimuli (Figure 14.1, panel C).

Interactions: The interaction between age and attention was not significant, indicating that the effect of attention was similar for young and older participants (Figure 14.1, panel D). The interaction between contrast type and attention was not significant, indicating that the effect of attention was similar for both first- and second-order stimuli (Figure 14.1, panel E). The interaction between contrast type and age was not significant, indicating that the effect of age was similar for first- and second-order stimuli (Figure 14.1, panel F). The three-way interaction was not significant.

14.1.3 Discussion

Similar to what was observed under exogenous conditions, the results obtained in this experiment suggest that endogenous attention does not

improve contrast sensitivity when a single dynamic grating was presented and cue validity was set at 100%. This finding is also similar to that observed under endogenous cueing conditions for static gratings. In the present experiment, overall performance was better in the older group compared to the young group, while overall performance was similar when first-order and second-order stimuli were used. The effect of age was similar for first- and second-order stimuli. Taken together, these results suggest that under conditions imposing a light processing load, attention does not improve contrast sensitivity and that no age-related differences exist in the effect of attention on contrast sensitivity.

Figure 14.1.1. Main effects and two-way interactions for a single dynamic grating with endogenous cue at 100% (EI).

14.2 Experiment II

14.2.1 Goals and Methods

The goal of this experiment was to investigate the impact of endogenous attention on contrast sensitivity in normal aging, under conditions imposing a heavier processing load than those used in Experiment I of this chapter. The increase in processing complexity was achieved by reducing cue validity from 100% to 75%. As in the previous experiment, a single dynamic grating was presented at one of four possible locations. The possibility of observing an effect of attention on contrast sensitivity as well as age-related attentional differences was higher in this experiment than in the previous experiment. Under exogenous cueing, attention improved contrast sensitivity under these conditions.

14.2.2 Results

Main effects: A significant main effect of attention was observed (Figure 14.2, panel A). The Tukey post-hoc comparison test revealed that performance was significantly worse on invalid trials (Mean: 59.82; SD: 15.72) than on both valid (Mean: 74.78; SD: 14.33) and neutral (Mean: 70.54; SD: 12.10) trials. Similar performance was observed on the valid and neutral trials. A significant main effect of age was found, in which overall

performance was better in the older group (Mean: 71.73; SD: 15.83) than in the young group (Mean: 65.03; SD: 14.21) (Figure 14.2, panel B). A significant main effect of contrast type was also observed (Figure 14.2, panel C).

Performance was significantly worse for second-order stimuli (Mean: 64.72; SD: 13.54) than for first-order stimuli (Mean: 72.04; SD: 16.27).

Interactions: The interaction between age and attention was not significant, indicating that the effect of attention was similar for young and older participants (Figure 14.2, panel D). The interaction between contrast type and attention was not significant, indicating that the effect of attention was similar for both first- and second-order stimuli (Figure 14.2, panel E). The interaction between contrast type and age was not significant, indicating that the effect of age was similar for first- and second-order stimuli (Figure 14.2, panel F). The three-way interaction was not significant.

14.2.3 Discussion

The results obtained in this experiment suggest that endogenous attention improved contrast sensitivity when a single dynamic grating is presented and cue validity was set at 75%. No age-related differences in the effect of attention on contrast sensitivity were observed. These findings are similar to what was observed under exogenous attention for dynamic gratings.

Furthermore, overall performance was better in the older group and when first-order stimuli were presented.

Figure 14.2. Main effects and two-way interactions for a single dynamic grating with endogenous cue at 75% (EII).

14.3 Experiment III

14.3.1 Goals and Methods

The goal of this experiment was to investigate the impact of endogenous attention on contrast sensitivity in normal aging under conditions imposing a heavier processing load than those used in Experiments I and II of this chapter. The increase in processing complexity was achieved by presenting four dynamic stimuli instead of a single stimulus at one of four locations. In this experiment, cue validity was set at 100%, such that the cue always predicted the location of the target accurately. The possibility of observing an attentional effect and age-related differences in the effect of attention on contrast sensitivity was higher in this experiment than in the previous experiments. When exogenous cues were used, both of these effects were observed and were thus expected in this experiment.

14.3.2 Results

Main effects: A significant main effect of attention was found with better performance in the valid trials (Mean: 91.44; SD: 6.60) than in the neutral trials (Mean: 68.97; SD: 10.66), indicating that attention improves contrast sensitivity (Figure 14.3, panel A). No main effect of age was found, indicating that performance was similar in the young and older groups (Figure

14.3, panel B). No main effect of contrast type was observed, indicating that performance was similar for first- and second-order stimuli (Figure 14.3, panel C).

Interactions: The interaction between age and attention was not significant, indicating that the effect of attention was similar in both age groups (Figure 14.3, panel D). The interaction between contrast type and attention was not significant, indicating that the effect of attention was similar for first- and second-order stimuli (Figure 14.3, panel E). The interaction between contrast type and age was not significant, indicating that the effect of age was similar for first- and second-order stimuli (Figure 14.3, panel F). The three-way interaction was not significant.

14.3.3 Discussion

Similar to what was observed with exogenous cues, the results of this experiment show that endogenous attention improves contrast sensitivity when multiple dynamic gratings are presented and cue validity is set at 100%. However, unlike for exogenous attention, no age-related differences on the effect of attention on contrast sensitivity were observed. This suggests that older individuals were able to use endogenous attention as efficiently as young individuals.

Figure 14.3. Main effects and two-way interactions for multiple dynamic gratings with endogenous cue at 100% (EIII).

14.4 Experiment IV

14.4.1 Goals and Methods

The goal of this experiment was to investigate the impact of endogenous attention on contrast sensitivity in normal aging under conditions imposing the heaviest processing load of the four experiments included in this chapter. The increase in processing complexity was achieved by presenting four dynamic stimuli and by setting cue validity at 75%. The possibility of observing an attentional effect and age-related differences in the effect of attention on contrast sensitivity was highest in this experiment. When exogenous cues were used under the same conditions, both of these effects were observed and are thus expected in this experiment.

14.4.2 Results

Main effects: A significant main effect of attention was observed, indicating that attention improves the ability to perceive contrast (Figure 14.4, panel A). The Tukey post-hoc comparison test revealed that performance was significantly better on the valid trials (Mean: 87.84; SD: 10.25) than on both the neutral (Mean: 69.38; SD: 10.60) and invalid (Mean: 63.84; SD: 18.43) trials. No significant difference in performance was observed between the neutral and invalid trials. A significant main effect of age was also observed,

indicating that performance was better in the young group (Mean: 77.05; SD: 17.88) than in the older group (Mean: 70.31; SD: 15.48) (Figure 14.4, panel B). No main effect of contrast type was observed, indicating that performance was similar for the first- and second-order stimuli (Figure 14.4, panel C).

Interactions: The interaction between age and attention was not significant, indicating that the effect of attention was similar for young and older participants (Figure 14.4, panel D). The interaction between contrast type and attention was not significant, indicating that the effect of attention was similar for first- and second-order stimuli (Figure 14.4, panel E). The interaction between contrast type and age was not significant, indicating that the effect of age was similar for first- and second-order stimuli (Figure 14.4, panel F). The three-way interaction was not significant.

14.4.3 Discussion

Similar to what was observed with exogenous cues, the results of this experiment show that endogenous attention improves contrast sensitivity when multiple static gratings are presented and cue validity is set at 100%. However, unlike for exogenous attention, no age-related differences on the effect of attention on contrast sensitivity were observed. This suggests that older

individuals were able to use endogenous attention as efficiently as young individuals.

Correct orientation discrimination (%)

Figure 14.4. Main effects and two-way interactions for multiple dynamic gratings with endogenous cue at 75% (EIV).

14.5 Neutral trials analysis

An ANOVA was performed on the results obtained for the neutral trials in each of the experiments included in this chapter. The results are presented in Figure 14.5. A significant main effect of contrast type was observed when a single stimulus was presented and cue validity was set at 75% (Experiment II), with better performance on first-order stimuli. This effect appears to be responsible for the significant main effect of contrast type observed in Experiment II. The only other significant result was a main effect of age when multiple gratings were presented and cue validity was set at 75% (Experiment IV). This effect appears to be responsible for the significant main effect of age observed in Experiment IV. Under all other conditions, no significant effects were observed for the neutral trials.

14.6 Summary of Chapter 14

As in the previous chapter, the goal of the experiments included in this chapter was to assess the impact of endogenous attention on contrast sensitivity in normal aging. While static gratings were used in chapter 13, dynamic gratings were used in this chapter. The processing load was gradually increased from Experiment I to Experiment IV, by changing the levels of cue validity (100% and 75%) and array size (single and multiple gratings). Based

on the literature, processing load is heavier when multiple gratings are presented compared to when a single grating is used. Similarly, processing load is heavier when the cue does not always accurately predict the location of the target (75% cue validity). Furthermore, two types of contrast were tested: simple first-order contrast and complex second-order contrast.

When a single dynamic grating was presented, endogenous attention improved contrast sensitivity only when cue validity was set at 75%. This is similar to what was observed under exogenous attentional conditions. When the cue always accurately predicted the location of the target (100% cue validity), endogenous attention did not improve contrast sensitivity. Under these conditions, adequate performance appears to be achieved by sensory processing alone. This can be thought of as a ceiling effect, where adding attention does not further improve performance. It is also possible that the grating itself acts as an attentional cue when only one grating was presented and captures attention automatically, thus explaining why adding an attentional cue had no effect.

When multiple dynamic gratings were presented, endogenous attention improved contrast sensitivity, under both levels of cue validity. This finding was also obtained under exogenous attentional conditions. However, unlike what was observed for exogenous attention, no attentional age-related

differences were observed when endogenous cues were used. While older individuals show deficits in exogenous attention, their performance was similar to that of young individuals when endogenous cues were used. This suggests that older individuals may be able to compensate for deficits in exogenous attention with endogenous attention.

Figure 14.5. Neutral trial analyses are presented for Experiments I-IV, for dynamic gratings under endogenous attention.

Chapter 15: Summary of results under endogenous attention

The goal of the experiments included in chapters 13 and 14 was to assess the impact of endogenous attention on contrast sensitivity in normal aging. Static (chapter 13) and dynamic (chapter 14) gratings were used. In each chapter, the processing load was gradually increased from Experiment I to Experiment IV, by changing the levels of cue validity (100% and 75%) and array size (single and multiple gratings). Based on the literature, processing load is heavier when multiple gratings are presented compared to when a single grating is used. Similarly, processing load is heavier when the cue does not always accurately predict the location of the target (75% cue validity). Furthermore, two types of contrast were tested: simple first-order contrast and complex second-order contrast. The results for endogenous attention are presented in Tables 15.1 (static gratings) and 15.2 (dynamic gratings). The pattern of results is similar to that obtained under exogenous attention (Tables 12.1 and 12.2) with respect to the effect of attention on contrast sensitivity. However, an important difference was observed between exogenous and endogenous attention. While age-related deficits in attention were observed under exogenous cueing conditions, no such age-related deficits were present under endogenous cueing conditions.

15.1 The effect of endogenous attention

Taken together, the results suggest that under light processing load, endogenous attention does not influence contrast sensitivity. When a single stimulus was presented and the cue always accurately indicated the location of the target (100% cue validity), no attentional effect was observed, regardless of whether the grating was static or dynamic. Under these conditions, it is possible that the grating itself acts as an attentional cue by grabbing attention automatically, thus explaining why no additional effect of the exogenous cue is found. Within the framework of the feature integration theory, it is possible that the grating acted as a pop-out target.

In the present research, one assumption was that attention may be distributed along a continuum rather than being an all-or-nothing process. Attentional effects are more likely to be observed under conditions requiring complex processing. Based on the literature, processing dynamic gratings imposes a heavier load on the visual system than does the processing of static gratings. The results are consistent with this: they show an effect of endogenous attention on contrast sensitivity when a single dynamic grating was presented, when the cue did not predict the location of the target on all trials (75% cue validity). This attentional effect was not observed when a single static grating was presented. Although the processing load was relatively

light when only one grating was presented, it was made heavier by introducing motion in the grating and by reducing the level of cue validity. These conditions made it more difficult to perform the task and the benefits of attention are present under such conditions.

When multiple gratings were presented, endogenous attention improved contrast sensitivity. This was true for static and dynamic gratings and for both levels of cue validity. The attentional effect appears to be mediated through different mechanisms for static and dynamic gratings. When static gratings were presented, the attentional effect was mediated through a combination of enhancement and inhibition. When dynamic gratings were presented, the attentional effect was mediated through inhibition alone when a single grating was presented and by enhancement alone when multiple gratings were presented. This pattern of result is different from what was observed under exogenous attention.

15.2 Age-related differences in the effect of endogenous attention

Unlike what was observed for exogenous attention, the effect of endogenous attention was similar in the young and older groups. This suggests that, although older individuals may show attentional deficits for exogenous cues compared to young individuals, they may not be at a disadvantage when

endogenous cues are used. When a significant effect of endogenous attention was observed, the attentional benefit was similar for the young and older groups. This suggests that older individuals may be able to compensate for deficits in exogenous attention with endogenous attention.

Although some age-related differences were observed when complex second-order stimuli were used, compared to simple first-order stimuli, these effects were likely due to differences between the configuration of the baseline experiment and that of all other experiments. Finally, when a single dynamic grating was presented, overall performance was better in the older group. However, differences between the baseline and this experiment appear to be responsible for this effect.

Table 15.1. Summary of the results obtained in the experiments in which endogenous cueing was used with static gratings. * significant result; * significant result but the interpretation needs to take into account the differences between the neutral trials in these conditions and the baseline

ENDOGENOUS STATIC	1 grating		4 gratings	
	100%	75%	100%	75%
Attention	ns	ns	*	*
Age	ns	*	ns	ns
Contrast type (CT)	ns	ns	ns	*
Age X Attention	ns	ns	ns	ns
CT X Attention	ns	ns	ns	*
CT X Age	ns	ns	ns	*

Table 15.2. Summary of the results obtained in the experiments in which endogenous cueing was used with dynamic gratings. * significant result; * significant result but the interpretation needs to take into account the differences between the neutral trials in these conditions and the baseline

ENDOGENOUS DYNAMIC	1 grating		4 gratings	
	100%	75%	100%	75%
Attention	ns	*	*	*
Age	*	*	ns	ns
Contrast type (CT)	ns	*	ns	ns
Age X Attention	ns	ns	ns	ns
CT X Attention	ns	ns	ns	ns
CT X Age	ns	ns	ns	ns

Chapter 16: General discussion

The purpose of the present research was to investigate the impact of visual attention on contrast sensitivity in normal aging. Three assumptions were made: 1) attention can influence contrast sensitivity; 2) changes in the aging brain are widespread, non-specific and cumulative; 3) stimuli and tasks that demand complex processing are more likely to reveal non-specific, age-related changes. The first goal was to confirm the impact of aging on contrast sensitivity as suggested by Habak and Faubert (2000). This was tested in the baseline experiment and the findings pertaining to this goal are discussed in section 16.2.1. The second goal was to determine whether attention could modulate contrast sensitivity. The third goal was to determine whether age-related differences in the effect of attention on contrast sensitivity exist. Finally, the fourth goal was to determine whether these effects vary with processing load. Based on the literature, it was hypothesized that attention would affect contrast sensitivity and that age-related differences would be more readily observed under conditions of increased processing load.

Processing load was manipulated in the following ways: type of attentional cue (exogenous and endogenous), array size (multiple and single target presentation), cue validity (75% and 100%), drifting speed (static and

drifting) and contrast type (first- and second-order gratings). The discussion below first focuses on the impact of attention on contrast sensitivity.

Overall, the results obtained in the present research suggest that both exogenous and endogenous attention influence contrast sensitivity. This effect was stronger when multiple gratings were presented and for dynamic gratings. Age-related differences in the effect of exogenous attention on contrast sensitivity were observed. When multiple gratings were presented under exogenous cueing conditions, performance was better in the young group than in the older group. Interestingly, however, these differences vanished under endogenous attention. This suggests that older individuals may be able to compensate for deficits in exogenous attention with endogenous attention. Under both exogenous and endogenous attentional conditions, the effects of type of contrast and cue validity were minimal.

16.1 The effect of attention on contrast sensitivity

Although there has been some debate as to whether attention, which is a higher-level function, can influence low level visual functions such as contrast sensitivity, there is mounting evidence suggesting that it does. For example, it has been shown that attention influences cortical, as well as sub-cortical functions (Zackon, Casson, Stelmach, Faubert, & Racette, 1997; Zackon,

Casson, Zafar, Stelmach, & Racette, 1999). The results obtained in the present research are consistent with both physiological and psychophysical evidence suggesting the possibility of attentional modulations on contrast sensitivity.

16.1.1 The impact of processing load

While the results of this research suggest that contrast sensitivity can be modulated by attention, this effect was observed under some conditions and not others. When multiple gratings were presented, the attentional effect was consistently observed under all conditions. Under this condition, attention improved contrast sensitivity for static and dynamic gratings, for cue validity levels of 75% and 100% and for exogenous and endogenous cues. In addition, when dynamic gratings were used, attention improved contrast sensitivity when a single grating was presented at 75% cue validity. Assuming that attention is a process distributed along a continuum, varying the processing load should vary the impact of attention. Under light processing loads, sensory processing may be sufficient, such that attention may not provide any additional improvement in performance. When, however, the processing load is heavier, the sensory mechanisms may no longer be sufficient and attentional processing may be necessary to achieve optimal performance.

The results demonstrate that attention had more of an impact on contrast sensitivity when multiple gratings were presented, as well as when dynamic gratings were presented. This suggests that increasing the processing load increased the impact of attention on contrast sensitivity. Further variations in processing load by varying drifting speed, cue validity and contrast type did not appear to modify the impact of attention on contrast sensitivity when multiple gratings were used.

On the other hand, drifting speed, cue validity and contrast type did have an impact on the attentional effect on contrast sensitivity when a single grating was presented. Under both exogenous and endogenous attention, improved contrast sensitivity was found only when a dynamic grating was presented at 75% cue validity. This suggests that although only a single grating was presented, varying drifting speed and cue validity increased the processing load enough to require the involvement of attention for optimal performance.

Under all other conditions, attention did not appear to influence contrast sensitivity when a single grating was presented. This finding is inconsistent with Carrasco et al. (2000), who showed an effect of exogenous attention with the presentation of a single static target. The discrepancy between the results obtained in the present research and those obtained by Carrasco et al. (2000) can be explained by differences in the stimulus

configuration. Carrasco et al. (2000) presented a single target at one of eight locations, while only four locations were included in the present research. Having more possible locations to monitor may have increased the processing load and thus revealed an attentional effect.

Another possible explanation for the lack of an attentional effect for single stimulus presentation in the present research may be that the single grating acted as an attentional cue. The appearance of a single grating may have captured attention automatically, such that the cue did not further improve performance. This explanation however, does not account for the fact that an attentional effect was observed under 75% cue validity, when a single dynamic grating was used, nor does it explain the inconsistencies between these results and those of Carrasco et al. (2000).

16.1.2 Attentional mechanisms

There is ongoing debate concerning the nature of the mechanisms underlying attentional processing. Attention may enhance the processing of the attended stimulus, or it may inhibit the processing of unattended stimuli. It is also possible that attentional effects are mediated by the combination of enhancement and inhibition. In the present research, the mechanisms underlying attentional processing were assessed by comparing performance on

valid and invalid trials to the performance on neutral trials. As such, attentional mechanisms could only be assessed when cue validity was set at 75% and when a significant attentional effect was obtained (mainly when multiple gratings were used).

The results in these conditions suggest that attention may be mediated through different combinations of inhibition and enhancement, depending on the type of attentional cues (exogenous or endogenous) and the drifting speed (static or dynamic). The results suggest that, when multiple static gratings were presented, both enhancement and inhibition mediate the exogenous and endogenous attentional effects. When multiple dynamic gratings were presented however, the underlying mechanisms were different for exogenous and endogenous attention. Under these conditions, the exogenous attentional effect was mediated through enhancement and inhibition, while the endogenous effect was mediated through enhancement alone. When a single, dynamic grating was presented, the attentional effect was mediated through inhibition alone, for both exogenous and endogenous cues.

Posner and Dehaene (1994) propose that the effect of attention may become increasingly driven by enhancement as one moves up in the processing hierarchy. This theory is based on physiological grounds. In primary processing areas, such as V1, the spontaneous firing rate of the cells is high.

Therefore, the only way for attention to influence processing in this area is to inhibit this cellular activity for non-attended stimuli. In higher processing areas however, the spontaneous firing rate is lower and attention can have an influence by enhancing cellular activity for attended stimuli.

Based on Posner and Dehaene (1994), one would expect differences in the attentional mechanisms based on drifting speed. Dynamic gratings are assumed to impose a heavier processing load than static gratings. Therefore, more evidence of enhancement would be expected when dynamic gratings are used. The results obtained in the present research are consistent with this view for exogenous attention but not for endogenous attention. The effect of exogenous attention was mediated through enhancement and inhibition when static gratings were used, but only by inhibition when dynamic gratings were used. This is inconsistent with the predictions of Posner and Dehaene. The effect of endogenous attention, however, was mediated through enhancement and inhibition when static gratings were presented, but by enhancement alone when dynamic gratings were presented. This is consistent with the theory of Posner and Dehaene.

The presentation of multiple gratings is also assumed to require more complex processing than the presentation of a single grating. According to Posner and Dehaene, this should result in a shift from inhibitory to enhancing

mechanisms. The results obtained in the present research are consistent with this prediction, in that the effect of endogenous attention was mediated through inhibition alone when a single dynamic grating was presented, but by enhancement alone when multiple dynamic gratings were presented. The underlying mechanisms of exogenous attention could not be determined when a single grating was presented, thus it is not possible to determine how these results compare to the predictions of Posner and Dehaene.

Based on Posner and Dehaene, differences in the attentional mechanisms were also expected between exogenous and endogenous attention. While exogenous attention is reflexive, endogenous attention requires volition and may involve more complex, higher-level processing. Therefore exogenous attention should be mediated more through inhibition while endogenous attention should be mediated more by enhancement. The results obtained in the present research when multiple dynamic gratings were presented are consistent with the theory proposed by Posner and Dehaene (1994) in that the effect of exogenous attention was mediated through inhibition alone while the effect of endogenous attention was mediated through enhancement alone. The mechanisms underlying the attentional effects were similar for exogenous and endogenous attention, independent of array size and cue validity.

Finally, the results obtained in the present research are inconsistent with those of Carrasco et al. (2000), who attributed the attentional effect they observed to enhancement of the attended stimulus. In the present research, under conditions similar to those of Carrasco et al. (2000), both enhancement and inhibition mediated the attentional effect, which supports the view of Posner and Dehaene (1994).

16.2 Age-related differences

The brain undergoes changes associated with normal aging. Evidence suggests that these changes are widespread and non-specific. As the brain ages, functional changes appear that have a small impact at each processing level. Therefore, when processing a stimulus requires a large number of steps, there is an accumulation of small functional deficits. As a result, complex stimuli are likely more affected by aging than are simple stimuli and tasks imposing a heavy processing load are more likely to be affected by aging than tasks imposing a light processing load. Age-related differences in performance can thus be observed in perceptual and also in attentional performance, depending on the processing load that is imposed.

16.2.1 Perceptual differences

In the present research, perceptual age-related differences were assessed in the baseline experiment, in which no attentional cues were presented. While one goal of the baseline experiment was to perceptually equate all participants, it was also designed to investigate age-related differences for simple and complex stimuli. In previous reports, no age effects were found in the perception of a one cycle per degree static, simple grating (Habak & Faubert, 2000; Owsley et al., 1983; Kline, 1987; Elliot et al., 1990). The results obtained in the present research, which demonstrate higher thresholds for static first-order stimuli in the older group than in the young group, are inconsistent with these previous findings.

Age-related differences were also found for second-order stimuli and these differences were larger than those found for first-order stimuli. These results are similar for static and dynamic gratings. This finding is consistent with the study of Habak and Faubert (2000), who also observed larger perceptual age-related differences for second-order stimuli compared to first-order stimuli. These age-related differences were similar for static and dynamic gratings.

The results of the baseline experiment for second-order stimuli did, however, differ from Habak and Faubert (2000) in one respect. In the present

research, the contrast thresholds were approximately 2.5 times larger in the older group compared to the young group, when complex second-order stimuli were used. Previous reports suggest contrast thresholds approximately twice as large for older individuals compared to young individuals for complex stimuli (Habak & Faubert, 2000; Trick & Silverman, 1991). This may be due to differences in the stimulus configuration between our studies. In the study of Habak and Faubert (2000), central presentation was used, while our stimuli were presented eccentrically, where there may be larger age-related differences in contrast sensitivity. Although this effect was larger in magnitude, it is in line with the previously reported findings.

In summary, perceptual age-related differences generally consistent with those previously reported were obtained in the present research.

16.2.2 Attentional differences

The present research was designed to assess whether attentional deficits exist in the older population in addition to perceptual deficits, or whether attention acts as a compensatory mechanism for age-related perceptual deficits. The findings obtained in this research suggest that age-related attentional deficits, as well as attentional compensation exist, depending on the type of attention. Although the results suggest the presence of age-related deficits in

exogenous attention, they also suggest that endogenous attention can compensate for these deficits in older individuals.

No attentional effects were observed under most conditions where a single grating was presented. When multiple gratings were presented, the results obtained in all conditions are consistent with the presence of age-related deficits in exogenous attention and the lack of such differences in endogenous attention. The only exception is the lack of a significant age-related difference for multiple static gratings for exogenous attention at 75% cue validity. However, a closer investigation of the results suggests that, although age-related differences did not reach statistical significance, there is a trend in the results that is consistent with an attentional deficit in the older group compared to the young group. The lack of statistical significance for age-related differences when multiple static gratings were used under exogenous attention set at 75% cue validity, may be due to a lack of power under this condition for detecting a small effect.

As described above, in some respects the results for endogenous cueing were similar to those obtained with exogenous cueing: no attentional effects were observed under most conditions where a single grating was presented, while the results obtained with multiple gratings show the impact of attention on contrast sensitivity. However, the pattern of age-related attentional deficits

is very different between the two types of cueing: with exogenous cueing, there are age-related attentional differences almost everywhere there is evidence of attention; with endogenous cueing there are no age-related deficits, such that the attentional effect is equally beneficial to young and older individuals. This suggests that although older individuals may show deficits for reflexive attention, they may be able to compensate for these deficits when they voluntarily shift their attention onto a target.

16.2.3 The impact of drifting speed and contrast type

Drifting speed and contrast type were tested as a means to manipulate the processing load. Creating heavier processing loads was expected to reveal age-related differences. In general, however, these two variables do not appear to have had a strong impact on age-related attentional differences, although the only attentional effect observed when a single grating was presented occurred when a dynamic stimulus was used. Similarly, although some age-related differences were found for second-order stimuli and not for first-order stimuli, this effect was rather inconsistent throughout the present research. Furthermore, contrast type did not appear to have an impact on whether or not an attentional effect was obtained. This pattern of results suggests that drifting speed and contrast type may not be important factors in the understanding of

the impact of attention and age-related attentional deficits on contrast sensitivity.

16.3 Implications and future research

Attentional age-related deficits were observed for exogenous cues, but not for endogenous cues. Deficits in visual processing may have a negative impact on the performance of daily activities, the ability to live independently and on quality of life. Given that visual deficits are associated with aging, the older population is more likely to suffer from decrements in quality of life associated with visual loss. In the context of an aging population, it is of paramount importance to develop methods to maintain functional abilities into older age. The growth in the percentage of our population in the older age groups is due in part to the resources that have been mobilized in the past decades for medical research and healthcare. Resources of the same magnitude now need to be directed towards the development of strategies and technologies that can identify deficits in functional vision and potentially improve the visual functions that are necessary for the performance of daily activities and independent living. The present research has implications that are in line with this long-term goal.

16.3.1 Value of functional assessments in older individuals

In typical clinical settings, visual functions, such as acuity and contrast sensitivity, are assessed under optimal conditions. Patients are asked, for example, to read an eye chart under ideal lighting conditions often one eye at a time, without moving their head or having a context to help with difficult visual decisions. In the real world however, performance on everyday tasks almost always occurs under less than optimal conditions, but individuals bring all their resources to each task: vision, attention, cognition. Thus, there is a discrepancy between clinically measured sensory losses and the ability to function in the real world. For example, some individuals with dramatic visual losses are able to function well because they can use their attention and cognition to compensate, while others with only mild deficits report significant functional difficulties. Unfortunately due to the lack of functional tests, individuals are classified according to their clinical results in terms of restrictions, such as driver's licences. This may result in individuals who can compensate being unfairly restricted, while individuals who are at risk remain unrestricted. Therefore, a pressing need exists to develop ways to test functional vision in the elderly population.

Real-world activities require complex visual processing and it is therefore unlikely that the assessment of any one visual function in isolation

will be sufficient to identify individuals with increased impairments in performing daily activities. Due to the poor association between visual perception and performance in real-world activities, other factors also need to be considered. Cognitive factors, such as attention, may have a potential influence on accident prevention.

The testing methods used in the present research could prove useful in assessing functional vision. This test provides measures of perceptual and cognitive functioning, which have been proposed to correlate well with real-world activities. Furthermore, this test measures contrast sensitivity, which correlates with driving performance. The combination of measures of contrast sensitivity and exogenous and endogenous attention may potentially help evaluate functional vision. The fact that age-related differences were observed under some conditions suggest that this test is sensitive to changes that occur in normal aging. The fact that older individuals performed as well as younger individuals using endogenous cueing suggests that this test would help to identify those who have the ability to compensate for loss of reflexive attention with volitional attention. Thus this type of test shows promise as a method to assess functional vision in the elderly population.

16.3.2 Improving functional vision in older individuals

The long-term goal of research in the general area of vision and aging is to maintain functional vision into older age, in order to maintain a satisfying level of quality of life. The results from relatively recent research suggest that older individuals may show improvements in performance of visual tasks following training aimed at increasing the processing speed of complex visual information. Significant improvements in the time needed to perform daily tasks such as reading the ingredients on cans of food, reading the instructions on medicine bottles, finding a phone number in the phone book and locating items on a crowded shelf, were observed (Edwards et al., 2002). Furthermore, this type of training was also found to improve performance on the Useful Field of View (UFOV) test (Roemaker et al., 2003). The UFOV test incorporates perceptual, attentive and cognitive factors and was shown to correlate well with the risk of involvement in car crashes. Taken together, these findings suggest that it may be possible to train older individuals to attend to and process visual information more efficiently.

The training methods described above were focussed on processing speed of complex visual information. The results obtained in the present research suggest that training older individuals on how to make more efficient use of endogenous attention may also prove to be a powerful tool in improving

functional vision. The potential strength of the test used in the present research is the specific use of contrast sensitivity and of endogenous attention. In comparison, the UFOV test uses supra-threshold targets and exogenous attention. In the present research, older individuals were able, without formal training, to compensate for deficits in exogenous attention with endogenous attention. This suggests that endogenous attention may be preserved in the older population and learning to make efficient use of it may lead to improvements in functional vision.

16.4 Limitations of the present research

The conclusions drawn from the results obtained in the present research must be tempered by an understanding of the limitations of this research. A discussion of these limitations is included below.

16.4.1 Differences between baseline and experimental conditions

The goal of the baseline experiment was to equate the performance of the young and older participants at the perceptual level, such that any age-related differences could be attributed to attention. However, because the stimulus configuration and the task were slightly different in the baseline experiment

compared to all other experiments², any increase or decrease in performance could be attributed to either attentional cueing, other changes in the paradigm, or to random variation. An analysis of the neutral trials was performed in each experiment to facilitate the distinction between these factors. In the sixteen experiments in which attention was introduced, the neutral trials are not influenced by attention and performance on these trials should therefore be similar to the performance obtained in the baseline experiment. In those cases where the neutral trials are similar across age groups and contrast type levels, a significant result can be readily interpreted to infer that attention played a role in altering the perceptibility of the gratings. In cases where the neutral trial analysis revealed differences, significant results require more complex discussion.

² The differences between the baseline experiment and all other experiments consisted in the location at which the stimuli were presented (directly above or below fixation in the baseline and at one of four locations in all other experiments), the number of stimuli presented at any one location (two briefly flashed stimuli at the same location in the baseline and only one stimulus at any one location in all other experiments), as well as the task itself (report whether the vertical grating appeared first or second in the baseline and orientation discrimination in all other experiments).

16.4.2 Eye movements

In the natural environment, attended stimuli are also foveated. There is a strong connection between the attentional and eye movement systems. Although it is possible to dissociate attentional shifts and eye movements under experimental conditions, eye movements should ideally be monitored. In the present research, it was not possible to monitor eye movements, leaving open the possibility that participants moved their eyes towards the target indicated by the attentional cue. If eye movements were performed in the direction of the target, then the improvement in performance may not be due to attention, but rather to foveal processing.

There are, however, factors that argue against this possibility. Under exogenous attention, the duration of each trial was 200 ms. The reflexive saccades triggered by exogenous cues have a latency of approximately 250 ms. Therefore, even if the exogenous cue triggered an eye movement, the onset of the eye movement would have occurred after the trial was over. Performance would not have been influenced by foveation.

Under endogenous attention, the arrow cue remained on the screen until participants shifted their attention in the direction indicated by the arrow. Participants therefore had enough time to move their eyes over to the location indicated by the cue. However, the following arguments, taken together,

suggest that voluntary eye movements did not occur in the experiments conducted under endogenous cueing. First, participants were thoroughly instructed to maintain central fixation, were periodically reminded throughout testing of the importance of fixating and were monitored by the experimenter who was in close proximity to each participant (Figure 16.1). Second, the latency of voluntary saccades was shown to be longer than the latency of reflexive saccades by more than 100 ms (Walker, Walker, Husain, & Kennard, 2000). Therefore, although participants had more time to initiate endogenous trials, more time was also necessary to launch voluntary saccades.

Finally, the results do not suggest the presence of eye movements. If eye movements were made in the endogenous conditions, then performance should be better for valid trials under all conditions. In other words, an artefactual effect of attention should be observed in all conditions. Instead, the results show an attentional effect for multiple targets for dynamic and static stimuli. However when a single target was presented, no attentional effect was observed, except for dynamic gratings at 75% cue validity. If participants were making eye movements, there is no reason to believe that they would do so selectively on some but not other conditions. The different pattern of result observed across the endogenous conditions suggests that eye movements were not an issue.

16.4.3 Lack of formal medical, visual and cognitive assessments

In the present research, the general health, cognitive and visual status of each participant was not formally assessed. Although it is possible that the older individuals might have been mildly impaired compared to the young group, this appears unlikely. Perceptually, all participants were equated in the baseline experiment, thus minimizing the effect of any medical or cognitive age-related differences in the perception of contrast sensitivity. In addition, the contrast thresholds obtained by the participants included in the present research are comparable to those of the participants included in the study of Habak and Faubert (2000). This suggests that our participants could perform as well as those included in their study who underwent thorough medical and cognitive assessments. Furthermore, the older participants recruited in the present research were active and independent members of the community and did not show obvious signs of cognitive impairment. Finally, the performance of the older participants was similar to that of the young participants when endogenous cues were used, suggesting that they could make good use of this cognitive ability.

16.4.4 Statistical power

Statistical power was not always high enough to detect small, but true differences. Power was adequate to detect attentional effects under all conditions however. Some of the inconsistencies observed in the results may be due to a lack of statistical power for the detection of small effects.

The relatively small number of invalid trials included in each experiment where the cue validity was set at 75% also represents a limitation on the interpretation of enhancement versus inhibition in attention. In these conditions, half the trials were neutral and while the other half were cued. Only 25% of the cued trials were invalid. Overall then, only one eighth of all trials were invalid. Thus, the relative impact of each invalid trial on performance was high, but the power of the analysis of invalid trials was low.

16.5 Conclusions

The results of this research suggest that both exogenous and endogenous attention can improve contrast sensitivity. Age-related differences were found in perceptual and attentional processing. At the perceptual level, older participants needed higher contrast thresholds to achieve similar performance to the young participants. At the attentional level, the impact of attention on contrast sensitivity was observed under exogenous but not under

endogenous attention. The benefits of exogenous attention were greater in the young group than in the older group. When endogenous cues were used, however, the effect of attention was similar in both age groups. In general, both the attentional effect and the age-related attentional differences on contrast sensitivity were dependent upon the processing load. These effects were more likely to be observed under the heavier processing loads imposed by array size (multiple gratings) and drifting speed (dynamic gratings). Increasing processing load with factors such as cue validity and contrast type did not result in a greater likelihood of observing age-related differences in attention. These findings have important implications for the development of assessment tools and training strategies for functional vision in the elderly population.

Figure 16.1. Photograph of the experimenter with one of the participants in the older group, showing the close proximity of the experimenter to the participants.

Chapter 17: References

- Anstis, S. (1980). The perception of apparent movement. Philosophical Transactions of the Royal Society of London Series B: Biological Science, 290, 153-168.
- Arundale, K. (1978). An investigation into the variation of human contrast sensitivity with age and ocular pathology. British Journal of Ophthalmology, 62, 213-215.
- Ball, K. K., Beard, B. L., Roenker, D. L., Miller, R. L., & Griggs, D. S. (1988). Age and visual search: expanding the useful field of view. Journal of the Optical Society of America A, 5, 2210-2219.
- Ball, K., & Owsley, C. (1993). The useful field of view test: A new technique for evaluating age-related declines in visual function. Journal of the American Optometry Association, 64, 71-79.
- Ball, K., & Sekuler, R. (1986). Improving visual perception in older observers. Journal of Gerontology, 41, 176-182.
- Bashinski, H. S., & Bacharach, V. R. (1980). Enhancement of perceptual sensitivity as the results of selectively attending to spatial locations. Perception & Psychophysics, 28, 241-248.

- Brink, J. M., & McDowd, J. M. (1999). Aging and selective attention: an issue of complexity or multiple mechanisms? Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 54, 30-33.
- Carrasco, M., Penpeci-Talgar, C., & Eckstein, M. (2000). Spatial covert attention increases contrast sensitivity across the CSF: support for signal enhancement. Vision Research, 40, 1203-1215.
- Cavanagh, P., & Mather, G. (1989). Motion: the long and the short of it. Spatial Vision, 4, 103-129.
- Chelazzi, L., Miller, E. K., Duncan, J., & Desimone, R. (1993). A neural basis for visual search in inferior temporal cortex. Nature, 363, 345-347.
- Chubb, C., & Sperling, G. (1988). Drift-balanced stimuli: a general basis for studying non-Fourier motion perception. Journal of the Optical Society of America A, 5, 1986-2007.
- Chubb, C., & Sperling, G. (1989). Two motion perception mechanisms revealed by distance driven reversal of apparent motion. Proceedings of the National Academy of Science USA, 86, 2985-2989.
- Colby, C. L. (1991). The neuroanatomy and neurophysiology of attention. Journal of Child Neurology, 6, S90-S118.

- Davis, E. T., Kramer, P., & Graham, N. (1983). Uncertainty about spatial frequency, spatial position, or contrast of visual patterns. Perception & Psychophysics, 33, 20-28.
- Dosher, B. A., Landy, M. S., & Sperling, G. (1989). Kinetic depth effect and optic flow. I. 3D shape from Fourier motion. Vision Research, 29, 1789-1813.
- Downing, C. J. (1988). Expectancy and visual-spatial attention: effects on perceptual quality. Journal of Experimental Psychology: Human Perception and Performance, 14, 188-202.
- Eason, R. G., Harter, M. R., & White, C. T. (1969). Effects of attention and arousal on visually evoked potentials and reaction time in man. Physiology and Behavior, 4, 283-289.
- Eckstein, M. P. (1998). The lower efficiency for conjunctions is due to noise and not serial attentional processing. Psychological Science, 9, 111-118.
- Edwards, J. D., Wadley, V. G., Myers, R. S., Roenker, D. L., Cissell, G. M., & Ball, K. K. (2002). The transfer of a speed of processing intervention to near and far cognitive functions. Gerontology, 48, 329-340.

- Elliott, D., Whitaker, D., & MacVeigh, D. (1990). Neural contribution to spatiotemporal contrast sensitivity decline in healthy ageing eyes. Vision Research, 30, 541-547.
- Faubert, J. (1994). Seeing depth in color: more than just what meets the eye. Vision Research, 34, 1165-1186.
- Faubert, J., Diaconu, V., Ptito, M., & Ptito A. (1999). Residual vision in the blind field of hemidecorticated humans predicted by a diffusion scatter model and selective spectral absorption of the human eye. Vision Research, 39, 149-157.
- Foley, J. M., & Schwartz, W. (1998). Spatial attention: effect of position uncertainty and number of distractor patterns on the threshold-versus-contrast function for contrast discrimination. Journal of the Optical Society of America, 15, 1036-1047.
- Gazzaley, A. H., Thakker, M. M., Hof, P. R., & Morrison, J. H. (1997). Preserved number of entorhinal cortex layer II neurons in aged macaque monkeys. Neurobiological Ageing, 18, 549-553.
- Greenwood, P. M., Parasuraman, R., & Alexander, G. E. (1997). Controlling the focus of spatial attention during visual search: effects of advanced aging and Alzheimer's disease. Neuropsychology, 11, 3-12.

- Grzywacz, N. M. (1992). One-path model for contrast-independent perception of Fourier and non-Fourier motions. Investigative Ophthalmology and Visual Science (Suppl.), 33, 954.
- Habak, C., & Faubert J. (2000). Larger effect of aging on the perception of higher-order stimuli. Vision Research, 40, 943-950.
- Haenny, P. E., & Schiller, P. H. (1988). State dependent activity in monkey visual cortex. I. Single cell activity in V1 and V4 on visual tasks. Experimental Brain Research, 69, 225-244.
- Harris, L. R., & Smith, A. T. (1992). Motion defined exclusively by second-order characteristics does not evoke optokinetic nystagmus. Vision Neuroscience, 9, 565-570.
- Ho, C. E. (1998). Letter recognition reveals pathways of second-order and third-order motion. Proceedings of the National Academy of Science of the USA, 95, 400-405.
- Horowitz, T., & Treisman, A. (1994). Attention and apparent motion. Spatial Vision, 8, 193-219.
- Ito, M., & Gilbert, C. D. (1999). Attention modulates contextual influences in the primary visual cortex of alert monkeys. Neuron, 22, 593-604.
- Johnston, A., McOwan, P. W., & Buxton, H. (1992). A computational model of the analysis of some first-order and second-order motion patterns by

- simple and complex cells. Proceedings of the Royal Society of London Series B: Biological Sciences, 250, 297-306.
- Kinchla, R. A. (1980). The measurement of attention. In R. S. Nickerson, Attention and Performance VIII. Hillsdale, NJ: Erlbaum.
- Kline, D. W. (1987). Aging and the spatiotemporal discrimination performance of the visual system. Eye, 1, 323-329.
- Laarni, J., Näsänen, R., Rovamo, J., & Saarinen, J. (1996). Performance in simple visual search at threshold contrasts. Investigative Ophthalmology and Visual Science, 37, 1706-1710.
- Ledgeway, T., & Smith, A. T. (1994). Evidence for separate motion detecting mechanisms for first- and second-order motion in human vision. Vision Research, 34, 2727-2740.
- Lee, D. K., Itti, C., Koch, C., & Braun, J. (1999). Attention activates winner-take-all competition among visual filters. Nature Neuroscience, 2, 375-381.
- Lee, D. K., Koch, C., & Braun, J. (1997). Spatial vision thresholds in the near absence of attention. Vision Research, 37, 2409-2418.
- Lu, Z.-L., & Doshier, B. A. (1998). External noise distinguishes attention mechanisms. Vision Research, 38, 1183-1198.

- Lu, Z.-L., Liu, C. Q., & Doshier, B. A. (2000). Attention mechanisms for multi-location first- and second-order motion perception. Vision Research, 40, 173-186.
- Lu, Z.-L., & Sperling, G. (1995). The functional architecture of human visual motion perception. Vision Research, 35, 2597-2722.
- Lu, Z.-L., & Sperling, G. (1996). Three systems for visual motion perception. Current Directions in Psychological Science, 5, 44-53.
- Luck, S. J., Chelazzi, L., Hillyard, S. A., & Desimone, R. (1997). Neural mechanisms of spatial selective attention in areas V1, V2, and V4 of macaque visual cortex. Journal of Neurophysiology, 77, 24-42.
- Luck, S. J., & Ford, M. A. (1998). On the role of selective attention in visual perception. Proceedings of the National Academy of Science of the USA, 95, 825-830.
- Luck, S. J., Hillyard, S. A., Mouloua, M., Woldorff, M. G., Clark, V. P., & Hawkins, H. L. (1996). Effects of spatial cuing on luminance detectability: psychophysical and electrophysiological evidence for early selection. Journal of Experimental Psychology: Human Perception and Performance, 20, 887-904.
- Mack, A., & Rock, I. (1998). Inattention blindness. Boston, MA: MIT Press.

- Madden, D. J., Connelly, S. L., & Pierce, T. W. (1994). Adult age differences in shifting focused attention. Psychology and Aging, 9, 528-538.
- Martinez, A., Anllo-Vento, L., Sereno, M. I., Frank, L. R., Buxton, R. B., Dubowitz, D. J., Wong, E. C., Hinrichs, H., Heinze, H. J., & Hillyard, S. A. (1999). Involvement of striate and extrastriate visual cortical areas in spatial attention. Nature Neuroscience, 2, 364-9.
- Mather, G., & West, S. (1993). Evidence for second-order motion detectors. Vision Research, 33, 1109-1112.
- Mazer, B. L., Sofer, S., Korner-Bitensky, N., & Gelinas, I. (2001). Use of the UFOV to evaluate and retrain visual attention skills in clients with stroke: a pilot study. American Journal of Occupational Therapy, 55, 552-557.
- McLeod, P., Driver, J., & Crisp, J. (1988). Visual search for a conjunction of movement and form is parallel. Nature, 332, 154-155.
- Moran, J., & Desimone, R. (1985). Selective attention gates visual processing in the extrastriate cortex. Science, 229, 782-784.
- Morrison, J. H., & Hof, P. R. (1997). Life and death of neurons in the aging brain. Science, 278, 412-419.

- Motter, B. C. (1993). Focal attention produces spatially selective processing in visual cortical areas V1, V2 and V4 in the presence of competing stimuli. Journal of Neurophysiology, 70, 909-919.
- Müller, M. M., Picton, T. W., Valdes-Sosa, P., Riere, J., Teder-Sälejärvi, W. A., & Hillyard, S. A. (1998). Effects of spatial attention on the steady-state visual evoked potential in the 20-28 Hz range. Cognitive Brain Research, 6, 249-261.
- Nakayama, K., & Silverman, G. H. (1986). Serial and parallel processing of visual feature conjunctions. Nature, 320, 264-265.
- O'Craven, K. M., Rosen, B. R., Kwong, K. K., Treisman, A., & Savoy, R. L. (1997). Voluntary attention modulates fMRI activity in human MT-MST. Neuron, 18, 591-598.
- Owsley, C., Sekuler, R., & Siemsen, D. (1983). Contrast sensitivity throughout adulthood. Vision Research, 23, 689-699.
- Palmer, J. (1994). Set-size effects in visual search: the effect of attention is independent of the stimulus for simple tasks. Vision Research, 34, 1703-1721.
- Pashler, H. (1987). Detecting conjunctions of color and form: Reassessing the serial search hypothesis. Perception and Psychophysics, 41, 191-201.

- Pentland, A. (1980). Maximum likelihood estimation; The best PEST. Perception and Psychophysics, 28, 377-379.
- Perneger, T.V. (1998). What's wrong with Bonferroni adjustments. British Medical Journal, 316, 1236-1238.
- Peters, A., Rosene, D. L., Moss, M. B., Kemper, T. L., Abraham, C. R., Tigges, J., & Albert, M. S. (1996). Neurobiological bases of age-related cognitive decline in the rhesus monkey. Journal of Neuropathology and Experimental Neurology, 55, 861-874.
- Posner, M. I. (1980). Orienting of attention. Quarterly Journal of Experimental Psychology, 32, 3-25.
- Posner, M. I., & Dehaene, S. (1994). Attentional networks. Trends in Neuroscience, 17, 75-79.
- Racette, L. (1997). Task difficulty determines the amount of attentional processing resources devoted to visual processing. Unpublished master's dissertation, Carleton University, Ottawa, Ontario, Canada.
- Ramachandran, V. S., Rao, V. M., & Vidyasagar, T. R. (1973). Apparent movement with subjective contours. Vision Research, 13, 1399-1401.
- Rapp, P. R., & Gallagher, M. (1996). Preserved neuron number in the hippocampus of aged rats with spatial learning deficits. Proceedings of

the National Academy of Sciences of the United States of America, 93, 9926-9930.

- Robinson, D. L., & Kertzman, C. (1995). Covert orienting of attention in macaques. III. Contributions of the superior colliculus. Journal of Neurophysiology, 74, 713-721.
- Robson, J. G. (1966). Spatial and temporal contrast sensitivity functions of the visual system. Journal of the Optical Society of America, 56, 583-601.
- Roelfsema, P. R., Lamme, V. A. F., & Spekreijse, H. (1998). Object-based attention in the primary visual cortex of the macaque monkey. Nature, 395, 376-381.
- Roenker, D. L., Cissell, G. M., Ball, K. K., Wadley, V. G., & Edwards, J. D. (2003). Speed-of-processing and driving simulator training improve driving performance. Human Factors, 45, 218-233.
- Rubin, H. (1997). Cell aging in vivo and in vitro. Mechanical and Ageing Development, 98, 1.
- Savitz, D. A., & Olshan, A. F. (1995). Multiple comparisons and related issues in the interpretation of epidemiologic data. American Journal of Epidemiology, 42, 904-908.

- Schieber, F. (1992). Aging and the senses. In Birren J. E., Sloan, R. & Cohen, G. eds. Handbook of Mental Health and Aging. New York: Academic Press, 251-306.
- Seideman, E., & Newsome, W. T. (1999). Effect of spatial attention on the response of area MT neurons. Journal of Neurophysiology, 81, 1783-1794.
- Shaw, M. L. (1984). Division of attention among spatial locations: a fundamental difference between detection of letters and detection of luminance. In H. Bouma, D. G. (eds), Attention and Performance X. Hillsdale, NJ: Erlbaum, 109-120.
- Shiu, L., & Pashler, H. (1994). Negligible effect of spatial precuing on identification of single digits. Journal of Experimental Psychology: Human Perception and Performance, 20, 1037-1054.
- Solomon, J. A., Lavie, N., & Morgan, M. J. (1997). Contrast discrimination function: Spatial cuing effects. Journal of the Optical Society of America, 14, 2443-2448.
- Somers, D. C., Dale, A. M., Seiffert, A. E., & Tootell, R. B. (1999). Functional MRI reveals spatially specific attentional modulation in human primary visual cortex. Proceedings of the National Academy of Sciences of the United States of America, 96, 1663-1668.

- Spear, P. D. (1993). Neural bases of visual deficits during aging. Vision Research, 33, 2589-2609.
- Sperling, G. (1989). Three stages and two systems of visual processing. Spatial Vision, 4, 183-207.
- Sperling, G., & Doshier, B. A. (1986). Strategy and optimization in human information processing. In K. R. Boff, L. Kaufman, & J. P. Thomas, Handbook of Perception and Human Performance, Vol. 1, New York: Wiley, 1-65.
- Sperling, G., & Lu, Z.-L. (1998). A systems analysis of motion perception. In T. Watanabe, High-level Motion Processing. Cambridge, MA: MIT Press, 153-183.
- Steinman, S. B. (1987). Serial and parallel search in pattern vision. Perception, 16, 389-398.
- Taylor, M. M., & Creelman, C. D. (1967). PEST: Efficient estimates on probability functions. Journal of the Acoustic Society of America, 41, 782-787.
- Tellinghuisen, D. J., Zimba, L. D., & Robin, D. A. (1996). Endogenous visuospatial precuing effects as a function of age and task demands. Perception & Psychophysics, 58, 947-958.

- Theeuwes, J., & Kooi, F. L. (1994). Parallel search for a conjunction of contrast polarity and shape. Vision Research, 34, 3013-3016.
- Treisman, A., & Gelade, G. (1980). A feature integration theory of attention. Cognitive Psychology, 12, 97-136.
- Treue, S., & Maunsell, J. H. R. (1996). Attentional modulation of visual motion processing in cortical areas MT and MST. Nature, 382, 539-541.
- Treue, S., & Maunsell, J. H. (1999). Effects of attention on the processing of motion in macaque middle temporal and medial superior temporal visual cortical areas. Journal of Neuroscience, 19, 7591-7602.
- Trick, G. L., & Silverman, S. E. (1991). Visual sensitivity to motion: age-related changes and deficits in senile dementia of the Alzheimer type. Neurology, 41, 1437-1440.
- Victor, J. D., & Conte, M. M. (1991). Spatial organization of non-Fourier interactions in form perception. Vision Research, 31, 1457-1488.
- Vincent, S. L., Peters, A., & Tigges, J. (1989). Effects of aging on the neurons within area 17 of rhesus monkey cerebral cortex. The Anatomical Record, 223, 329-341.
- von Grünau, M. W., Bertone, A., & Pakneshan, P. (1998). Attentional selection of motion states. Spatial Vision, 11, 329-347.

- Walker, R., Walker, D. G., Husain, M., & Kennard, C. (2000). Control of voluntary and reflexive saccades. Experimental Brain Research, 130, 540-544.
- Watanabe, K., & Shimojo, S. (1998). Attentional modulation in perception of visual motion events. Perception, 27, 1041-1054.
- Watson, A. B., & Robson, J. G. (1981). Discrimination at threshold: labelled detectors in human vision. Vision Research, 21, 1115-1122.
- Weale, R. (1963). The Aging Eye. London: Lewis.
- Weale, R. (1975). Senile changes in visual acuity. Transactions of the Ophthalmological Society of the UK, 95, 36-38.
- Werkhoven, P., Sperling, G., & Chubb, C. (1993). The dimensionality of texture-defined motion: a single channel theory. Vision Research, 33, 463-485.
- Wilson, H. R., Ferrerra, V. P., & Yo, C. (1992). A psychophysically motivated model for two-dimensional motion perception. Visual Neuroscience, 9, 79-97.
- Wilson, H. R., & Mast, R. (1993). Illusory motion of texture boundaries. Vision Research, 33, 1437-1446.
- Wolfe, J. M., Cave, K. R., & Franzel, S. L. (1989). Guided search: An alternative to the modified feature integration model for visual search.

Journal of Experimental Psychology: Human Perception & Performance, 15, 419-433.

- Wong, T. P., Campbell, P. M., Ribiero-da-Silva, A., & Cuello, A. C. (1998).
Synaptic numbers across cortical laminae and cognitive performance of
the rat during ageing. Neuroscience, 84, 403-412.
- Wurtz, R. H., & Mohler, C. W. (1976). Enhancement of visual responses in
monkey striate cortex and frontal eye fields. Journal of
Neurophysiology, 39, 766-772.
- Zackon, D. H., Casson, E. J., Stelmach, L., Faubert, J., & Racette, L. (1997).
Distinguishing subcortical and cortical influences in visual attention.
Investigative Ophthalmology and Visual Science, 38, 364-371.
- Zackon, D. H., Casson, E. J., Zafar, A., Stelmach, L., & Racette, L. (1999).
The temporal order judgment paradigm: Midbrain contribution under
exogenous and endogenous cueing conditions. Neuropsychologia, 37,
511-520.

APPENDIX A

Summary tables for all analyses

ANOVA summary table for the baseline experiment presented in Chapter 9.

Source	df	SS	MS	F	p
Contrast type	1	1.63	1.63	141.44	<0.001*
Age	1	0.48	0.48	41.22	<0.001*
Drifting speed	1	0.03	0.03	2.17	0.15
Age X Contrast type	1	0.35	0.35	30.03	<0.001*
Age X Drifting speed	1	<0.01	<0.01	0.31	0.58
Contrast type X Drifting speed	1	0.02	0.02	1.43	0.24
Contrast type X Age X Drifting speed	1	<0.01	<0.01	0.07	0.80
Residual	48	0.55	0.55		
Total	55	3.06	3.06		

ANOVA summary table when a single static grating was presented with an exogenous cue at 100% (chapter 10.3).

Source	df	SS	MS	F	p
Attention	1	167.59	167.59	0.75	0.39
Age	1	146.66	146.66	0.66	0.42
Contrast type	1	0.17	0.17	0.001	0.98
Age X Attention	1	21.10	21.10	0.10	0.76
Contrast type X Attention	1	62.95	62.95	0.28	0.60
Contrast type X Age	1	1.57	1.57	0.001	0.93
Attention X Age X	1	62.95	62.95	0.28	0.60
Residual	48	10,717.08	223.27		
Total	55	11,180.07	203.27		

ANOVA summary table when a single static grating was presented with an exogenous cue at 75% (chapter 10.4).

Source	df	SS	MS	F	p
Attention	2	472.00	236.00	1.08	0.35
Age	1	180.47	180.47	0.82	0.37
Contrast type	1	61.50	61.50	0.28	0.60
Age X Attention	2	115.97	57.99	0.27	0.77
Contrast type X Attention	2	81.15	40.57	0.19	0.83
Contrast type X Age	1	421.32	421.32	1.92	0.17
Attention X Age X Contrast type	2	287.40	143.70	0.66	0.52
Residual	72	15,773.55	219.08		
Total	83	17,393.36	209.56		

ANOVA summary table when multiple static gratings were presented with an exogenous cue at 100% (chapter 10.5).

Source	df	SS	MS	F	p
Attention	1	1,862.06	1,862.06	27.44	<0.001*
Age	1	508.51	508.51	7.49	0.01*
Contrast type	1	48.44	48.44	0.71	0.40
Age X Attention	1	435.97	435.97	6.42	0.02*
Contrast type X Attention	1	0.08	0.08	0.001	0.97
Contrast type X Age	1	887.35	887.35	13.08	<0.001*
Attention X Age X Contrast type	1	48.44	48.44	0.71	0.40
Residual	48	3,257.69	67.87		
Total	55	7,048.53	128.16		

Simple effect analysis summary table for the effect of attention in the young group, when multiple static gratings were presented with an exogenous cue at 100% (chapter 10.5).

Source	df	SS	MS	F	p
Attention	1	2,050.01	2,050.01	29.76	<0.001*
Residual	26	1,790.99	68.88		
Total	27	3,840.99			

Simple effect analysis summary table for the effect of attention in the older group, when multiple static gratings were presented with an exogenous cue at 100% (chapter 10.5).

Source	df	SS	MS	F	p
Attention	1	248.02	248.02	2.63	0.12
Residual	26	2,451.02	94.27		
Total	27	2,699.03			

Simple effect analysis summary table for the effect of age when first-order stimuli were used, when multiple static gratings were presented with an exogenous cue at 100% (chapter 10.5).

Source	df	SS	MS	F	p
Age	1	26.20	26.20	0.27	0.61
Residual	26	2,547.43	97.98		
Total	27	2,573.63			

Simple effect analysis summary table for the effect of age when second-order stimuli were used, when multiple static gratings were presented with an exogenous cue at 100% (chapter 10.5).

Source	df	SS	MS	F	p
Age	1	1,369.67	1,369.67	11.65	0.002 *
Residual	26	3,056.80	117.57		
Total	27	4,426.46			

ANOVA summary table when multiple static gratings were presented with an exogenous cue at 75% (chapter 10.6).

Source	df	SS	MS	F	p
Attention	2	9,701.68	4,850.84	26.04	<0.001*
Age	1	297.66	297.66	1.60	0.21
Contrast type	1	3,336.17	3,336.17	17.91	<0.001*
Age X Attention	2	660.61	330.31	1.773	0.18
Contrast type X Attention	2	2,807.99	1,403.97	7.534	0.001*
Contrast type X Age	1	1,505.59	1,505.59	8.080	0.01*
Attention X Age X Contrast type	2	229.36	114.68	0.62	0.54
Residual	72	13,415.29	186.32		
Total	83	31,954.292	384.99		

Tukey test summary table for the effect of attention when multiple static gratings were presented with an exogenous cue at 75% (chapter 10.6).

Comparison	Difference of means	p	q	p < .05
Valid vs. Invalid	26.23	3	10.17	Yes
Valid vs. Neutral	15.07	3	5.84	Yes
Neutral vs. Invalid	11.16	3	4.33	Yes

Simple effect analysis for the effect of attention when first-order stimuli were used, when multiple static gratings were presented with an exogenous cue at 75% (chapter 10.6).

Source	df	SS	MS	F	p
Age	2	11,078.80	5,539.40	24.22	<0.001*
Residual	39	8,918.97	228.69		
Total	41	19,997.77			

Tukey test summary table for the effect of attention in first-order stimuli, when multiple static gratings were presented with an exogenous cue at 75% (chapter 10.6).

Comparison	Difference of means	p	q	p < .05
Valid vs. Invalid	39.73	3	9.83	Yes
Valid vs. Neutral	18.13	3	4.49	Yes
Neutral vs. Invalid	21.61	3	5.35	Yes

Simple effect analysis for the effect of attention when second-order stimuli were used, when multiple static gratings were presented with an exogenous cue at 75% (chapter 10.6).

Source	df	SS	MS	F	p
Age	2	1,430.82	715.41	3.88	0.03*
Residual	39	7,189.54	184.35		
Total	41	8,620.36			

Tukey test summary table for the effect of attention in second-order stimuli, when multiple static gratings were presented with an exogenous cue at 75% (chapter 10.6).

Comparison	Difference of means	p	q	p < .05
Valid vs. Invalid	12.72	3	3.51	Yes
Valid vs. Neutral	12.01	3	3.31	No
Neutral vs. Invalid	0.71	3	0.20	No

Simple effect analysis for the effect of age when first-order stimuli were used, when multiple static gratings were presented with an exogenous cue at 75% (chapter 10.6).

Source	df	SS	MS	F	p
Age	1	232.18	232.18	0.47	0.50
Residual	40	19,765.59	494.14		
Total	41	19,997.77			

Simple effect analysis for the effect of age when second-order stimuli were used, when multiple static gratings were presented with an exogenous cue at 75% (chapter 10.6).

Source	df	SS	MS	F	p
Age	1	1,571.07	1,571.07	8.92	0.005 *
Residual	40	7,049.29	176.23		
Total	41	8,620.36			

ANOVA summary table for the neutral trial analysis when a single static grating was presented with an exogenous cue at 100% (chapter 10.1).

Source	df	SS	MS	F	p
Age	1	139.51	139.51	0.80	0.38
Contrast type	1	34.88	34.88	0.20	0.66
Contrast type X Age	1	22.32	22.32	0.13	0.72
Residual	24	4,207.59	175.32		
Total	27	4,404.30	163.12		

ANOVA summary table for the neutral trial analysis when a single static grating was presented with an exogenous cue at 75% (chapter 10.2).

Source	df	SS	MS	F	P
Age	1	14.29	14.29	0.14	0.71
Contrast type	1	0.00	0.00	0.00	1.00
Contrast type X Age	1	432.14	432.14	4.18	0.05
Residual	24	2,483.93	103.50		
Total	27	2,930.36	108.53		

ANOVA summary table for the neutral trial analysis when multiple static gratings were presented with an exogenous cue at 100% (chapter 10.3).

Source	df	SS	MS	F	p
Age	1	1.40	1.40	0.03	0.88
Contrast type	1	26.20	26.20	0.47	0.50
Contrast type X Age	1	260.57	260.57	4.70	0.04*
Residual	24	1,331.85	55.49		
Total	27	1,620.01	60.00		

ANOVA summary table for the neutral trial analysis when multiple static gratings were presented with an exogenous cue at 75% (chapter 10.4).

Source	df	SS	MS	F	p
Age	1	162.72	162.72	1.88	0.18
Contrast type	1	412.72	412.72	4.78	0.04*
Contrast type X Age	1	830.58	830.58	9.62	0.01*
Residual	24	2,073.21	86.38		
Total	27	3,479.24	128.86		

ANOVA summary table when a single dynamic grating was presented with an exogenous cue at 100% (chapter 11.1).

Source	df	SS	MS	F	p
Attention	1	93.52	93.52	0.33	0.57
Age	1	0.77	0.77	0.003	0.96
Contrast type	1	5,531.79	5,531.79	19.49	<0.001*
Age X Attention	1	0.28	0.28	0.001	0.98
Contrast type X Attention	1	51.97	51.97	0.18	0.67
Contrast type X Age	1	467.73	467.73	1.65	0.21
Attention X Age X	1	173.90	173.90	0.61	0.44
Residual	48	13,626.34	283.88		
Total	55	19,946.30	362.66		

ANOVA summary table when a single dynamic grating was presented with an exogenous cue at 75% (chapter 11.2).

Source	df	SS	MS	F	p
Attention	2	1,744.88	872.44	3.86	0.03*
Age	1	61.50	61.50	0.27	0.60
Contrast type	1	3,495.58	3,495.58	15.46	<0.001*
Age X Attention	2	39.30	19.65	0.09	0.92
Contrast type X Attention	2	257.90	128.95	0.57	0.57
Contrast type X Age	1	1,185.94	1,185.94	5.25	0.03*
Attention X Age X Contrast	2	323.89	161.95	0.72	0.49
Residual	72	16,281.25	226.13		
Total	83	23,390.23	281.81		

Tukey test summary table for the effect of attention when a single dynamic grating was presented with an exogenous cue at 75% (chapter 11.2).

Comparison	Difference of means	p	q	p < .05
Valid vs. Invalid	10.38	3	3.65	Yes
Valid vs. Neutral	1.63	3	0.57	No
Neutral vs. Invalid	8.75	3	3.08	No

Simple effect analysis summary table for the effect of age when first-order stimuli were used, when a single dynamic grating was presented with an exogenous cue at 75% (chapter 11.2).

Source	df	SS	MS	F	p
Age	1	893.79	893.79	3.76	0.06
Residual	40	9,498.14	237.45		
Total	41	10,391.93			

Simple effect analysis summary table for the effect of age when second-order stimuli were used, when a single dynamic grating was presented with an exogenous cue at 75% (chapter 11.2).

Source	df	SS	MS	F	p
Age	1	353.66	353.66	1.55	0.22
Residual	40	9,149.07	228.73		
Total	41	9,502.73			

ANOVA summary table when multiple dynamic gratings were presented with an exogenous cue at 100% (chapter 11.3).

Source	df	SS	MS	F	p
Attention	1	2,581.40	2,581.40	30.34	<0.001*
Age	1	1,051.92	1,051.92	12.36	<0.001*
Contrast type	1	283.69	283.69	3.33	0.07
Age X Attention	1	607.04	607.04	7.13	0.01*
Contrast type X Attention	1	0.02	0.02	<0.01	0.99
Contrast type X Age	1	10.25	10.25	0.12	0.73
Attention X Age X Contrast type	1	86.98	86.98	1.02	0.32
Residual	48	4,084.20	85.09		
Total	55	8,705.49	158.28		

Simple effect analysis summary table for the effect of attention in the young group, when multiple dynamic gratings were presented with an exogenous cue at 100% (chapter 11.3).

Source	df	SS	MS	F	p
Attention	1	2,846.02	2,846.02	49.37	<0.001*
Residual	26	1,498.71	57.64		
Total	27	4,344.73			

Simple effect analysis summary table for the effect of attention in the older group, when multiple dynamic gratings were presented with an exogenous cue at 100% (chapter 11.3).

Source	df	SS	MS	F	p
Attention	1	342.42	342.42	3.00	0.10
Residual	26	2,966.43	114.09		
Total	27	3,308.84			

ANOVA summary table when multiple dynamic gratings were presented with an exogenous cue at 75% (chapter 11.4).

Source	df	SS	MS	F	p
Attention	2	8,037.39	4,018.70	20.03	<0.001*
Age	1	1,636.19	1,636.19	8.16	0.01*
Contrast type	1	2.87	2.87	0.01	0.91
Age X Attention	2	1,474.60	737.30	3.68	0.03*
Contrast type X Attention	2	21.62	10.81	0.05	0.95
Contrast type X Age	1	466.81	466.81	2.33	0.13
Attention X Age X Contrast type	2	164.44	82.22	0.41	0.67
Residual	72	14,443.57	200.61		
Total	83	26,247.50	316.24		

Tukey test summary table for the effect of attention when multiple dynamic gratings were presented with an exogenous cue at 75% (chapter 11.4).

Comparison	Difference of means	p	q	p < .05
Valid vs. Invalid	23.62	3	8.83	Yes
Valid vs. Neutral	8.34	3	3.12	No
Neutral vs. Invalid	15.28	3	5.71	Yes

Simple effect analysis summary table for the effect of attention in the young group, when multiple dynamic gratings were presented with an exogenous cue at 75% (chapter 11.4).

Source	df	SS	MS	F	p
Attention	2	8,176.41	4,088.21	19.53	<0.001*
Residual	39	8,163.95	209.33		
Total	41	16,340.37			

Simple effect analysis summary table for the effect of attention in the older group, when multiple dynamic gratings were presented with an exogenous cue at 75% (chapter 11.4).

Source	df	SS	MS	F	p
Attention	2	1,335.58	667.79	3.76	0.03*
Residual	39	6,935.37	177.83		
Total	41	8,270.94			

Tukey test for the effect of attention in the young group, when multiple dynamic gratings were presented with an exogenous cue at 75% (chapter 11.4).

Comparison	Difference of means	p	q	p < .05
Valid vs. Invalid	33.48	3	8.66	Yes
Valid vs. Neutral	10.80	3	2.79	No
Neutral vs. Invalid	22.68	3	5.87	Yes

Tukey test for the effect of attention in the older group, when multiple dynamic gratings were presented with an exogenous cue at 75% (chapter 11.4).

Comparison	Difference of means	p	q	p < .05
Valid vs. Invalid	13.77	3	3.86	Yes
Valid vs. Neutral	5.89	3	1.65	No
Neutral vs. Invalid	7.88	3	2.21	No

ANOVA summary table for the neutral trial analysis when a single dynamic grating was presented with an exogenous cue at 100% (chapter 11.1).

Source	df	SS	MS	F	p
Age	1	0.06	0.06	<0.001	0.99
Contrast type	1	2,255.70	2,255.70	7.11	0.01*
Contrast type X Age	1	606.02	606.02	1.91	0.18
Residual	24	7,611.30	317.14		
Total	27	10,473.08	387.89		

ANOVA summary table for the neutral trial analysis when a single dynamic grating was presented with an exogenous cue at 75% (chapter 11.2).

Source	df	SS	MS	F	p
Age	1	<0.001	<0.001	<0.001	1.00
Contrast type	1	750.89	750.89	3.39	0.08
Contrast type X Age	1	357.14	357.14	1.61	0.22
Residual	24	5,321.43	221.73		
Total	27	6,429.46	238.13		

ANOVA summary table for the neutral trial analysis when multiple dynamic gratings were presented with an exogenous cue at 100% (chapter 11.3).

Source	df	SS	MS	F	p
Age	1	30.38	30.38	0.34	0.57
Contrast type	1	139.51	139.51	1.55	0.23
Contrast type X Age	1	18.76	18.76	0.21	0.65
Residual	24	2,158.36	89.93		
Total	27	2,347.01	86.93		

ANOVA summary table for the neutral trial analysis when multiple dynamic gratings were presented with an exogenous cue at 75% (chapter 11.4).

Source	df	SS	MS	F	p
Age	1	1,028.35	1,028.35	6.04	0.02 *
Contrast type	1	7.70	7.70	0.05	0.83
Contrast type X Age	1	230.36	230.36	1.35	0.26
Residual	24	4,087.36	170.31		
Total	27	5,353.78	198.29		

ANOVA summary table when a single static grating was presented with an endogenous cue at 100% (chapter 13.1).

Source	df	SS	MS	F	p
Attention	1	34.18	34.18	0.23	0.63
Age	1	586.64	586.64	3.95	0.05
Contrast type	1	369.00	369.00	2.48	0.12
Age X Attention	1	56.50	56.50	0.38	0.54
Contrast type X Attention	1	156.95	156.95	1.06	0.31
Contrast type X Age	1	369.00	369.00	2.48	0.12
Attention X Age X Contrast type	1	156.95	156.95	1.06	0.31
Residual	48	7,131.70	148.58		
Total	55	8,860.91	161.11		

ANOVA summary table when a single static grating was presented with an endogenous cue at 75% (chapter 13.2).

Source	df	SS	MS	F	p
Attention	2	23.03	11.51	0.06	0.94
Age	1	1,521.50	1,521.50	8.43	0.01*
Contrast type	1	678.59	678.59	3.76	0.06
Age X Attention	2	226.04	113.02	0.63	0.54
Contrast type X Attention	2	19.01	9.501	0.05	0.95
Contrast type X Age	1	7.44	7.44	0.04	0.84
Attention X Age X Contrast type	2	494.79	247.40	1.37	0.26
Residual	72	12,989.29	180.41		
Total	83	15,959.69	192.29		

ANOVA summary table when multiple static gratings were presented with an endogenous cue at 100% (chapter 13.3).

Source	df	SS	MS	F	p
Attention	1	4,153.67	4,153.67	55.74	<0.001*
Age	1	4.36	4.360	0.06	0.81
Contrast type	1	81.87	81.87	1.10	0.30
Age X Attention	1	1.57	1.57	0.02	0.89
Contrast type X Attention	1	1.57	1.57	0.02	0.89
Contrast type X Age	1	274.39	274.39	3.68	0.06
Attention X Age X Contrast type	1	10.25	10.25	0.14	0.71
Residual	48	3,576.70	74.512		
Total	55	8,104.63	147.35		

ANOVA summary table when multiple static gratings were presented with an endogenous cue at 75% (chapter 13.4).

Source	df	SS	MS	F	p
Attention	2	30,701.46	15,350.73	82.29	<0.001*
Age	1	653.95	653.95	3.51	0.07
Contrast type	1	1,736.05	1,736.05	9.31	0.003*
Age X Attention	2	278.32	139.16	0.75	0.48
Contrast type X Attention	2	1,826.46	913.23	4.90	0.01*
Contrast type X Age	1	839.96	839.96	4.50	0.04*
Attention X Age X Contrast type	2	8.60	4.30	0.02	0.98
Residual	72	13,430.80	186.54		
Total	83	49,475.61	596.09		

Tukey test summary table for the effect of attention when multiple static gratings were presented with an endogenous cue at 75% (chapter 13.4).

Comparison	Difference of means	p	q	p < .05
Valid vs. Invalid	46.54	3	18.03	Yes
Valid vs. Neutral	18.77	3	7.27	Yes
Neutral vs. Invalid	27.77	3	10.76	Yes

Simple effect analysis summary table for the effect of attention in first-order stimuli, when multiple static gratings were presented with an endogenous cue at 75% (chapter 13.4).

Source	df	SS	MS	F	p
Attention	2	23,742.58	11,871.29	67.22	<0.001*
Residual	39	6,887.75	176.61		
Total	41	30,630.33			

Simple effect analysis summary table looking at the effect of attention in second-order stimuli, when multiple static gratings were presented with an endogenous cue at 75% (chapter 13.4).

Source	df	SS	MS	F	p
Attention	2	8,785.34	4,392.67	20.58	<0.001*
Residual	39	8,323.88	213.43		
Total	41	17,109.23			

Tukey test summary table for the effect of attention in first-order stimuli, when multiple static gratings were presented with an endogenous cue at 75% (chapter 13.4).

Comparison	Difference of means	p	q	p < .05
Valid vs. Invalid	57.81	3	16.28	Yes
Valid vs. Neutral	22.81	3	6.42	Yes
Neutral vs. Invalid	35.00	3	9.85	Yes

Tukey test summary table for the effect of attention in second-order stimuli, when multiple static gratings were presented with an endogenous cue at 75% (chapter 13.4).

Comparison	Difference of means	p	q	p < .05
Valid vs. Invalid	35.27	3	9.03	Yes
Valid vs. Neutral	14.73	3	3.77	Yes
Neutral vs. Invalid	30.54	3	5.26	Yes

Simple effect analysis summary table for the effect of age when first-order stimuli were used, when multiple static gratings were presented with an endogenous cue at 75% (chapter 13.4).

Source	df	SS	MS	F	p
Age	1	5.81	5.81	0.01	0.93
Residual	40	30,624.52	765.61		
Total	41	30,630.33			

Simple effect analysis summary table for the effect of age when second-order stimuli were used, when multiple static gratings were presented with an endogenous cue at 75% (chapter 13.4).

Source	df	SS	MS	F	p
Age	1	1,488.10	1,488.10	3.81	0.06
Residual	40	15,621.13	390.53		
Total	41	17,109.23			

ANOVA summary table for the neutral trial analysis when a single static grating was presented with an endogenous cue at 100% (chapter 13.1).

Source	df	SS	MS	F	p
Age	1	68.36	68.36	0.41	0.53
Contrast type	1	1.40	1.40	0.01	0.93
Contrast type X Age	1	68.36	68.36	0.41	0.53
Residual	24	4,040.18	168.34		
Total	27	4,178.29	154.75		

ANOVA summary table for the neutral trial analysis when a single static grating was presented with an endogenous cue at 75% (chapter 13.2).

Source	df	SS	MS	F	p
Age	1	514.29	514.29	4.39	0.05*
Contrast type	1	322.32	322.32	2.75	0.11
Contrast type X Age	1	89.29	89.29	0.76	0.39
Residual	24	2,810.71	117.11		
Total	27	3,736.61	138.39		

ANOVA summary table for the neutral trial analysis when multiple static gratings were presented with an endogenous cue at 100% (chapter 13.3).

Source	df	SS	MS	F	p
Age	1	5.58	5.58	0.06	0.81
Contrast type	1	30.38	30.38	0.34	0.57
Contrast type X Age	1	89.29	89.29	1.00	0.33
Residual	24	2,149.06	89.54		
Total	27	2,274.31	84.23		

ANOVA summary table for the neutral trial analysis when multiple static gratings were presented with an endogenous cue at 75% (chapter 13.4).

Source	df	SS	MS	F	p
Age	1	50.22	50.22	0.41	0.53
Contrast type	1	339.51	339.51	2.78	0.11
Contrast type X Age	1	273.44	273.44	2.24	0.15
Residual	24	2,928.57	122.02		
Total	27	3,591.74	133.03		

ANOVA summary table when a single dynamic grating was presented with an endogenous cue at 100% (chapter 14.1).

Source	df	SS	MS	F	p
Attention	1	126.63	126.63	0.60	0.44
Age	1	1,901.46	1,901.46	9.05	0.004*
Contrast type	1	416.01	416.01	1.98	0.17
Age X Attention	1	1.98	1.98	0.01	0.92
Contrast type X Attention	1	111.30	111.30	0.53	0.47
Contrast type X Age	1	24.24	24.24	0.12	0.74
Attention X Age X Contrast type	1	261.67	261.67	1.25	0.27
Residual	48	10,091.02	210.23		
Total	55	12,934.31	235.17		

ANOVA summary table when a single dynamic grating was presented with an endogenous cue at 75% (chapter 14.2).

Source	df	SS	MS	F	p
Attention	2	3,326.82	1,663.41	9.04	<0.001*
Age	1	941.69	941.69	5.12	0.03*
Contrast type	1	1,125.67	1,125.67	6.12	0.02*
Age X Attention	2	220.42	110.21	0.60	0.55
Contrast type X Attention	2	121.88	60.94	0.33	0.72
Contrast type X Age	1	131.25	131.25	0.71	0.40
Attention X Age X Contrast	2	387.50	193.75	1.05	0.35
Residual	72	13,245.65	183.97		
Total	83	19,500.87	234.95		

Tukey test summary table for endogenous attention when a single dynamic grating was presented with an endogenous cue at 75% (chapter 14.2).

Comparison	Difference of means	p	q	p < .05
Valid vs. Invalid	14.96	3	5.84	Yes
Valid vs. Neutral	4.24	3	1.66	No
Neutral vs. Invalid	10.71	3	4.18	Yes

ANOVA summary table when multiple dynamic gratings were presented with an endogenous cue at 100% (chapter 14.3).

Source	df	SS	MS	F	p
Attention	1	7,068.76	7,068.76	88.63	<0.001*
Age	1	37.51	37.51	0.47	0.50
Contrast type	1	260.73	260.73	3.27	0.08
Age X Attention	1	1.240	1.240	0.02	0.90
Contrast type X Attention	1	100.45	100.45	1.26	0.27
Contrast type X Age	1	11.16	11.16	0.14	0.71
Attention X Age X Contrast type	1	2.79	2.79	0.04	0.85
Residual	48	3,828.13	79.75		
Total	55	11,310.76	205.65		

ANOVA summary table when multiple dynamic gratings were presented with an endogenous cue at 75% (chapter 14.4).

Source	df	SS	MS	F	p
Attention	2	8,840.49	4,420.24	24.13	<0.001*
Age	1	954.28	954.28	5.21	0.03*
Contrast type	1	47.44	47.44	0.26	0.61
Age X Attention	2	30.22	15.11	0.08	0.92
Contrast type X Attention	2	380.59	190.30	1.04	0.36
Contrast type X Age	1	321.66	321.66	1.76	0.19
Attention X Age X Contrast	2	117.64	58.82	0.32	0.73
Residual	72	13,188.17	183.17		
Total	83	23,880.48	287.72		

Tukey test summary table for the effect of endogenous attention when multiple dynamic gratings were presented with an endogenous cue at 75% (chapter 14.4).

Comparison	Difference of means	p	q	p < .05
Valid vs. Invalid	24.00	3	9.38	Yes
Valid vs. Neutral	18.46	3	7.22	Yes
Neutral vs. Invalid	5.54	3	2.16	No

ANOVA summary table for the neutral trial analysis when a single dynamic grating was presented with an endogenous cue at 100% (chapter 14.1).

Source	df	SS	MS	F	p
Age	1	890.38	890.38	3.27	0.08
Contrast type	1	478.83	478.83	1.76	0.20
Contrast type X Age	1	63.32	63.32	0.23	0.63
Residual	24	6,531.46	272.14		
Total	27	7,963.99	294.96		

ANOVA summary table for the neutral trial analysis when a single dynamic grating was presented with an endogenous cue at 75% (chapter 14.2).

Source	df	SS	MS	F	p
Age	1	89.29	89.29	0.74	0.40
Contrast type	1	750.89	750.89	6.25	0.02*
Contrast type X Age	1	228.57	228.57	1.90	0.18
Residual	24	2,885.71	120.24		
Total	27	3,954.46	146.46		

ANOVA summary table for the neutral trial analysis when multiple dynamic gratings were presented with an endogenous cue at 100% (chapter 14.3).

Source	df	SS	MS	F	p
Age	1	26.20	26.20	0.21	0.65
Contrast type	1	18.76	18.76	0.15	0.70
Contrast type X Age	1	1.40	1.40	0.01	0.92
Residual	24	3,020.83	125.87		
Total	27	3,067.18	113.60		

ANOVA summary table for the neutral trial analysis when multiple dynamic gratings were presented with an endogenous cue at 75% (chapter 14.4).

Source	df	SS	MS	F	p
Age	1	493.08	493.08	5.41	0.03*
Contrast type	1	187.72	187.72	2.06	0.16
Contrast type X Age	1	162.72	162.72	1.78	0.19
Residual	24	2,189.29	91.22		
Total	27	3,032.81	112.33		

APPENDIX B

Graphs of the three-way interactions

Three-way interaction when a single static grating was presented with an exogenous cue at 100% (chapter 10.1).

Three-way interaction when a single static grating was presented with an exogenous cue at 75% (chapter 10.2).

Three-way interaction when multiple static gratings were presented with an exogenous cue at 100% (chapter 10.3).

Three-way interaction when multiple static gratings were presented with an exogenous cue at 75% (chapter 10.4).

Three-way interaction when a single dynamic grating was presented with an exogenous cue at 100% (chapter 11.1).

Three-way interaction when a single dynamic grating was presented with an exogenous cue at 75% (chapter 11.2).

Three-way interaction when multiple dynamic gratings were presented with an exogenous cue at 100% (chapter 11.3).

Three-way interaction when multiple dynamic gratings were presented with an exogenous cue at 75% (chapter 11.4).

Three-way interaction when a single static grating was presented with an endogenous cue at 100% (chapter 13.1).

Three-way interaction when a single static grating was presented with an endogenous cue at 75% (chapter 13.2).

Three-way interaction when multiple static gratings were presented with an endogenous cue at 100% (chapter 13.3).

Three-way interaction when multiple static gratings were presented with an endogenous cue at 75% (chapter 13.4).

Three-way interaction when a single dynamic grating was presented with an endogenous cue at 100% (chapter 14.1).

Three-way interaction when a single dynamic grating was presented with an endogenous cue at 75% (chapter 14.2).

Three-way interaction when multiple dynamic gratings were presented with an endogenous cue at 100% (chapter 14.3).

Three-way interaction when multiple dynamic gratings were presented with an endogenous cue at 75% (chapter 14.4).