The Effect of Visual Active Selection on the Modulation of the Motion Aftereffect for First- and Second-Order Motion Components

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A Thesis

In

The Department

of

Psychology

Presented in Partial Fulfillment of the Requirements

for the Degree of Doctor of Philosophy at

Concordia University

Montreal, Quebec, Canada

March 2007

Your file Votre référence
ISBN: 978-0-494-30121-0
Our file Notre référence
ISBN: 978-0-494-30121-0

ABSTRACT

The Effect of Visual Active Selection on the Modulation of the Motion Aftereffect for First- and Second-Order Motion Components

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In the literature about the effect of attention on motion processing, it is clear that attention improves the processing of motion. However, it is not clear what happens to the processing of a motion in the same visual field as another actively attended motion. Is the unattended motion unprocessed, processed to a lesser degree or suppressed? This is the question that I investigated in this thesis. The effect of active visual selection during adaptation to components of a plaid on the motion aftereffect (MAE) duration was investigated using a dynamic test stimulus oriented either like the attended component or like the unattended component. The plaids were composed of two spatially superimposed, but temporally alternating square-wave or sine-wave gratings differing by 140 degrees in motion direction. The results show that active suppression occurs in the MAE duration for a non-attended moving component of a plaid when attention is actively directed to another moving component in the same visual field during adaptation. This is true whether the adaptation plaid is made up of either: 1) two first-order gratings, 2) two second-order gratings, or 3) a mixture of first-order and second-order gratings. I also demonstrated that adapting to a single grating produced longer MAE than grating when the same grating was a component of a plaid. Therefore, the presence of an unattended moving component in the same visual field as an attended moving component reduces the strength of the MAE for the attended component of a plaid. The results of this thesis suggest that: 1) Attention is decreased when many moving stimuli are present in the visual field. 2) Attention acts on motion processing in the same manner when first-order motion and second-order motion are processed. 3) The suppression of the unattended moving stimuli is not perfect. During adaptation, attention involuntarily switched to the unattended moving component, which could be an adaptive mechanism in order to be able to react and avoid collision with unattended moving stimuli heading toward us.

ACKNOWLEDGMENTS

Particular thanks go to my thesis supervisor Dr. Michael von Grünau for his encouragement and guidance in the designs of the experiments presented in this thesis and especially in the writing of this thesis. I am grateful also to Dr. Rick Gurnsey for his valuable suggestions and comments and to Cindy Potechin for editing the manuscript.

I wish also to acknowledge the volunteers who participated in these studies. They volunteered a considerable number of hours and I am very grateful to them.

Finally I also wish to express my deepest thanks to my husband Steve Boutin for his support and encouragement throughout the preparation of this thesis.

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Visual perception is a process that allows the human brain to construct a vivid representation of the external world (De Valois, 2000, p. xv). It contributes greatly to our knowledge of the environment and to the physical place we occupy within it (Cutting, 1986, p.3). An important aspect of visual perception for the survival of humans is motion perception (Watanabe, 1998, p.vii). "Motion perception is the process by which we acquire perceptual knowledge about the motion of objects and surfaces in the image" (Derrington, Allen & Delicato, 2004, p. 183). The perception of motion provides us with information about changes that occur in our environment as we move within it or as objects move around us. Without the ability to perceive motion, it would be difficult to avoid collisions with objects and to segregate objects from their backgrounds. This makes the study of motion perception highly relevant for understanding humans' adaptation to their world. Given the importance of motion for human survival, it is not surprising to find that motion is a highly salient stimulus (Nothdurft, 2002; Royden, Wolfe & Klempen, 2001; Treisman & Gelade, 1980).

The Motion Pathway

Motion is processed at different stages along a neuronal pathway. The information is thought to travel from the retina to the lateral geniculate nucleus, to area V1 and up to the medial temporal and the medial superior temporal areas (MT/MST) (Niedeggen & Wist, 1998). Motion sensors are the units that analyze motion at the early levels in the motion pathway such as in area V1. The early levels are believed to decode simple motion. Simple motion is based on luminance changes across the retina such as a bright bar moving on a dark background. Each area of the visual field contains many sensors, each individual sensor being preferentially sensitive to luminance contrast in a particular direction. The output of these sensors is combined to provide information about the direction of the motion in a two-dimensional plane at higher levels within the motion pathway. Thus, according to Derrington et al. (2004), one way our visual system derives knowledge about the location, speed and direction of a moving object is by identifying which sensors have responded to the motion of the object. The integration of the different motion inputs occurs later in the motion pathway such as in areas MT and MST.

Models of Motion Sensors

Models of motion sensors deal with the early level of the motion pathway. These combinations are also referred to as motion detectors in the literature. Over the years, many computational models of motion sensors have been proposed to explain the processing of the signals generated by the motion of a feature of an image directly across the retina. The different computational models of motion sensors described below propose that there are sensors that respond selectively and preferentially to a particular direction of motion defined by luminance (Adelson & Bergen, 1985; van Santen & Sperling, 1985; Watson & Ahumada, 1985). Motion defined by spatial modulation of luminance over time on the retina is called first-order motion (Cavanagh & Mather, 1989).

The oldest computational model of a motion sensor that is still used currently is the correlational-Reichardt motion sensor (Derrington, 2000, p. 268; Lu & Sperling 1995). Many versions of this sensor have been proposed. It was originally designed to explain optomotor responses in insects (Reichardt, 1961). Van Santen and Sperling (1984, 1985) adapted the Reichardt model to the detection of motion in humans and called the new version the elaborated Reichardt sensor model. In the elaborated Reichardt sensor model the raw data are first transformed using a spatio-temporal low pass linear filter. This model suggests that the input passes through two adjacent receptors. One of the receptors receives the input after a time delay. This time delay permits one to derive the direction of a motion because it causes the two receptors to receive the output from the spatio-temporal filter at the same time. The output of the filtered values is multiplied before it is averaged and correlated together. Unlike the original Reichardt sensor, the Elaborated Reichardt sensor is able to detect motion in opposite directions.

Other models of motion detection have been proposed such as the motion energy-filtering model (Adelson and Bergen, 1985) and the linear spatio-temporal model (Fennema and Thompson, 1979; Johnston, Mc Owan and Buxton, 1992; Watson and Ahumada, 1985). Although these computational models of motion detections have different starting points and ways to compute motion signals, their outcomes are similar (Derrington, 2000, p. 274). Since the end results of each of the motion sensors described in this section are the same, it is difficult to know which one our brain may be using (Derrington, 2000, p. 274).

These motion sensors explain the analyses of simple, linear luminance motion input. They model what happens at the early stage of motion processing (V1). It is difficult explaining second-order motion using this mechanism. Second-order motion is a motion produced by stimulus characteristics other than luminance such as the contrast modulation of textured elements (Derrington, 2000, p. 264; Ledgeway, 1994; Turano & Pantle, 1989). An example of this type of motion is the modulation of a texture-contrast over time while the luminance of the whole stimulus remains constant. The moving texture-contrast grating is a second-order stimulus because it has the same average luminance at each spatial location (Lu & Sperling, 1996).

Feature tracking can also be used to analyze motion. Feature tracking infers motion from changes in the retinal position of objects over time (Ullman, 1980). This model of motion perception states that salient features in the image, such as an edge, are identified and their position are tracked or matched over time (Sato, 1998, p.116). Feature tracking has the advantage of being able to detect first- and second-order motion. The critics of this model state that it is not clear what constitutes a feature (a point, an edge, or a blob) and what is being matched (Adelson & Bergen, 1985). Additionally, models of motion perception based solely on feature tracking have difficulties explaining what happens when the appearance of the tracked edge of the image changes in form and when the object is rotated over time. For instance, in a random dot kinematogram, different directions of local motion may be perceived in different directions but an observer still perceive an overall coherent motion direction (Sperling & Lu, 1998, p. 164). In this type of stimuli, tracking a feature will not give the accurate direction of the overall pattern.

The fact that certain motion sensors are blind to second-order motion has been influential in the development of other models of motion processing. Historically, Braddick (1974) proposed two separate systems of motion perception. Based on his study of displacement analysis of apparent motion, Braddick (1974) proposed two mechanisms of motion, processing different types of motion: short- versus long-range motion. However, subsequent studies showed that the same motion system could process short- and long-range motion stimuli if the short-range motion underwent some preliminary rectification (Cavanagh & Mather, 1989). Cavanagh and Mather (1989) proposed that two types of stimuli with different characteristics determine the output of the motion mechanism rather than they're being two mechanisms of motion processing. They distinguished between first-order and second-order motion. Evidence exists to support the idea that first- and second-order motions are processed, at least initially, by separate mechanisms. The fact that second-order motion does not evoke optokinetic nystagmus while first-order motion does (Harris & Smith, 1992), that second-order motion does not permit recovery of 3-D images from 2-D motion while first-order motion does (Dosher, Landy & Sperling, 1989), that second-order motion, in contrast to first-order motion, does not produce a static MAE (Derrington & Badcock, 1985; Nishida, Ashida & Sato, 1994) and that a plaid made-up of two first-order components produces a suppression in the MAE of the unattended component (von Grünau, Bertone & Pakneshan, 1998), while a plaid made-up of a first- and a second-order component does not (von Grünau & Faubert, 1998) support the idea that first- and second-order motions are processed, at least initially, by separate mechanisms. For these reasons, it has been suggested that the Reichardt type sensors described earlier in this section might not be the only mechanism used by the brain to analyze motion. In von Grünau et al. (1998) and in the experiments of this thesis, a suppression of the MAE is defined as producing a MAE of shorter duration than the MAE for the condition where attention is directed to both components equally (control condition). Also, an enhancement of the MAE is defined as producing a MAE of longer duration than the MAE for the condition where attention is directed to both components equally.

According to Derrington et al. (2004) it is generally agreed upon in the motion perception literature that the visual system uses motion sensors and feature tracking to derive information about moving objects. It is also generally accepted that they might be part of more complex motion detection models that derives information about moving objects through other methods as well.

Integrating Motion Models

The idea that there is more than one method used by the visual system for motion perception has become increasingly popular in the literature. The models of motion perception often combine different mechanisms of motion analysis.

Seiffert and Cavanagh (1999) argued that a motion sensor paired with a feature tracking system is sufficient to analyze the motion of simple and complex stimuli such as the spatial modulation of contrast (a type of second-order motion).

Wilson, Ferrera and Yo, (1992) and Solomon and Sperling (1994) proposed that one additional step is required before the motion signals reach the motion sensor in order to render second-order motion sensible to the motion sensor. After rectification, for instance by squaring, the second-order motion can be detected by the motion sensors described in the previous section (Nishida & Sato, 1995).

Smith (1994) proposed three systems of motion analysis. An intensity-based system that analyzes first-order motion only, an intensity-based system in which a nonlinear transform step is added to the first-order motion to transform the luminance profile to one of second-order motion, and a type of feature tracking system that could analyze both, first and second-order motion (Smith, 1994). The intensity systems referred to by Smith are modeled using the motion sensors.

Lu and Sperling (1995, 1996) proposed a model of motion perception that integrates different motion detector mechanisms. Lu and Sperling's (1995) model of motion perception suggests that three motion systems co-exist and that five computations for motion direction discrimination occur. Monocular mechanisms of motion detection detect first- and second-order motion for the right and left eye separately (these are the motion sensors). However, there is a 10 % cross over from the left and right eyes in these almost monocular systems. There is a motion-energy sensor for the analysis of first-order motion coming from the right eye and a motion-energy sensor for the analysis of first-order motion of the left eye. Also, there is a motion-energy sensor for the analysis of second-order motion coming from the right eye and a motion-energy sensor for the analysis of second-order motion from the left eye. A texture grabber is a spatial filter that rectifies the full-wave of the second-order stimulus by taking the absolute value of each point's difference from the mean. For the processing of second-order motion a texture grabber rectifies the motion information before the input is passed through the motion-energy detector. The information extracted by these four motion-energy sensors is summed. The information is then sent to 1) a third-order system, which is a feature weighting mechanism ruled by a saliency map and 2) directly to further processing and cognitive processing. The saliency map is "a neural representation of the visual space in which the locations of important features are marked" (Lu & Sperling, 1996). In Lu and

Sperling's model (1995) selective attention is a top-down process that is generated at the cognitive level and which sends feedback to the feature weighting level of the third-order motion processing only. The third-order motion detection system is slower than the first- and the second-order motion detection systems, is binocular instead of monocular. Unlike the first- and second-order motion detection systems, the third-order system is able to compute all types of motions. However due to longer time needed to process moving information, we need the first- and the second-order motion systems.

The literature about the processing of motion by the visual system has not yet clearly defined the different steps involved and the order of these steps. However, it is clear that at an early level first- and second-order motion are either not processed by the same mechanism or second-order motion need some rectification before to be detected by the same mechanism as first-order motion because psychophysical experiments have demonstrated different results for first- and second-order motions. Therefore, in this thesis, the difference in attention modulation for first- and second-order motion was investigated. This can give information about how attention acts within the visual system in order to produce its modulatory effect on motion processing. The study of the interaction between the different stages of motion processing is highly relevant to understanding motion processing (Watanabe & Miyauchi, 1998, p. 95).

The Motion Aftereffect as a Tool to Study Motion Processing

There are many psychophysical tools used to make inferences about the processing of motion by our brain. A useful one is a psychophysical phenomenon called the motion aftereffect (MAE) (Derrington et al., 2004; Verstraten, Fredericksen, van

Wezel, Lankheet & van de Grind, 1996; Wade & Verstraten, 1998). The MAE consists of the appearance of motion in a stationary stimulus or an ambiguously moving stimulus after a prolonged adaptation to a moving stimulus. The stationary stimulus or the ambiguously moving stimulus subsequently appears to move in the direction opposite to the motion of the adapting stimulus (Wade & Verstraten, 1998; Wohlgemuth, 1911). This illusion of motion is used as an indication that the brain baseline processing has been altered by the motion information (Sutherland, 1961).

The perception of motion in a stationary stimulus following staring at a moving stimulus was documented as early as Aristotle (ca 330BC) (Wade & Verstraten, 1998). However, Aristotle omitted to describe the direction of the apparent motion. In the early part of the 19th century, Purkinje and Addams independently described the MAE in detail for the first time, indicating its direction (Wade & Verstraten, 1998). At that time, Addams called the MAE the waterfall illusion because he experienced the illusion while looking at a still rock after having adapted to the motion of a waterfall. The physically stationary rock appeared to be moving in the direction opposite to the waterfall motion (Wade, 1994). Today, the term MAE is used because many types of moving stimuli other than a waterfall are known to produce this illusion.

When using the MAE as a tool to investigate motion perception, the experimental procedure requires two phases. In the first phase, called adaptation, a participant is exposed for an extended period of time to a moving stimulus. In the second phase, called test, a static stimulus or a dynamic stimulus is presented. It is during the second phase that the measurement of the MAE occurs. When a dynamic test is used, the test stimulus could consist of randomly moving dots (Blake & Hiris, 1993), pattern-less sinusoidal flicker (Green, Chilcoat & Stromeyer, 1983), or counterphase luminance gratings (von Grünau et al., 1998). A MAE measured with an ambiguously moving test is called a dynamic MAE while a MAE measured with a static test is called a static or classic MAE.

Over the years, several methods for measuring the MAE have been used. The most common and the oldest method is a measure of the duration of the effect. The participant is asked to record the time during which the illusory motion is perceived in the direction opposite to the adaptation direction. Recording the duration is the simplest method for measuring the MAE. In the literature, the matching method and the nulling method are also used to measure the MAE. The matching method involves asking the participants to match the direction and the speed of the perceived MAE with a real motion (e.g. Hiris & Blake 1993). The nulling method involves asking the participants to cancel out the perceived MAE motion using a real motion in the opposite direction to the perceived motion during the test (e.g. Ledgeway 1994; von Grünau & Dubé, 1992). A critique of the matching and nulling methods is that real motion does not possess the same characteristics as apparent motion. For instance, it has been demonstrated that contrary to real motion, features of apparent motion cannot be tracked although they seem to drift (Pantle, 1998, p. 28). Thus when using these methods to measure the MAE the researcher might be misled by the different nature of the two stimuli. For this reason, the method of duration remains the simplest, most straightforward and the most used method to measure the MAE although it is sometimes difficult to determine when the MAE ends (Wade & Verstraten, 1998, p.19).

Several models have been proposed to explain the neuronal mechanism of the MAE. The ratio-model is one of the oldest models. Sutherland (1961) proposed that neuronal fatigue due to prolonged adaptation to the luminance contrast of the moving stimulus occurred in the neurons that responded to the orientation and the direction of a moving stimulus. This neuronal fatigue causes these neurons to fire less compared to the neurons responding to motion in the opposite direction. When the stimulus becomes stationary, the spontaneous activity of the neurons responding to motion in the opposite direction is stronger than the spontaneous firing of the fatigued neurons. This imbalance causes the perception of motion in the direction opposite to the adapted direction. Sutherland's hypothesis is supported by the findings that there are cells in the primary visual cortex of the cat and rabbits that respond selectively to orientation and direction of motion (Barlow & Hill, 1963a, 1963b, Barlow, Hill, & Levick, 1964; Hubel & Wiesel, 1959, 1962). For instance, Barlow, Hill and Levick (1964) found that in retinal motion selective ganglion cells in the rabbit the firing rate is reduced compared to the baseline after prolonged adaptation with motion in their preferred direction.

It is well documented that adaptation to a luminance-defined moving stimulus produces a MAE using static and dynamic tests (Mukai & Watanabe, 2001; von Grünau & Dubé, 1992; Wohlgemuth, 1911). However, adaptation to a second-order motion stimulus produces no MAE using a static test (Culham, Nishida, Ledgeway, Cavanagh, von Grünau, Kwas, Alais & Raymond, 1998) or produces only a weak MAE (Anstis & Mather, 1985; Derrington & Badcock, 1985; Ledgeway, 1994; Nishida & Sato, 1992). When a dynamic test is used adaptation to a second-order motion produces a reliable MAE (von Grünau, 1986). The difference between the MAE produced with a first- and a second-order stimulus in a static test suggests that the static MAE reflects early motion processing because the motion sensors are not sensitive to motion produced by means other than luminance modulation (Nishida & Sato, 1995). On the other hand, a dynamic test picks up a MAE produced by higher levels in the motion hierarchy (Culham, Verstraten, Ashida & Cavanagh, 2000). Many research findings support Culham et al.'s (2000) hypothesis.

Bertone (1999) proposed the following list of such research findings. For instance, it has been found that 1) the interocular transfer of first-order motion is complete when the dynamic MAE is used (Nishida et al., 1994; von Grünau 2002), but only partially complete when the static MAE is used (Moulden, 1980; Nishida et al., 1994; von Grünau 2002). Adapting to a stimulus with one eye and being tested with the other eye produces a MAE as strong as if tested with the adapted eye with a dynamic test but not with a static test. 2) The test and the adaptation stimulus must be at the same retinal location in order to produce a MAE with static test patterns (Anstis & Gregory, 1965), but the MAE can be produced at other retinal locations than the location of the adaptation when a dynamic test is used (Bertone, 1999; von Grünau & Dubé, 1992). 3) The static MAE is large when the spatial frequency of the adaptation and the test are the same (Cameron, Baker & Buxton, 1992; Georgiades & Harris, 2002; Over, Broerse, Crassini & Lovegrove, 1973). However, with the dynamic MAE the MAE is produced regardless of whether the spatial frequency of the adaptation and the test match or not (Ashida & Osaka, 1994). 4) The velocity of the adapting stimulus affects the magnitude static MAE but not the magnitude of the dynamic MAE (Ashida & Osaka, 1995). All these facts suggest that the adaptation effect picked up by a dynamic test takes place at higher levels of processing within the motion pathway, where binocular signals are dominant (Bertone, 1999; von Grünau 2002) and where the receptive fields are larger (von Grünau 2002; von Grünau & Dubé, 1992).

The MAE is a useful tool to study motion processing in humans because it gives information on the strength of a motion signal and it can be readily and non-invasively used with human observers. The MAE duration increase as the adaptation time increase in a logarithmic function (Kwas, 1999). In this thesis, the dynamic MAE illusion will be used to study the effect of attention on motion processing. The dynamic MAE can serve as a tool to study motion processing at all levels along the motion pathway. The MAE will be paired with another useful psychophysical tool called the plaid to look at the effect of attention on different types of motion.

The Plaid as a Tool to Study Motion Processing

A plaid is a bivectorial stimulus that is composed of two superimposed gratings moving in different directions at the same spatial location (Adelson & Movshon, 1982; Culham et al., 1998, p.109). The two gratings can be transparent and be presented simultaneously or presented in temporal alternation. Whether the plaid is made up of superimposed gratings or fast alternating gratings, the same percepts are experienced while viewing the plaid. The plaid can produce the perception of transparent motion in the direction of the two moving components that form the plaid. The two motions of the gratings can also bind together to produce a unified motion in a third direction. This percept is called coherent motion. This coherent motion can be a smooth and straight motion or it can be perceived as a zig zagging motion.

The plaid is a useful tool to study the interaction between different motion components at the same spatial location. It can be used to study complex motion at higher levels of integration in the motion pathway and to study simple motion at lower levels by directing attention to the motion of different components of a complex motion. The integration of the two motions that form the plaid is believed to be performed at a higher level in the motion pathway while the analysis of each individual motion is believed to be performed at a lower level. Gizzi and Kats (1990) studied how neurons in different areas of the visual system respond to grating versus plaid. They found that neurons in V1 only respond to grating while neurons in MT respond to gratings and plaids.

MAE produced using plaid has been used to study motion perception. After adaptation to either a transparent plaid (Wenderoth, Bray & Johnstone, 1988) or a plaid made up of gratings alternating in time (von Grünau & Dubé, 1992; von Grünau et al., 1998), the stronger resulting MAE is unitary and opposite to the coherent motion of the adaptation motion. This unidirectional MAE opposite to the coherent motion of the adaptation motion occurs independently of whether the participants perceived transparent or coherent motion during the adaptation (Burke & Wenderoth, 1993). These findings suggest that this MAE is created after both individual motions have been integrated instead of being created for both motion components and then combined (Culham et al., 1998). A well working model to predict the direction of the MAE in plaid is the intersection of constraints solution (Adelson and Movshon, 1984). However, using a dynamic test, von Grünau et al. (1998) also found MAEs for the components of a plaid but these MAEs were contingent on having attention directed to a particular component of the plaid during adaptation.

Experiments that have used plaids to produce MAE have influenced the model of MAE. Sutherland's ratio-model of MAE cannot explain the perceived MAE in the direction of the coherent motion of an adapting plaid. Instead, this model predicts that the plaid will produce two MAEs: one in the direction for each motion component that forms the plaid (e.g. Verstraten, Fredericksen & van de Grind, 1994; von Grünau et al., 1998; von Grünau & Dubé, 1992). Mather (1980) introduced the distribution-shift model in order to explain the MAE in the direction of the coherent motion in plaids. Unlike the ratio model, this model states that neurons that do not respond optimally to the motion direction are also included in the computation in order to predict the direction of the MAE. The neurons that respond to all directions of motion in the display and not just those responding to opponent directions are involved in the computation but to different degrees of activation. The strongest MAE is predicted to be in the direction opposite to the weight of all neurons responsible for different directions and orientations. This model is accurate in predicting the MAE in plaids when no attention is preferentially given to one component of the plaid. Sutherland's Ratio-model of motion perception could however be used to explain what happens when attention is involved. Therefore attention could bias which neurons would fire in a given situation (Sohn, 2005) or attention directed to the components of a complex stimulus can isolate the processing of one motion in a complex moving stimulus.

Attention

In the scientific literature, attention has many definitions. van Zomeren and Brouwer (1994) stated that the definition of attention is messy and confusing. For this reason, instead of attempting to provide a vague definition of attention that encompasses many aspects of it, a brief historical overview of the definition of attention will be presented. The description of different types of attention will follow. Finally, the operational definition of attention used in this thesis will be outlined.

Leibniz (who lived between 1646 and 1716) described the phenomena of attention explicitly calling these phenomena by the term "apperception". He stated that apperception is required to become consciously aware of a stimulus. He made a distinction between passive and active "apperception" when he stated that "apperception" could be an act of will or could be captured automatically by an element of nature (van Zomeren & Brouwer, 1994, p.7).

James (1890) first described attention as used today. The definition of attention offered by James is now famous and is cited in most publications about attention (Koski, 1999). James (1890) stated, "Everyone knows what attention is. It is the taking possession by the mind in clear and vivid form of one out of what seem several simultaneous objects or trains of thought. Focalization and concentration of consciousness is of its essence. It implies withdrawal from some things in order to deal better with others" (p.416). In his definition, James acknowledged that attention is responsible for an organism's enhanced ability to respond to its environment and it can be endogenous or exogenous (Mueller & Rabbitt, 1989). He also acknowledged that attention allows an organism to focus on one element of its environment among others (van Zomeren & Brouwer, 1994, p.10). James also stated that attention to one stimulus reduces the salience of other unattended stimuli (Koski, 1999, p.1). The definition of attention proposed by James is rich and involves the concepts of selectivity, intensity, perception and cognition (van Zomeren and Brouwer, 1994, p.10). However, this definition of attention is general and is not easily amenable to scientific research. Researchers have operationally redefined parts of James's definition in order to study attention using the scientific method. These definitions differ depending on the paradigms used in the different studies.

In recent years, attention has been defined metaphorically as an internal spotlight or a zoom lens (Eriksen & Yeh, 1985). Although the spotlight metaphor suggests that attention is an enhancing process, attention has also been described as a suppressive process that serves to reduce the selection of irrelevant stimuli (Deutsch & Deutsch, 1963; Obersteiner, 1879. p. 453).

Among other modern definitions of attention readily amenable to research are sustained attention, focused attention and divided attention. Sustained attention is defined as "any aspect of attention that is characterized by its duration, particularly time-on task effects often using time scales of minutes to hours (van Zomeren & Brouwer, 1994, p.217). An example of sustained attention in a MAE experiment would be to focus on a moving component of a plaid for a prolonged period of time during adaptation.

Focused attention "refers to a situation where reacting to only one source of stimulation is required, usually in the presence of distraction" (van Zomeren & Brouwer, 1994, p.216). An example of focused attention in a MAE experiment would be to focus on a moving component of a plaid while ignoring the other components during adaptation.

Divided attention refers to the situation where a subject has to attend to two or more stimuli or sources of stimulation, or to various components within one task (van

Zomeren & Brouwer, 1994, p. 4). An example of divided attention in a MAE experiment would be to present a string of letters at the fixation point while the participant is required to attend to a moving plaid and to indicate when its color changes and to indicate when a vowel is presented at the fixation point.

Attention can represent an active or passive process. When a spatial location is selected by the will of the organism (also referred to as voluntary, endogenous, or as top-down process), it is referred to as active selection. This selection is goal directed. Active selection occurs on the basis of intentions such as when focusing on a detail of a construction (e.g. concentration on one component of a plaid) (van Zomeren & Brouwer, 1994, p.7). Another example is to voluntarily direct attention to an area of the visual field where a target stimulus is most likely to appear (Mueller & Rabbitt, 1989). Passive selection occurs when a spatial location is automatically captured by attention (also referred to as automatic, exogenous, reflexive or as a bottom-up process). Passive selection is driven by external stimuli (van Zomeren & Brouwer, 1994, p.7). For example, Passive selection occurs when attention shifts automatically to a component of a transparent plaid that is not cued. In this situation, attention is captured automatically by one of the components of the stimulus. Passive and active selections are two distinct ways in which selection of motion occurs (Cowan, 1997, p. 4). The locus of attention and the central fixation are not necessarily associated. One can move the locus of attention while keeping fixation at the same area of a display (Chaudhuri, 1990; Eriksen & Hoffman, 1972; Eriksen & Yeh, 1985).

The different types of attention and ways to select a stimulus could take place at different levels along the motion pathway (e.g. Lu & Sperling, 1995; Watanabe &

Miyauchi, 1998) and can affect different types of motion in different ways (e.g. von Grünau et al. 1998; von Grünau & Faubert, 1998). It is impossible to study all the aspects of attention within one thesis. In this thesis, the focus will be on the effect of active selection in task requiring sustained and focused attention. In the experiments presented in this thesis, the participants were required to voluntarily focus their attention to one component of a moving plaid for several seconds while ignoring the other component of the plaid. The plaids were formed using combinations of different types of motion (first- and second-order motion). The effects of these attention manipulations on motion processing will be studied using the MAE illusion.

It has been well documented in the literature that: 1) Motion is a salient stimulus that attracts attention. Royden et al. (2001) used the visual search paradigm to show that a moving stimulus embedded within stationary stimuli is found faster than to find a stationary stimulus within moving distractors. 2) Attention increases motion processing when it is directed to a moving stimulus (Sohn, 2005; von Grünau et al. 1998). 3) Attention biases the direction of a perceived motion (Cavanagh, 1992; Lankheet & Verstraten, 1995; von Grünau, Racette & Kwas, 1996; Watanabe & Miyauchi, 1998). For instance, Cavanagh (1992) demonstrated that attention could determine the direction of a perceived motion and its subsequent MAE. He presented two opposite motions within an annulus at the same spatial location. One motion was defined by isoluminant color modulation and the other motion was defined by luminance modulation. He asked the participant to either track the motion of either the color or the luminance component. He found that directing attention to one motion component biased the perception of the overall motion of the annulus in that direction. Using the line motion illusion, von

Grünau et al. (1996) found that directing attention using a prime at one end of a bar presented a few milliseconds later produced an illusion of motion starting from the prime and moving along the bar. The illusion of motion will move left to right if the prime is presented to the left and right to left if the prime is presented to the right. 4) Attention directed away from a moving adaptation stimulus decreases the MAE (Chaudhuri, 1990; Georgiades & Harris, 2000, 2002; Rees, et al. 1997; Rezec et al. 2004; Shulman, 1991, 1993; Takeuchi & Kita, 1994).

Attention and MAE

Wohlgemuth (1911) wrote the first account of the effect of attention on the MAE. He studied the characteristics of the MAE for his doctoral thesis. His participants were asked to perform mental arithmetic and to repeat nouns presented at fixation while they were adapting to a moving stimulus. Wohlgemuth tested the effect of those demands on the MAE and concluded that attention had no effect on the MAE. Many contemporary research studies, using a similar distractor design with more modern methodologies and technologies, proved Wolhlgemuth's conclusion to be wrong (e.g. Chaudhuri; 1990, Georgiades & Harris, 2000; 2002; Rees, Frith & Lavie, 1997; Rezec, Krekelberg & Dobkins, 2004; Shulman 1991, 1993; Sohn, 2005; Takeuchi & Kita, 1994).

Recent studies have shown that: 1) Allocating attention away from a moving adapting stimulus reduces the subsequent MAE. For instance, Chaudhuri (1990) directed the attention of his participants away from the adaptation stimulus by asking them to perform an attention-demanding task at a central fixation while they adapted to a moving textured background. The participants were required to either passively fixate the alphanumeric stimuli (passive condition) or to attend actively to the alphanumeric stimuli and to indicate when a number was presented (attention condition). Chaudhuri showed that the MAE in the active attention condition was reduced as compared to the MAE in the passive condition. Chaudhuri (1990) also showed that directing attention to an aspect of the moving adapting stimulus, not involving motion, did not reduce the size of the MAE. When he asked his participants to attend to the changing color of the textured background and to indicate when the textured background changed color, the MAE remained as strong as when they attended passively to the adapting moving stimulus. Chaudhuri (1990) interpreted this result as indicating that attention directed to a property other than motion that does not involve motion does not affect the population of neurons responsible for motion.

2) Attention has a graded effect on the MAE. For instance, Rees et al. (1997) manipulated the degree of attentional demands in a distractor task and showed that these manipulations influence the production of MAE in accordance with the degree of attention demanded. The participants adapted to an expanding field of dots while processing words presented within a blank ellipse at fixation. The participants performed either a low-load attention task or a high-load attention task presented within the fixation ellipse. During the low-load attention task, words made up of either lower-case letters or upper-case letters were presented successively and the participants were asked to indicate when an upper-case letter word was present. During the high-load attentional task, words were presented successively and the participants were asked to indicate when a two-syllable word was present. Rees et al. (1997) found that both conditions reduced the MAE but that performing the high-load attention task during adaptation reduced the

MAE more than performing the low-load attention task. This study suggests that as the distracting task demand increases the MAE strength decreases.

3) Different types of attention (ex. active versus passive) have different effects on motion processing. Georgiades and Harris (2000) demonstrated that exogenous (passive attention) as well as endogenous (active attention) selection could modulate the MAE differently. They presented their participants with a moving grating. At the same time, participants were presented with a series of letters or a stationary display containing a zero at fixation. Participants had to either identify the different letters or they fixated passively at the changing characters or the stationary zero. The experimenters argue that the difference between the condition in which the participants viewed changing letters and produced a response and the condition in which the participants passively viewed changing letters and did not produce a response reflects a difference in endogenous selection demands. The condition in which the participants viewed passively a changing letter compared to the condition in which they passively viewed an unchanging zero reflects a difference in exogenous selection demands. They measured the duration of the MAE and compared the effect of endogenous selection and exogenous selection demands. They found that increased endogenous demands reduced the MAE, duration for low as well as high spatial frequencies. However, increased exogenous demands reduced the duration of the MAE for a low spatial frequency stimulus but not for a high spatial frequency stimulus. This study suggests that there is an interaction between the characteristics of the adapting moving stimulus and the different kinds of selection (active vs. passive) on the MAE.

4) Attention can bias the direction of the MAE. Shulman (1993) showed that when two unambiguously moving stimuli that rotate in opposite directions are presented during adaptation and the participants have to attend to only one of the moving components of the adapting stimulus, the direction of the perceived MAE in a subsequent ambiguous test was in the direction opposite to the attended stimulus during adaptation. He showed that attending to the component moving in the opposite direction reverse the sign of the MAE.

5) Attention can generate a MAE for a component of a moving complex stimulus that would otherwise not be present. Attention directed to a moving component of a complex stimulus produces a MAE in a dynamic test in the direction opposite to the direction of the motion of the component (Chaudhuri, 1990; Sohn, 2005; von Grünau et al. 1998).

As is clear from the above review, the MAE has been used extensively to study the effect of attention on motion processing. All modern MAE studies are in agreement with the fact that attention is an important factor in the processing of motion.

Rationale for the Present Experiments

The purpose of the experiments of this thesis is to study the effect of allocating and withdrawing attention on different types of motion (first- and second-order motion) stimuli. The goal is to better understand the locus of action of active selection, a type of attention, within the motion pathway and the effect of withdrawing active selection of a component of a complex moving stimulus.

In the literature, it is unclear what happens to a stimulus that is present in the same visual field as an attended stimulus but to which attention is not selectively drawn. Stimuli not selected by attention could either remain unprocessed, be processed with less efficiency or processing of these stimuli could be actively suppressed. Reviews of the literature on attention have looked at the evidence for the processing of stimuli outside the "window of attention" (Fox, 1994; Johnston & Dark, 1986; Kinchla, 1992;). According to Fox (1994) some researchers argue that there is an active inhibition of the unattended component (e.g. Miller, 1991; Tipper & Cranston, 1985). However, other researchers argue that unselected stimuli are unprocessed and/or their processing fades over time (Johnston & Dark, 1982). Many MAE studies have demonstrated that directing attention away from an adapting moving stimulus reduced the processing of this stimulus but these studies did not inform us on the nature of this reduction of processing (e.g. Chaudhuri, 1990; Georgiades & Harris, 2000; 2002; Lankheet & Verstraten, 1995; Rees, Frith & Lavie, 1997; Rezec, Krekelberg & Dobkins, 2004; Shulman 1991, 1993; Sohn, 2005; Takeuchi & Kita, 1994). For instance, Lankheet & Verstraten (1995) presented two superimposed sheets of dots moving in opposite directions as the adaptation stimulus and asked the participants to attend to only one sheets of dots during adaptation or to the overall motion of the two sheets of dots. They showed that attending to one field of dots when two fields of dots were presented in the same spatial location, produced a MAE opposite to the direction of the attended field of dots. When attention was allocated to the overall motion instead of one field of dots, the MAE was cancelled out. This study shows that attention can modulate the direction of the MAE and that directing attention to an ambiguous motion made up of two motions does not produce a MAE. This experiment, however, does not inform us about the effect of attention on the unattended stimulus because the MAE is cancelled out when attention is not allocated to a specific field of dots. Furthermore, in this study, each field of dots was differentiated by a color. Therefore, the participants were not instructed to attend strictly to a motion but to a motion and a color.

In the literature, it is also not clear at which level along the motion pathway attention influences the processing of motion. Some researchers state that visual attention exerts its effect only at higher levels in the motion pathway (Cullham et al., 2000; Lu & Sperling, 1995, 1996; Sperling & Lu, 1998; Treisman & Gelade, 1980). However, other research has demonstrated that even at early stages in the motion pathway, attention has an effect on motion processing (Watanabe & Miyauchi, 1998, p. 97).

For example, Culham et al. (2000) used static and dynamic tests to study the effect of attention along the motion pathway. Culham, et al. used radial counterphase flickered stimuli in which motion energy was equal in clockwise and counter clockwise directions. This stimulus produced an ambiguous motion that can be disambiguated by attentionally tracking one of the components. They found that attentionally tracking one component produces a MAE in the direction opposite to the tracked motion with a dynamic test but not with a static test. They suggested that this difference between static and dynamic testing of the MAE indicates that attentive tracking acts at a higher stage in the hierarchy such as in MST or even higher.

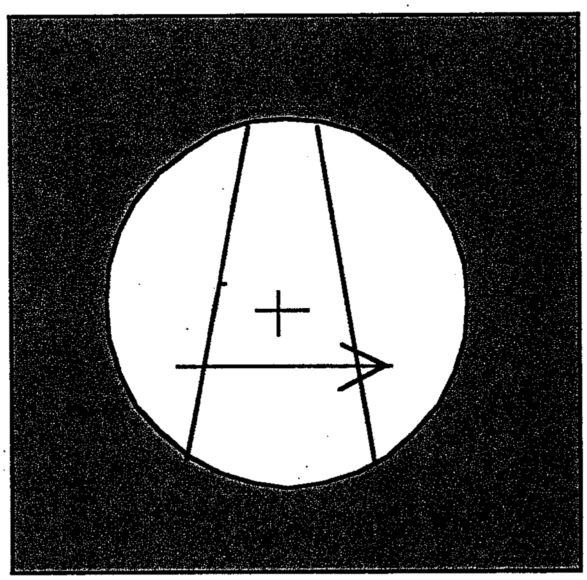


Figure 1. Reproduction of the stimulus used in Watanabe and Miyauchi study based on the stimulus illustrated in their article in order to facilitate the description of the method used in their study (Watanabe & Miyauchi, 1998, p. 99).

The following study, however, suggests that attention might influence the perception of motion early in the motion pathway. Using the MAE paradigm, Watanabe and Miyauchi (1998) used the stimulus reproduced in Figure 1 to demonstrate that attending to a contour of a wedge stimulus biases the direction of the perceived motion and the direction of the subsequent MAE (p.100). The participants were asked to fixate at a fixation point in the center of the display. They were also asked to pay attention to a) the right side of the wedge which was tilted + 45 degrees b) the left side of the wedge which was tilted - 45 degrees c) to the display in general. When attention was directed to the whole display, the participants reported perceiving a horizontal motion toward the right, in the direction of the integrated motion. When attention was directed to the left wedge of this stimulus, tilted - 45 degrees from the vertical, the stimulus appeared to move downward. When attention was directed to the right wedge of this stimulus, tilted + 45 degrees from the vertical, the stimulus appeared to move upward (p. 98). In their experiment, the MAE was always opposite to the attended motion direction during adaptation. Local motions of luminance contrast, such as when participants attended to a wedge of this stimulus are known to be processed at a low level in the motion pathway (Adelson & Bergen, 1985). The motions of complex stimuli formed by a combination of two motion directions are known to be processed higher in the motion pathway (Watanabe & Miyauchi, 1998). This finding indicates that in the absence of attention being directed specifically to one particular component of a complex stimulus, the integrated motion of a complex moving stimulus is processed preferentially as compared to the non-attended motion component of the same stimulus. However, attention directed to a simple motion of a complex stimulus can isolate that motion and affect the MAE, showing the processing of that simple motion.

Other studies seem to show that the MAE produced for the integrated motion of a moving plaid might not be as strongly dependent on manipulation of attention as the MAE produced for one component of a complex stimulus. Del Vecchio and von Grünau (2002) used a transparent plaid and measured the MAE using a test in the orientation of the coherent motion of the plaid after the participants adapted to only one moving component of the plaid or to both components of the plaid. Transparent plaids permit this dissociation because they are plaids in which the participant perceive two motion directions, each one in a direction perpendicular to the orientation of one of the two components that form the plaid (Stoner & Albright, 1992; Stoner, Albright & Ramachandran, 1990). Whether attention was directed to the overall motion of the plaid or to the motion of only one component during adaptation, a strong MAE in the direction opposite to the overall motion was produced (Del Vecchio & von Grünau, 2002). However, the MAE in the direction opposite to a component of the complex stimulus was only produced when attention was directed to that component during adaptation (Del Vecchio & von Grünau, 2002; von Grünau et al. 1998). This finding suggests that the MAE produced for the overall motion of a plaid might not be as strongly dependent on attention as the MAE produced for one component of a complex stimulus.

The studies that directly lead to the hypotheses of this thesis are elaborated below. These studies have investigated what happens to an unattended moving component in terms of motion processing and the locus of action of attention for that component. For instance, von Grünau et al. (1998) used a plaid made up of two first-order square-wave gratings to show that the motion processing of an unattended component of a plaid is suppressed. One of the gratings was moving – 20 degrees from the vertical and the other grating was moving + 20 degrees from the vertical. They asked the participants to attend to one of the gratings during adaptation or to attend to the whole display. They measured the subsequent MAE in the orientation of the attended component or in the orientation of the unattended component. They demonstrated that attention can be directed to a component of a plaid even when the two components are at the same spatial location. These results are in accordance with other previous results (e.g. Culham et al. 1992; Lankheet and Verstraten, 1995). They also showed that directing attention to one component of a plaid increased the MAE for that component while suppressing the MAE for the non-attended component. Since the two motions were defined by luminance changes over time in this study, they are likely to be processed early in the visual pathway (V1) and (early MT) where simple motion is processed. They concluded that: 1) Allocating attention to one component of a complex moving stimulus weakens processing of the other moving component in the same visual field and 2) attention can modulate the processing of simple motions believed to be processed at low levels within the motion pathway. This experiment was performed using two first-order motion components. In order to understand the possible interaction between motions believed to be processed at different stages along the motion pathway, the next logical step was to redo this study using heterogeneous plaids made up of a first- and a second-order motion component. The study of the differential effect of attention on different types of motion and their interactions is highly relevant to understanding motion processing because it can help determine where attention exerts its effects in the visual system in order to modulate motion processing.

In a pilot study, von Grünau and Faubert (1998), studied the effect of attention on first- and second-order motion using the same methodology as that used in von Grünau et al. (1998). Their second-order motion stimulus consisted of a modulation of texture over time. They used a plaid made-up of two sine-wave gratings. One grating was made-up of a first-order motion and the second grating was made-up of a second-order motion. They asked the participants to attend to one of the gratings during adaptation or to attend to the whole display. They measured the subsequent MAE using test stimuli in the orientation of the attended component or in the orientation of the unattended component. As in von Grünau, et al. (1998) they found that attending to one component of a plaid increased the MAE for that component. However, they found no suppressive effect on the MAE when the test stimulus had the same orientation as the non-attended component of the adaptation plaid. They concluded that the interaction between first- and second-order motions may not be of the same nature as the interaction between two first-order components. Therefore, they stated that their experiment gives more evidence for separate processing for first- and second-order motion. One problem with this conclusion is that their lack of a suppressive effect is based on a failure to reject a null hypothesis. Therefore a lack of power could have accounted for failure to observe a suppressive effect. In fact, only three subjects participated in this experiment, and two of them were the experimenters who where aware of the purpose of the study. Also, it is not clear if the interaction between first- and second-order motions did not permit the suppressive effect or whether the nature of the second-order motion affected the results.

In this thesis, the effect of attention on motion perception will be investigated using first- and second-order motion and the MAE. Two questions will be addressed: 1) what happens to the processing of a moving stimulus that is in the visual field but that is not selected by attention? 2) At which level along the motion pathway does attention exert its effect in order to influence the processing of motion? The problems and concerns discussed earlier about the previous experiments will be corrected.

Based on the literature just reviewed, It has been hypothesized that: 1) Attention directed to one component of a plaid will increase the MAE for a test of the same orientation. This will be true for homogeneous plaids made-up of two first-order motion components, two second-order motion components and for heterogeneous plaids made-up of a first- and a second-order motion component. 2) A test of the orientation as the unattended component will reveal a suppression of the MAE in homogeneous plaids made-up of two first-order motions (von Grünau et al., 1998) but not in heterogeneous plaids made-up of a first- and a second-order motion (von Grünau & Faubert, 1998). 3) It is unclear whether homogeneous plaids made-up of two second-order motions will produce a suppression when the test is oriented in the orientation of the unattended component due to a lack of previous literature.

The aim of this study is to expand on the work of von Grünau and Faubert (1998). It is tried to develop a better understanding of how different types of motions are influenced by attention and to make inferences about where attention modulates motion processing along the motion pathway.

Experiment 1: Preliminary Experiment

von Grünau et al. (1998) used first-order homogeneous plaids to show that it is possible to influence the direction of attention using overt instructions and that active selection of one component of a complex moving stimulus, such as a plaid, enhances the duration of the MAE for that attended component as compared to when no attention manipulation is present. They also showed that the MAE for the unattended component of the plaid is reduced as compared to the condition in which there is no manipulation of attention, they observed a suppressive effect. The dependence of MAE on the allocation of attention indicates that attention influences the processing of motion by the brain.

von Grünau and Faubert (1998) used heterogeneous plaids made-up of first- and second-order gratings to investigate the effect of selective attention. They directed participants' attention to or away from a component grating and measured the resulting MAE. They found that with a heterogeneous plaid, as with a homogeneous plaid made up of two first-order components (von Grünau et al. 1998), the MAE was enhanced for the plaid component that was attended during adaptation. However, contrary to the suppressive effect found in the study of von Grünau et al. (1998), von Grünau and Faubert (1998) found no suppressive effects of withdrawing of attention from a plaid component for heterogeneous plaids. They hypothesized that the difference in the suppressive effect of active withdrawal of attention in heterogeneous and homogeneous plaids might be an indication that first- and second-order motions are processed at different levels along the motion pathway.

von Grünau and Faubert's (1998) conclusion is in agreement with previous psychophysical studies (Edward & Badcock, 1995; Ledgeway & Smith, 1994; Scott-

Samuel & Georgeson, 1999; Scott-Samuel & Smith, 2000; Smith & Ledgeway, 1997), physiological studies (Zhou & Baker, 1993), functional imaging studies (Smith, Greenlee, Singh, Kraemer & Henning, 1998) and neuropsychological studies (Greenlee & Smith, 1997; Vaina, Makris, Kennedy & Cowey, 1998). All these studies suggest that the mechanisms that process first- and second-order motion are different. However, by comparing the results of von Grünau et al. (1998) and von Grünau and Faubert (1998), it is difficult to arrive at a clear conclusion about the differential suppressive effect in homogeneous and heterogeneous plaids. First, many other variables could account for the difference between these two studies in the suppressive effect. Second, statistical analysis of the difference cannot be investigated because the results come from two distinct studies. Furthermore, it is important to keep in mind that the von Grünau and Faubert study had only 3 participants, which included the two investigators. It might be a lack of statistical power that accounted for the different results of von Grünau et al. (1998) and von Grünau and Faubert (1998).

In the present study, it was attempted to replicate the results of von Grünau et al. (1998) and of von Grünau and Faubert (1998) within one study. It was intended to understand if it is the nature of the second-order component or if it is the interaction between the first- and the second-order components that did not permit the suppressive effect in von Grünau and Faubert (1998). The effect of selective attention on the MAE duration after adaptation to plaids made up of 1) two first-order gratings, 2) two second-order gratings, and 3) a mixture of first-order and second-order gratings was investigated.

Method

Participants

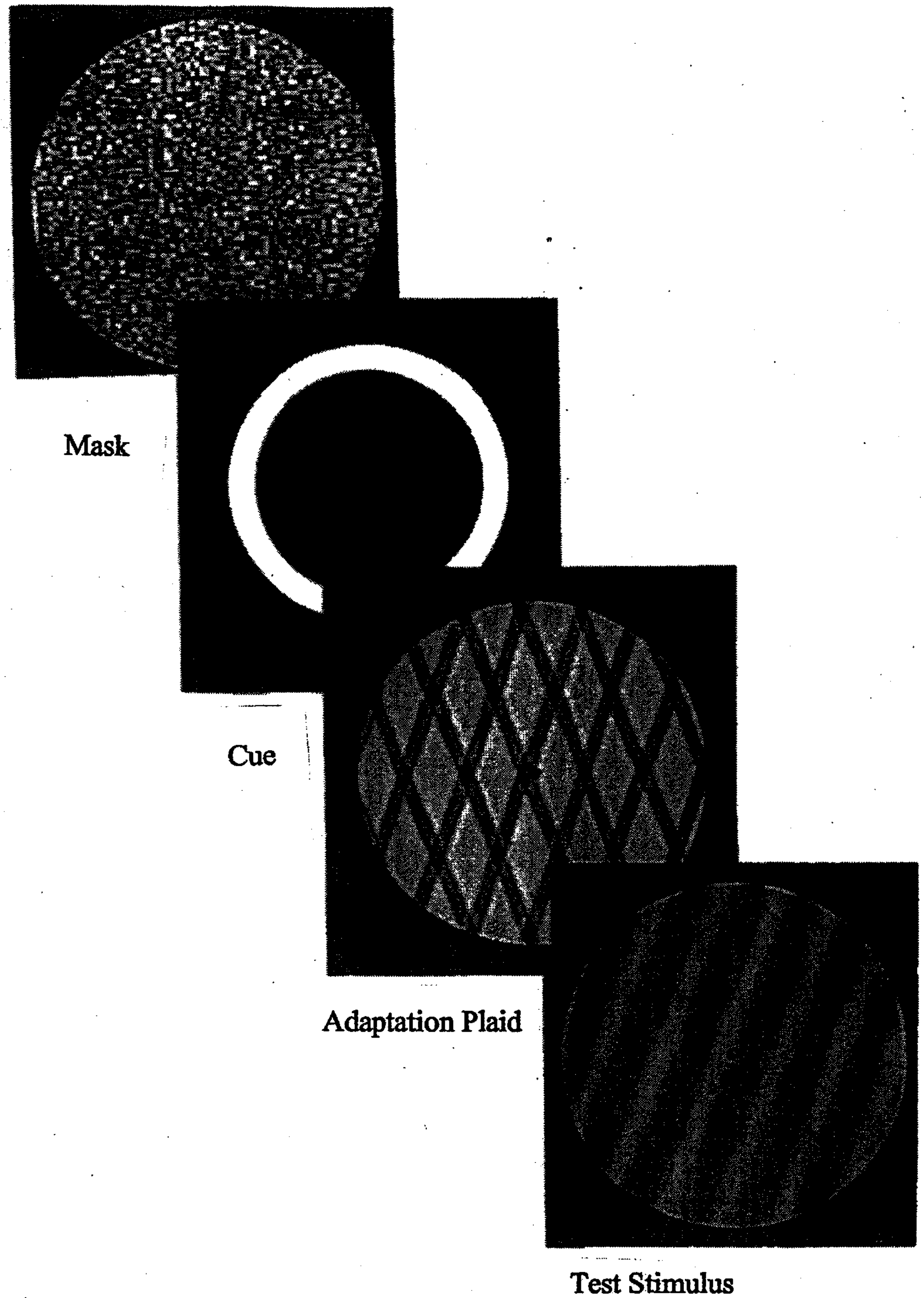
Five psychophysically experienced observers (4 females and 1 male) participated in all the conditions of the experiment. Four participants were right-handed and one was left-handed. The ages of the participants ranged between 22-56. Three participants were naïve as to the purpose of the experiment. Two participants were not naïve as to the purpose of the experiment since they were the experimenter and the supervisor. All participants were required to have normal or corrected-to-normal vision. Informed consent was obtained prior to the participation in the experiment.

Apparatus and Materials

The stimuli were presented on a Power Macintosh 7300/180 computer. The VPixx 1.4 program developed by Peter April (http://www.vpixx.com/) was used to create and present the stimuli. The stimuli were displayed on 17-inch studio Apple monitor with a refresh rate of 75 Hz. The screen resolution was 800 x 600 pixels. The color depth was set at 256 levels. A chin rest was used to stabilize the participant's head position during testing. Color calibration and luminance readings were taken using a Minolta CS-100 Chroma Meter. A 25 watt light bulb in a funnel type lamp was used to dimly light up the testing room during testing.

Stimuli

Mask. A mask consisting of a black and white dynamic checkerboard pattern was used between each trial to prevent earlier stimuli from influencing the outcome of subsequent stimuli. The mask was presented for 160 frames or 1.68 seconds (Figure 2).



<u>Figure 2</u>. Sequence of events presented within a trial. For the purpose of this illustration, the picture of the plaid presents both gratings simultaneously. In the experiment, the two gratings were presented in alternation as described in the text. Therefore at the intersection of the two gratings no dark areas were physically present.

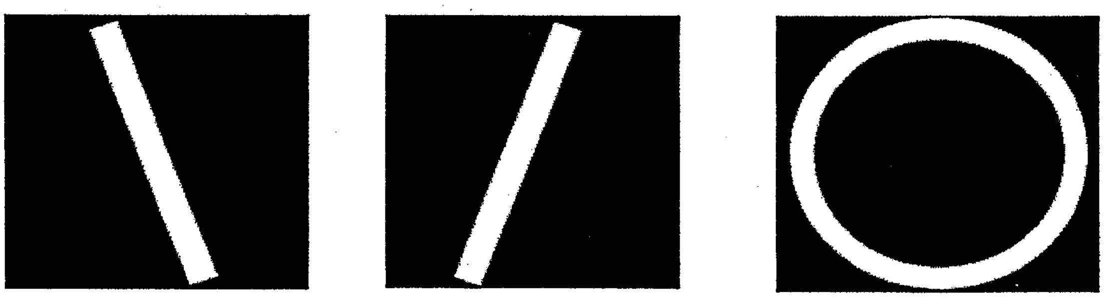


Figure 3. Cues indicating the plaid component to which attention should be directed. The white bar titled to the left and to the right indicated to attend to the grating component moving to the left and to the right respectively. The circle indicated that both components should be attended equally.

Cue. A cue indicated the plaid component to which attention should be directed. The cue consisted of either a white bar oriented 20 deg from the vertical, a white bar oriented -20 deg from the vertical or a white circle. The bar tilted 20 deg from the vertical, indicated to attend to the grating component oriented 20 deg from the vertical and moving to the right. The bar tilted -20 deg from the vertical indicated to attend to the grating component oriented -20 degree from the vertical and moving to the left. The circle indicated to attend to both components of the adaptation plaid equally (Figure 3).

Adaptation Plaids. The adaptation plaid stimuli consisted of two spatially superimposed but temporally alternating square-wave gratings that were moving in directions differing by 140 deg in motion direction. The duty cycle of the gratings was 0.75. The plaids consisted of 1) two first-order, luminance-defined, gratings, 2) two second-order, texture-defined gratings or 3) a mixture of one first-order and one second-order grating. The spatial frequency of the gratings was 0.5 cycles per degree and their temporal frequency was 7.52 cycles/sec. One temporal cycle for each grating consisted of 5 static presentations of the grating shifted each time by 1/5 of a cycle. The component gratings were temporally interleaved every frame. Each frame lasted 13.3 msec since the computer was set at 75Hz. There was no luminance difference at the intersections of the two gratings because they were not temporally presented together.

The luminance was 12.4 cd/m^2 for the second-order grating. The luminance of the first-order dark bars varied from participant to participant according to the contrast yielding the 50% threshold between the first- and the second-order component. This threshold was determined using the counterphase grating method that included noise elements in the first-order component. This method is described in Appendix A. The adaptation stimuli were presented within a circular aperture of 12 degrees of visual angle.

Second-order stimulus. The second-order stimulus used to make the plaid was a contrast-defined noise square-wave grating. The grating had a spatial frequency of .5 cycles/degree. The equation that defined the luminance profile at each point on the x and y axes was:

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

This formula is adapted from Bertone (1999). L_{mean}, the mean luminance of the display, is 12.4 cd/m^2. m_{env} is the modulation depth of the envelope. f is the spatial frequency of the envelope. m_{car} is the contrast of the carrier. R(x, y) is the carrier made of static noise of 1 pixel * 1 pixel, measuring approximately 2.24 arc min. The grayish colored, static carrier was formed using a squared modulation. The luminance of each dot was assigned as a function of (x), where the luminance of x ranged from 0 to 1. Fixed noise elements (the carrier) were multiplied with the square-wave grating (the envelope) in order to form the second-order stimulus. The amplitude of the modulating grating was .5. The symmetry of the wave was .5. The second-order grating was oriented either 20 or -20 degrees away from a vertical and the temporal frequency of the motion was 7.52 cycles/sec. One temporal cycle of the second-order grating consisted of 5 static presentations of the grating shifted each time by 1/5 of a cycle. The duty cycle of the grating, which describes the relative width of the positive and negative lobes of the cycle, was .75 (Figure 4).

First-order stimulus. The first-order stimulus used to make the plaid was a luminance-modulated square-wave grating. The spatial frequency and symmetry of the first-order stimulus were identical to those of the second-order stimulus. The grating was oriented either 20 or -20 degrees away from the vertical and the temporal frequency of the motion was 7.7 cycles/sec. The temporal cycles of the first-order grating, as well as its duty cycle, were identical to those of the second-order grating. A uniform sheet of static noise was added (Figure 4). The luminance contrasts of the first-order stimulus were set for each participant using the counterphase method with noise added and with the same characteristics as the one of the second-order motion.

MAE Test. The test stimuli consisted of a flickering grating made up of two identical counter-phase gratings moving in opposite directions. There were two types of test orientation (20 deg and -20 deg). The spatial frequency of the gratings was 0.5 cycles per degree and their drift frequency was 2Hz. The duty cycle of the gratings was 0.5 and the symmetry of the grating was .5. No noise was introduced in this stimulus. The stimuli were presented in a circular aperture of 12 degrees of visual angle.

Procedure

First, the experiment was described verbally to the participant by the experimenter, and a written consent form describing the instructions of the experiment was given to the participant (Appendix B). The participant was asked to read and sign the consent form if he/she agreed to participate in the experiment. The participant was allowed to quit the experiment at any time. Each participant was tested individually. Before the experiment, the contrast of the first-order component was adjusted using the counterphase method with noise (Table A). Before the experiment, the participant stabilized his or her head on the chin and forehead rest placed in front of a monitor and fixated a point in the center of

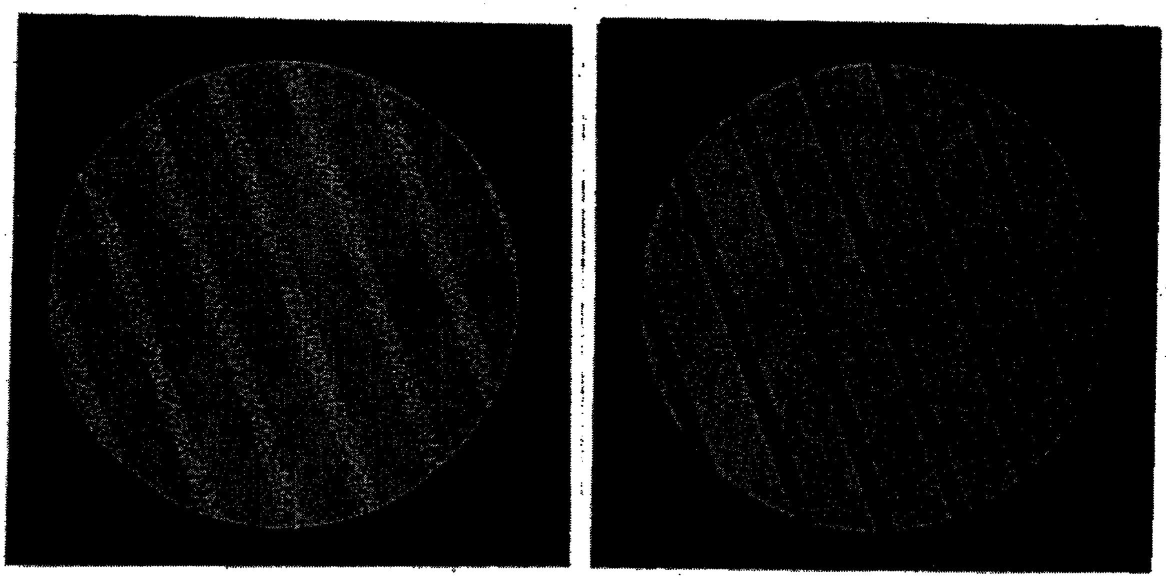


Figure 4. First- and second-order motion square-wave gratings used to form the motion plaids.

the computer screen. The participant was told to maintain fixation during the whole trial. The participant was then ready to begin the experiment.

A trial consisted of the following steps: 1) The participant initiated each trial by pressing the space bar of the computer keyboard when ready. 2) One of three cue stimuli was presented to the participant for a period of 2 sec, indicating which component of the plaid to attend to during adaptation. 3) The adaptation plaids appeared on the computer screen for 20 sec. While the plaid was presented, the participant fixated at the fixation point while trying to attend to the component indicated by the cue stimulus. During adaptation, the participant monitored his/her attention by pressing one of three keys continuously in order to provide a measure of the length of time the participant succeeded in attending to the required component of the plaid. Two keys were used to indicate the components to which the participant attended (z and x keys), and a third was used if coherent motion of the plaid was perceived (c key). Coherent motion of the plaid was defined as having both directions of motion merging together in a motion that went in a straight or zig-zaging path in the downward direction (Adelson & Movshon et al., 1982). 4) A dynamic test stimuli was presented oriented either in the direction of the attended or in the direction of the non-attended component. The participant was required to press one of two keys (left or right arrow keys) to indicate the direction of the perceived motion. The participant could switch keys if the perception of motion changed direction during the test. The participant pressed a third key (0 key) to indicate that the perception of motion had terminated. This allowed the measurement of the duration as well as the direction of the perceived motion.

Table A. Threshold luminance contrast for each participant for the all experiments of this Thesis using the sine-wave counterphase gratings method.

Participant	replications	Luminance Contrast
ap	100	.1174
cv	100	.1349
fx	100	.1368
mvg	75	.1386
nw	50	.1140
os	100	.1375
sb	100	.1359
sm	100	.1510
ss	100	.1179
asd	50	.1472
cp	50	.1722
mi	50	.1758

Note. A higher score indicates a darker first-order.

The participant performed ten trials for each of the four types of plaid. Six stimulus combinations were presented for each plaid, which included two test directions (either in the direction of the attended component or in the direction of the unattended component of the adaptation plaid) and three cues (left, right, neutral). A trial condition lasted approximately 3 minutes. The whole experiment lasted about 2 hours and 40 minutes.

Results and Discussion

Attention

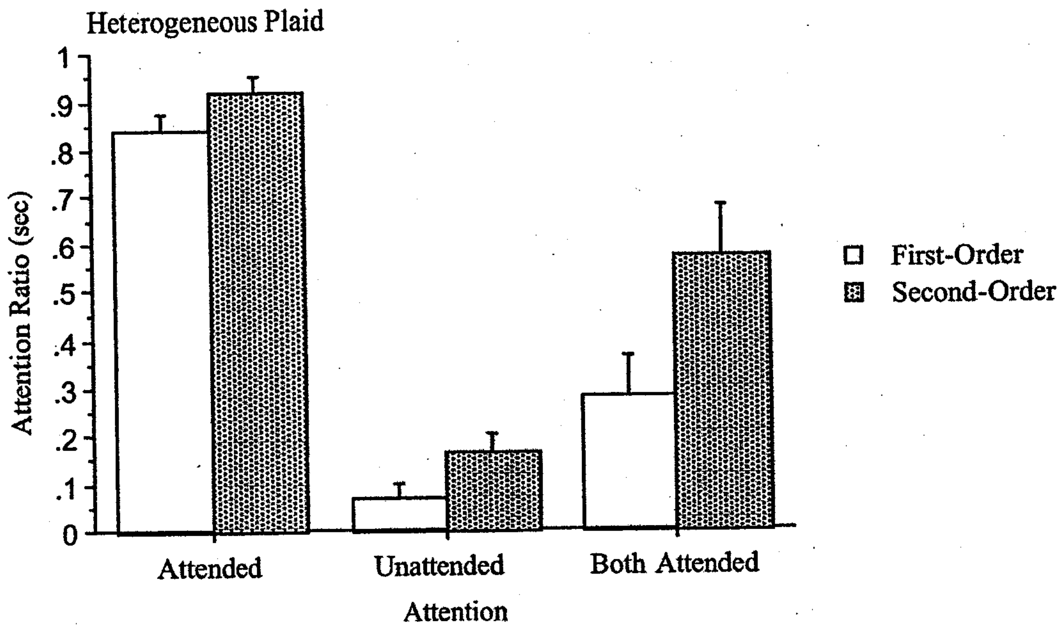
The results of the five participants were included in the group data analysis for attention. The analysis of the attention results was made to ensure that the participants performed the attention task as required. Also, this analysis provided information about the degree of attention of the participants across different types of plaids and different types of attended components.

The raw data for attention consisted of the time in seconds the participant attended to the cued component, the uncued component and to one component of the condition when no component was cued for the adaptation plaid (half the time the right one and half the time the left one). The raw data for attention were transformed into ratios. The ratios consisted of 1) the duration of time (sec) the motion of the cued component was dominant divided by the sum of the durations of time where each component and the coherent motion dominated. 2) The duration of time where the motion of the uncued component was dominant divided by the sum of the durations for the cued, uncued and the coherent motion. 3) For the conditions in which there was no motion direction cued (circle), half of the time the ratios consisted of the amount of time (sec) during which the component moving to the right was dominant over the amount of time the left, the right and the coherent motion were dominant. The other half of the time the ratios consisted of the amount of time (sec) during which the component moving to the left was dominant over the amount of time the left, the right and coherent motion were dominant. For each adaptation plaid, the participants were presented with three attention cues, two types of component and two types of plaid for a total of 12 different stimulus combinations. The means for each participant for the 12 cells were made up of 40 data points.

Each of the five participants underwent four repetitions yielding 20 data points. Due to a mistake while writing the stimulus files, the data of one of the conditions were not recorded into the excel file for each participant, removing a total of 10 data points in the calculation of the mean. This occurred for the condition where a mixture of one second- and one first-order grating was presented and in which the first-order component was moving to the right and the second-order component to the left. In this condition, the participant was required to attend to the grating moving to the right and was tested for MAE duration with a counter phase grating oriented in the same direction as the cued grating. Consequently, since a repeated measures design was used the means for all conditions for each participant were based only on attention to gratings moving to the left.

A three way repeated measures ANOVA was used to analyze the attention results. The three independent variables were 1) type of adaptation plaid (homogeneous or heterogeneous plaid), 2) type of component attended (first- or second-order), 3) attention types (attended component, unattended component, and no attention instruction). The 2 x 2 x 3 repeated-measures analysis of variance indicated a statistically significant main effect for attention $F\ (2,8) = 74.142, p < .0001$. None of the other main effects or interactions were statistically significant (Figure 5). When the attention is switched between both components, it seems that the second-order component is more salient. This is a comparison that could not be investigated further in this analysis because of the non-significant interaction but that will be tested in the next experiment (See Appendix C for means and *SEM*s and Appendix D for the source table).

Bonferroni correction was used when performing post hoc tests for the main effect of attention ($\alpha' = \alpha / k$). Three post-hoc comparisons ($p < .0167$) were performed. Bonferroni correction tests showed that cuing one component of a plaid increased the allocation of attention on this component (M = .817, *SEM* = .031) as compared to when no attention allocation cue was given (M = .391, *SEM* = .051) (t (19)= 10.65 $p < .0001$) and as compared to the uncued component (M = .119, *SEM* = .015) (t (19)=20.08 p< .0001). Furthermore, the time attention was allocated to an uncued component was statistically significantly shorter than when no component was cued (t (19)=-5.82 p< .0001). Using a one group t-test, each condition (attended, unattended and no attention allocation cue) differed significantly from the zero baseline indicating that for all the conditions attention was present (attended (t (19)=26.10, p< .0001), unattended (t (19)=7.69 p< .0001), no attention allocation cue given (t (19)=7.61 p< .0001)). Therefore it is not the presence or the absence of attention but the amount of time attention was allocated to a component of a complex stimulus that differed from one condition to the other. The participants were unable to completely ignore the uncued component when asked to do so. However, since there is a significant difference in the amount of attention directed to each plaid component between the conditions, the conclusion is that the participants, as a group, performed the attention task as required in the instruction of this experiment and in a way that would allow discrimination between the group for the



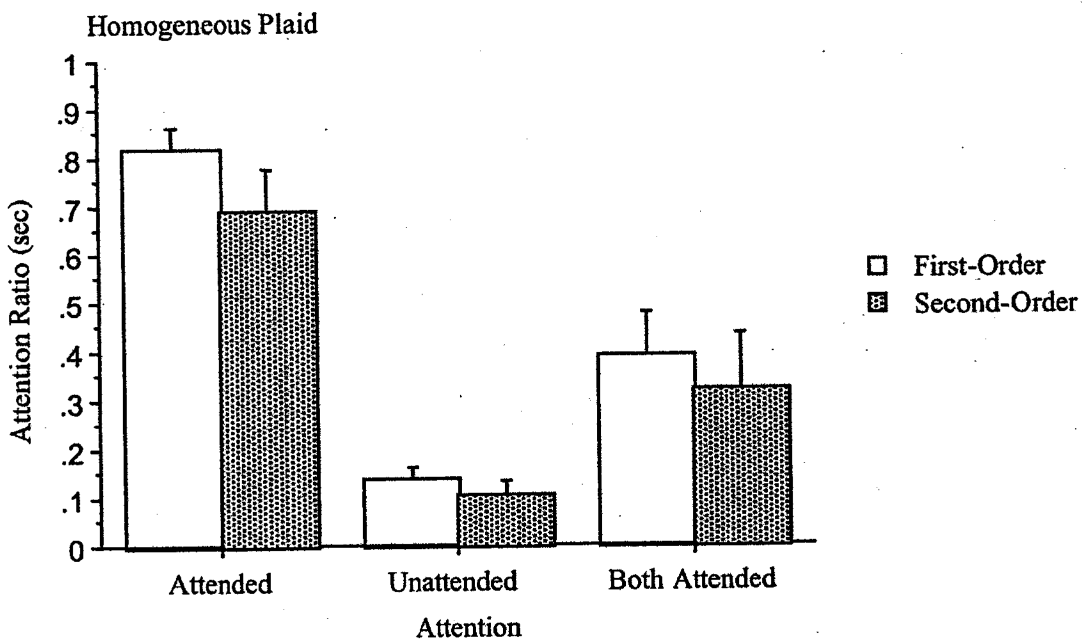


Figure 5. Mean and standard error of measurement of the attention ratio and the type of plaids (n = 5).

analysis of the MAE. Another conclusion is that the participants were equally able to attend or to ignore a component of a homogeneous plaid as a component of a heterogeneous plaid. Another conclusion is that the participants were equally able to attend or ignore a first-order component as a second-order component.

The participants were able to avoid the perception of coherence most of the time. However, in the control condition in which the participants were not instructed to attend to one particular plaid component, a larger percentage of coherence (11.63%) was produced than in the other experimental conditions combined (3.42%). This finding suggests that the participants adapted less to the individual component of the adaptation plaid in the former condition as compared to the later. Therefore, this might have reduced the MAE duration for the components of the plaid in the former condition (Figure 5).

Motion Aftereffect

The data of the same five participants that were included in the analysis of attention were included in the MAE statistical analysis. The raw data consisted of the duration and the direction of the perceived motion in the counter phase test stimulus. A perceived motion in a test after adaptation in the direction opposite to the motion attended was defined as a positive MAE (+ sign) and a perceived motion in the same direction as the attended motion was defined as a negative MAE (- sign). For each adaptation plaid described in the attention section the participant was presented with two test orientations (same orientation as the attended component of the adaptation plaid, same orientation as the unattended component of the adaptation plaid). A 3 x 2 x 2 repeated measures ANOVA was used to analyze the effect of the independent variables on the duration of the MAE. The first independent variable was attention. The test was 1) in the same orientation as the attended component, 2) in the same orientation as the unattended component, or 3) no orientation was cued and the test was oriented either to the left or to the right in an equal proportion among trials. The second independent variable was the type of component to which the participant attended, first- or second-order component. The third independent variable was the type of plaid, homogeneous or heterogeneous. For the homogeneous plaids, the unattended component of the plaid was made up of the same type of component as the attended component. For the heterogeneous plaids, the unattended component and the attended component of the plaid were made up of different motion types (Figure 6) (See appendix E for means and *SEM*s and appendix F for the source table).

The main effect for attention was statistically significant, (F (2,8) = 7.86, $p <$ .013). This main effect combined heterogeneous plaids and homogeneous plaids and attention to first- and second-order components. None of the other main effects and interactions were statistically significant. Bonferroni correction was used in order to perform post hoc tests for the main effect for attention. Three post-hoc comparisons ($p <$ .0167) were performed.

In the first comparison, the duration of the MAE when the cued and tested orientation was the same with the control condition in which no component of the plaid was cued and the test was oriented left or right was compared. It has been hypothesized that the MAE duration would be longer when the test was in the same orientation as an attended component than for when no attention instruction was given. The statistical analysis of this comparison did not reach statistical significance although the results were

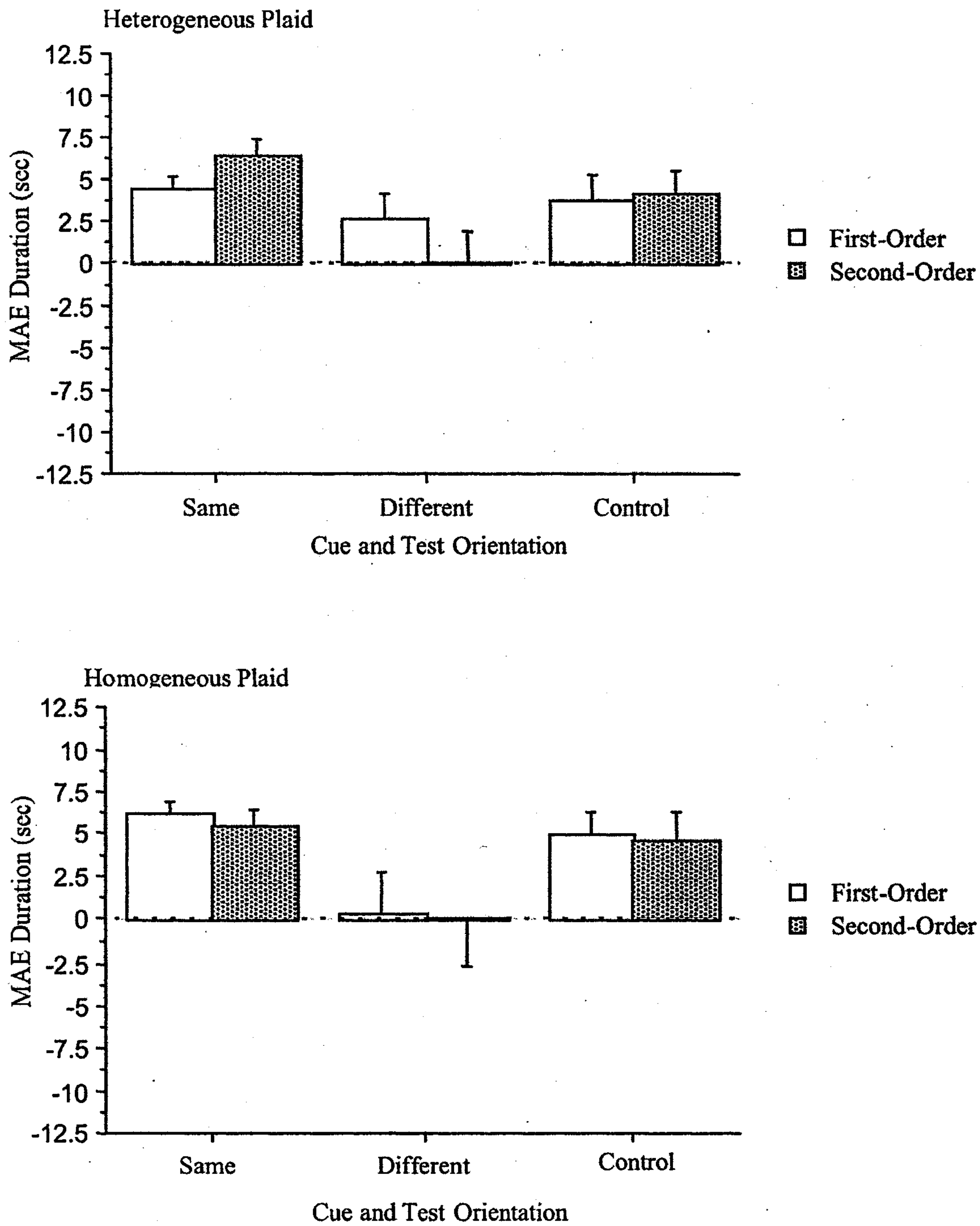


Figure 6. Mean and standard error of measurement of the MAE duration for heterogeneous (top) and homogeneous (bottom) plaids (n=5).

in the direction of our hypothesis. When the test was in the same orientation as the attended component of the adaptation plaid (M = 5.58, *SEM* = .45) the MAE was not statistically longer than in the control condition (M = 4.35, *SEM* = .69) (t (19)= 2.35 $p <$ .029).von Grünau et al. (1998) and von Grünau and Faubert (1998) found a statistically significant result between the attended component condition and the control condition.

Next the case in which the attended and the tested orientations were the same was contrasted with the case in which the cued and tested orientations were different. As hypothesized, a statistically longer MAE was produced when the test and the adaptation component were in the same orientation (M = 5.58, *SEM* = .45), as compared to when the test was in the orientation of the unattended component of the adaptation plaid (M = .744, *SEM* = 1.01) (t (19)= -4.15 $p <$ .0005). Therefore attending to a component of a complex stimulus produces a longer MAE than when the component is to be ignored.

The last comparison showed that when the test was in the orientation of the unattended component of the adaptation plaid a shorter MAE was produced as compared to the MAE produced in the control condition (t (19)= -3.04, $p <$ .007). This finding suggests suppression in the production of the MAE for the unattended component. These results support Sohn (2004) and von Grünau et al. (1998) results.

It would have been expected the MAE to be larger for an attended component of a plaid as compared to the control condition. When the MAE durations produced for each condition are compared to the zero baseline a significant MAE was found for an attended component (t (19)= 5.59, $p <$ .0001) and for a component of a plaid in the control condition (t (19)= 4.35, $p <$ .0001). However the unattended component of the same plaid did not produce a MAE. In this latter situation the MAE was not significantly different from the zero baseline (p= .47). In addition of having a suppression as defined in this thesis, this finding shows that for the unattended component, the MAE is even reduced to zero.

The present results argue against Wohlgemuth's (1911) conclusion that attention had no effect on the production of the MAE. The present results are in agreement with many modern findings that attention manipulations can modify the production of the MAE (Chaudhuri, 1990; Culham et al., 2000; Georgiades & Harris, 2000, 2002; Rees et al., 1997; Shulman, 1991, 1993; Takeuchi & Kita, 1994).

The purpose of this experiment was to combine the condition of the experiments of von Grünau et al. (1998) and von Grünau and Faubert (1998) into a single experiment. The adaptation stimulus used in von Grünau et al. (1998) and the adaptation stimulus used in von Grünau and Faubert (1998) studies has been combined to investigate the difference in the results found in these two studies, which concerned the suppression of the MAE for a test in the orientation of an unattended component of a plaid. Using a homogeneous plaid, von Grünau et al. (1998) found a suppression of the MAE for a test in the orientation of an unattended component of a plaid. von Grünau and Faubert (1998), using the same method and procedures but using a heterogeneous plaid, found no such suppression of the MAE. Both studies however found longer MAEs when the test and cued orientation was the same.

In this study, a suppression of the MAE was found when the test was in the same orientation as the unattended component as compared to the MAE produced when the participants were required to attend equally often to the two plaid components. This suppression was present in homogeneous plaids made up of two first-order components or made up of two second-order components. Furthermore, a suppression of the MAE for an unattended component of an adaptation plaid was also present in heterogeneous plaids. These results suggest that the systems that process first-order motion and second-order motion either interact or are the same system. These results are different from those of von Grünau and Faubert (1998). The fact that homogeneous and heterogeneous plaids did not produce significantly different MAE durations suggests that the attention manipulations affected both types of motion in the same way. This is in accordance with the theory of Lu and Sperling (1995), which states that first- and second-order components are processed by the same motion systems after some rectification of the second-order stimulus has taken place. It is also consistent with the fact that attention affects motion processing at a higher level than the level where first- and second-order motion are analyzed. After having discussed these results with Sperling (Sperling, personal communication). However the second-order component used in this study could have behaved more like a first-order component due to the possible crowding of white or dark pixels at the junction of the bars forming the gratings. In this study, square-wave gratings were used to form the plaid. Square-wave gratings were used here because sine-wave gratings render the attention task harder for the participants. However, according to Sperling, these sharp edges could introduce first-order artifacts in what was called a second-order component in this study. If this is the case, the distinction between first- and second-order motions is not present in the study.

Longer MAEs were expected when the test was in the same orientation as the attended component of the adaptation plaid as compared to the control condition in which attention wondered freely during adaptation. It is surprising that the difference in MAE duration for the attended component as compared to the control condition was not statistically significant because: 1) In von Grünau and Faubert (1998), as well as in von Grünau et al. (1998), an enhancement in the MAE was found. 2) The attention level was clearly enhanced when the participants were asked to attend to a particular component of a plaid. 3) Although the number of participants was small in this experiment and a three way ANOVA was used for the statistical analysis of the results, the eta^2 was of medium size for the main effect of attention and the power was enough to reach statistical significance for the main effect. The lack of MAE enhancement might reflect a lack of power of the Bonferroni comparison.

The magnitude of the attentional effect could also in part have been reduced by the procedure of the study. The participants were required to press a key when the adaptation stimulus ended and the test stimulus appeared. This extra task may have been distracting for the participants and consequently may have lowered the MAE duration. Furthermore, the duration of the test stimulus depended on the reaction time of the participant at pressing on the required key at the end of the adaptation period, which in turn may have reduced the duration of the recorded MAE.

The hypotheses tested in this experiment will be re-tested in the next experiment using improved software, methodology, stimuli and a larger number of participants.

Conclusion

The results of this experiment support a suppression of the MAE for the actively unattended component of a plaid. A simpler explanation could be the time difference between the conditions. The longer the time that a component is attended the longer the

MAE. This was tested in experiment 4 and shown not to be the case. For that reason I prefer to talk in terms of a suppression. It is not clear in this study as to whether this suppression occurred with plaids made-up of a mixture of first- and second-order components and plaids made-up of two second-order motion components because of the square-wave gratings used in the construction of the adaptation stimuli.

Experiment 2: Main Experiment

The present experiment was designed to re-test the hypotheses of experiment 1. The effect of selective attention on the processing of first- and second-order motion was investigated using the MAE illusion. This experiment, however, used improved computer software, improved methodology, a larger number of participants and more powerful statistical analyses.

The computer software used in this experiment, in contrast to the computer software used in the preliminary experiment, relieved the participants from the distracting task of indicating when the adaptation stimulus disappeared. Therefore, the participants could allocate their attention more efficiently to the experimental task.

A first methodological improvement was to modify the instruction for the control condition. In the control condition of this experiment, the participants were instructed to attend freely to both components of the plaid while avoiding the perception of coherence (coherence during adaptation reduces the time the participants adapt to the individual components of the plaid). In the preliminary, the perception of coherence or transparency in the adaptation plaid was manipulated by the choice of the parameters used in the composition of the plaids. In the main experiment, the perception of coherence or transparency in the adaptation plaid was manipulated by the choice of the parameters used in the composition of the plaids (a 140 degree direction difference rarely produces coherence) and by the instructions about attention. In the experimental conditions with specific attention participants rarely perceived the components moving coherently (3.43 % of the time). However, coherent motion was more often perceived in the control condition (11.63 % of the time). The aim of the new instruction was to reduce the amount of coherent motion perceived in the control condition.

A second methodological improvement was to use sine-wave gratings instead of square-wave gratings in the construction of the adaptation plaids. According to Sperling (personal communication) square-wave gratings can introduce first-order artifacts in the second-order stimuli due to the sharp edges of the bars that form the grating. In the preliminary experiment, a difference in the suppression of the MAE might not have been found between first- and second-order motion when the test and the adaptation stimuli were of different orientations because contaminated second-order stimuli were used.

In order to increase the power of the experiment, a larger number of participants than in the preliminary experiment was used. Also, orthogonal planned comparisons were used in order to investigate statistical significance of the MAE result. This type of analysis is more powerful. The comparisons were planned using the results of the preliminary experiment as well as the results of the von Grünau et al. (1998) and von Grünau and Faubert (1998) experiments. The planned comparisons were designed to test these hypotheses: 1) Attention allocation to a component of a plaid stimulus during adaptation increases the subsequent MAE duration for that component. 2) Directing attention away from a moving stimulus during adaptation decreases the subsequent MAE duration for that component. 3) Homogeneous plaid type will produce larger MAE suppression for the unattended component than heterogeneous plaids. 4) Attending to a first-order component will produce the same MAE as attending to a second-order component.

Method

Participants

12 participants performed the experiment (8 females and 4 males). The participants were aged between 22-56. All participants had previous experience with psychophysical experiments. 10 were naïve to the purpose of the experiment. All participants had to have normal or corrected-to-normal vision.

Apparatus and Materials

The same apparatus as in the preliminary experiment was used in this experiment with one exception. The VPixx 1.4 software developed by Peter April (http://www.vpixx.com/) was replaced by a newer version: the VPixx 1.76.

Stimuli

Mask. The mask stimulus was the same as in the preliminary experiment.

Cue. The same cues as in the preliminary experiment were used in this experiment. However, when the circle was presented the instruction in this experiment was to monitor their attention that freely alternated between the components of the plaid while avoiding the perception of coherence during adaptation.

Adaptation Plaids. The same adaptation plaids as in the preliminary experiment were used in this experiment, but the plaids comprised sine-wave components (Figure 7). The second-order stimulus used to make the plaid was a contrast-defined noise sine-wave

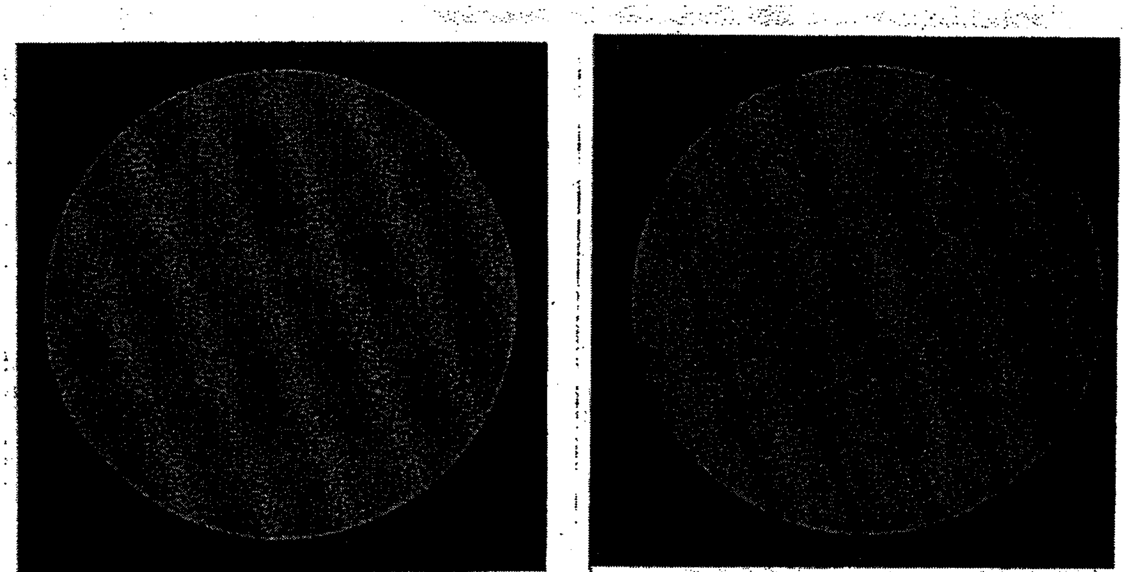


Figure 7. First- and second-order sine-wave gratings used in the plaids.

grating. The grating had a spatial frequency of .5 cycles/degree. The equation that defined the luminance profile at each point on the x and y axes was:

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

This formula is adapted from Bertone (1999). L_{mean} is 12.4 cd/m^2, the mean luminance of the display. m_{env} is the modulation depth of the envelope. f is the spatial frequency of the envelope. m_{car} is the contrast of the carrier. R(x, y) is the carrier made of static noise of 1 pixel * 1 pixel, measuring approximately 2.24 arc min. The grayish colored, static carrier was formed using a sinusoidal modulation. The luminance of each dot was assigned as a function of sin(x), where the luminance of x ranged from 0 to 2π. Fixed noise elements (the carrier) were multiplied with the sine wave grating (the envelope) in order to form the second-order stimulus. The amplitude of the wave was .5. The symmetry of the wave was .5. The second-order grating was oriented either 20 or -20 degrees away from the vertical. The temporal frequency of the motion was 7.7 cycles/sec. One temporal cycle of the second-order grating consisted of 5 static presentations of the grating shifted each time by 1/5 of cycle. The duty cycle of the grating was .75. The first-order stimulus used to make the plaid was a luminance-modulated sine-wave grating. The symmetry of the first-order stimulus was identical to the symmetry of the second-order stimulus. The motion of the grating was oriented 20 or -20 degrees away from the vertical and the temporal frequency of the motion was 7.7 cycles/sec. The temporal cycles of the first-order grating, as well as its duty cycle, were identical to those of the second-order grating. A uniform sheet of static noise was added to the grating made up of first-order motion. The luminance contrasts of the first-order stimulus were determined individually for each participant using the counterphase grating method with noise added described in the equation experiment (Appendix A).

MAE Test. The test stimuli consisted of the same flickering grating as in the preliminary experiment made-up of two counter phase gratings moving in opposite directions. The tests were in the same orientation as the attended component or in the same orientation as the unattended component.

Procedure

Each participant performed the experiment individually. First, the experiment was described verbally to the participant by the experimenter, and a written consent form describing the purpose of the experiment was given to the participant (Appendix B). The participant was asked to read and sign the consent form if he/she agreed to participate in the experiment. The participant was allowed to withdraw from the experiment at any time. For each participant the contrast of the first-order component was adjusted using the data of the equation experiment (Appendix A). Before beginning the experiment, the participant stabilized his/her head on the chin rest placed in front of the computer and fixated at a red dot in the center of the computer screen. The participant started each trial by pressing the space bar of the computer keyboard when ready. A mask was then presented for 800 ms and, immediately after one of three cue stimuli was presented to the participant for 2 sec, indicating which component of the plaid to attend during the presentation of the adaptation stimulus. The cue stimulus was followed by the presentation of one of the four plaids, which served as adaptation stimuli. The adaptation period lasted 20 seconds. During the presentation of the plaid, the participant was required to fixate the red dot and to attend to the component indicated by the prior cue stimulus as much as possible. During adaptation, the participants recorded their dominant percept by continuously pressing three keys. The keys indicated that his/her attention was directed to 1) the left component, 2) the right component, and 3) he/she perceived coherence of both components. The plaid was followed by a dynamic test stimulus oriented in one of two ways. The test stimulus was oriented: 1) in the orientation of the attended component, 2) in the orientation of the unattended component. The participant was required to press the arrow keys to indicate the direction of the perceived motion. To determine the duration of the motion aftereffect, the participant pressed the "0" key when the perceived motion became ambiguous again.

The participant performed 5 trials for each of the adaptation plaids. The homogeneous plaids consisted either two first-order components, or two second-order components. The heterogeneous plaids consisted of a mixture of first- and second-order components in which the second-order component was either moving to the right or to the left. For each adaptation plaid, the participant was presented with three different cues.

The conditions consisted of: 1) sine-wave homogeneous plaid and attention to first-order component, 2) sine-wave homogeneous plaid and attention to the second-order component, 3) sine-wave homogeneous plaid and attention to both components equally, 4) sine-wave heterogeneous plaid and attention to the first-order component, 5) sine-wave heterogeneous plaid and attention to the second-order component, 6) sine-wave heterogeneous plaid and attention to both components equally. The whole experiment lasted approximately 1 hour and 40 minutes.

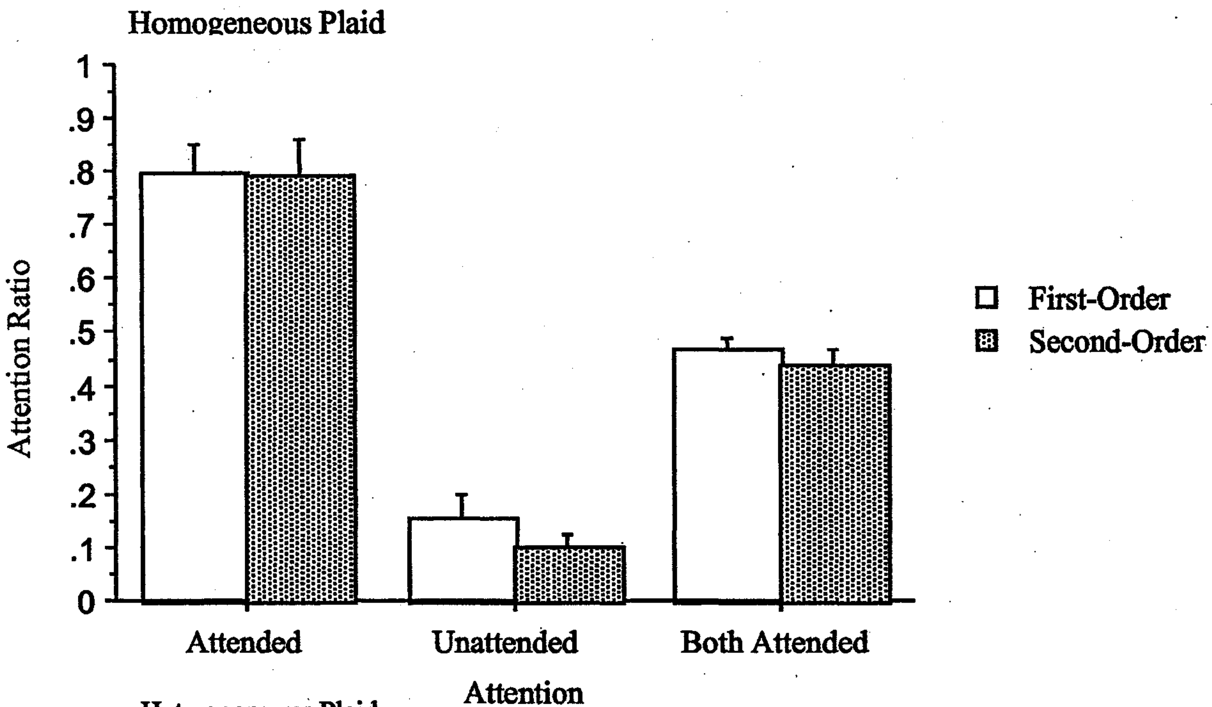
Results and Discussion

Attention

The results of 11 of the 12 participants that participated in the experiment were included in the group data analysis for attention. One participant was removed from the group data analysis because this participant omitted to record attention for 35% for the trials. The analysis of the attention results was made to ensure that the participants performed the attention task as required. Also, this analysis provided information about the degree of attention of the participants across the different types of plaid and types of attended component.

The raw data for attention were transformed into a ratio in the same manner as in the preliminary experiment. For each adaptation plaid, the participants were presented with three attention cues, two types of component and two types of plaid for a total of 12 different stimulus combinations.

A three way repeated measures ANOVA was used to analyze the attention results. The three independent variables were 1) type of adaptation plaid (homogeneous or heterogeneous plaid), 2) type of component attended (first- or second-order), 3) attentional manipulation (attended component, unattended component, and both components). The 2 x 2 x 3 repeated-measures analysis of variance indicated a statistically significant main effect for attention $F\ (2,20) = 78.20, p < .0001$. The plaid * component interaction was also statistically significant $F\ (1,10) = 7.26, p < .02$. None of the other main effects and interactions were statistically significant. (Figure 8) (See Appendix H for means and *SEM*s and Appendix I for the source table).



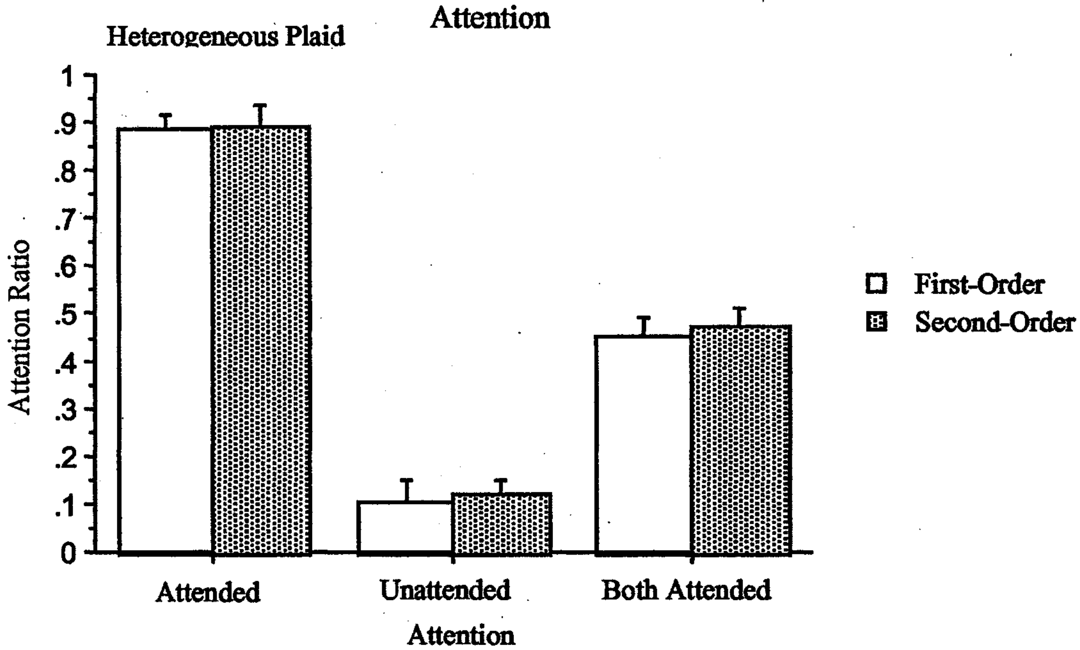


Figure 8. Mean and standard error of measurement of the attention ratio and the type of plaids (homogeneous versus heterogeneous) (n = 11).

experimental condition to the other (attended (t (43)=30.97 p< .0001), unattended (t (43)=6.42 p< .0001), no attention allocation cue given (t (43)=28.17 p< .0001)).

For the significant interaction between the type of plaid and the type of component, four comparisons were tested using the Bonferroni correction factor ($p <$ .0125). The Bonferroni Correction tests showed that none of the comparisons were statistically significant. Therefore, homogeneous and heterogeneous plaids did not produce large enough difference when a second-order component was attended (homogeneous plaid: M = .442, *SEM* = .057; heterogeneous plaid: M = .494, *SEM* = .06) ($p >$ .03) to be detected by the Bonferonni correction test. Homogeneous and heterogeneous plaids did not produce statistically significant differences as well when a first-order component was attended (homogeneous plaid: M = .472, *SEM* = .052; heterogeneous plaid: M = .480, *SEM* = .061) ($p >$ .73). When a homogeneous plaid was presented, the amount of attention to the first-order component was equal to that of the second order component (first-order: M = .472, *SEM* = .052; second-order: M = .442, *SEM* = .057) ($p >$ .07). When a heterogeneous plaid was presented, attention to the first-order was equal to that of the second order component (first-order: M = .480, *SEM* = .061; second-order: M = .494, *SEM* = .06) ($p >$ .21). Therefore it has been concluded that, as in the preliminary experiment, that the participants did attend or ignore a component in both homogeneous and heterogeneous plaids. Finally, It has been concluded that the participants were able to attend or ignore both first-order and second-order components. With more power a difference between the groups might have been found. Also, with four comparisons the Bonferroni post hoc test is stringent. With a less conservative post hoc test, different results might have been found.

According to these results about the direction of attention, It has been concluded that the participants, as a group, performed the attention task as required in the instructions of this experiment. This is similar to the results found in the preliminary experiment.

MAE

The data of the 11 participants were included in the MAE statistical analysis. The raw data consisted of the duration and direction of the perceived motion in the counter phase test stimulus as in the preliminary experiment.

Planned comparisons were used to test the following four hypotheses: 1) Attention allocated to a component of a plaid stimulus during adaptation increases the subsequent MAE duration for that component. 2) Directing attention away from a moving stimulus during adaptation decreases the subsequent MAE duration for that component. 3) In a plaid, having an unattended component of the same type as the attended component produces larger MAE suppression for the unattended component than having an unattended component of a different type as the attended component during adaptation. 4) attending to a first-order component produces the same amount of MAE as attending to a second-order component. The design of the planned comparisons is presented in Appendix J. The results of this experiment are presented in Figure 9. The negative MAE duration means that instead of perceiving a motion in the direction opposite to the attended motion of the adaptation plaid (MAE), a motion in the same direction as the motion attended during the presentation of the adaptation plaid was perceived when the test was presented. The negative MAE durations found in this experiment were not

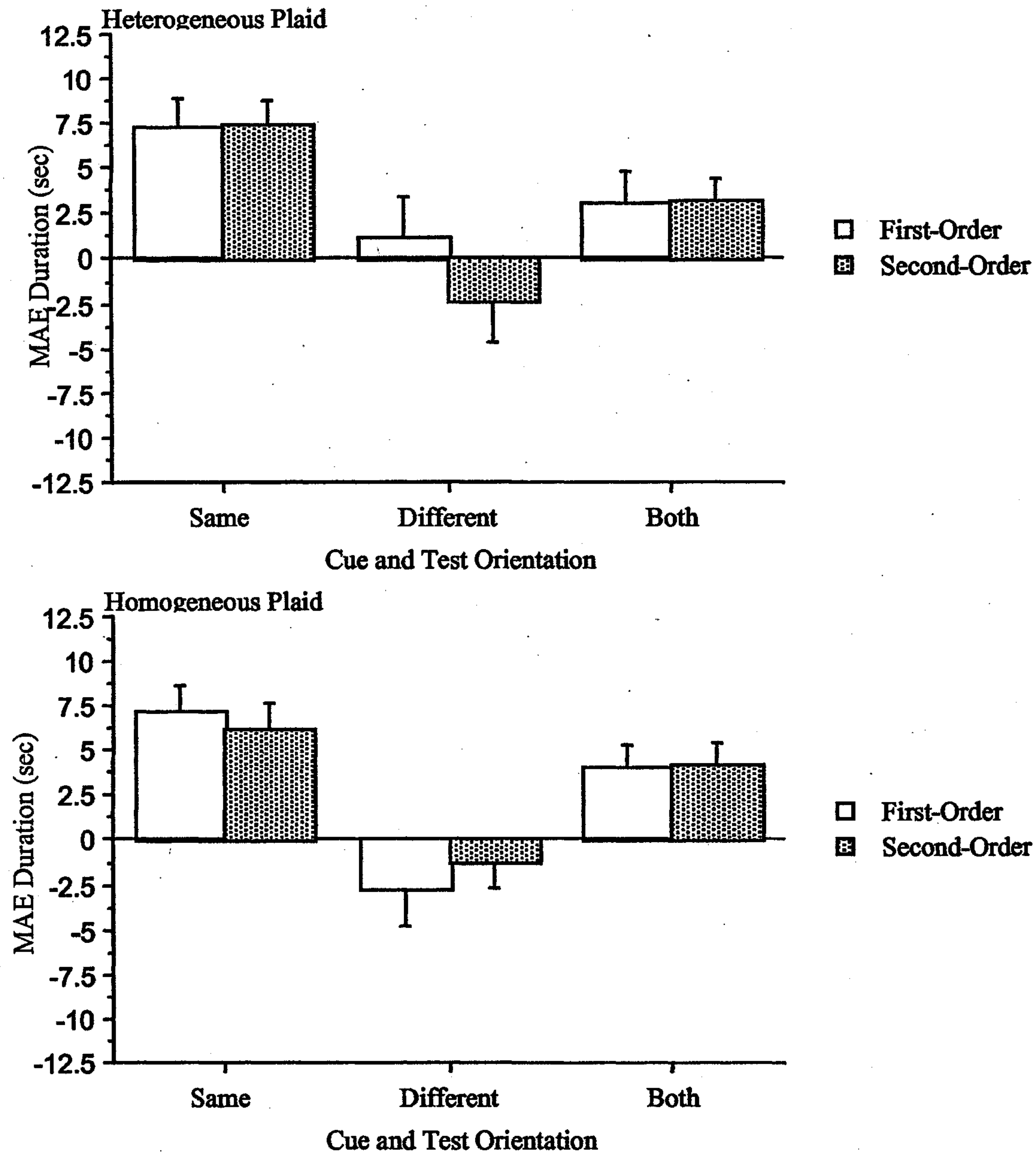


Figure 9. Mean and standard error of measurement of the MAE and the type of plaids (homogeneous versus heterogeneous) (n = 11).

statistically different from the zero baseline (Heterogeneous, different, second, $p > .31$; Homogeneous, different, first, $p > .21$; Homogeneous, different second, $p > .40$)

To test if attention to a plaid component during adaptation increases the subsequent MAE duration (Hypothesis 1), The condition in which cued and test orientation was the same was contrasted against all other conditions (cued and test orientation different and no cue). The condition in which the cued and test orientation were of different orientation was combined with no cue condition because to keep the planned comparison orthogonal. Furthermore, the most important question about the suppressive effect of attention is answered by the second comparison below. For this comparison, the data of homogeneous and heterogeneous plaids as well as first- and second-order components were merged. As hypothesized, when the test and the attended component of the adaptation plaid were in the same orientation the MAE was stronger ($M = 7.64$, $SEM = .97$) than when they were in different orientations or no cue was given ($M = .90$, $SEM = .49$) ($t(31) = 6.74$, $p < .0001$). This finding is in agreement with the results of von Grünau and Faubert and with the results of von Grünau et al (1998).

The second comparison was aimed at investigating the suppression of the MAE when the cued component of the plaid and the test were in a different orientation as compared to the control group (Hypothesis 2). Here, according to Sohn (2004), von Grünau et al. (1998) and to the preliminary experiment of this thesis, suppression of the MAE should be present. However, according to von Grünau and Faubert (1998), no suppression of the MAE should be found.

As found in von Grünau et al. (1998), and the preliminary experiment of this thesis, the MAE duration for an unattended component of a plaid ($M = -3.36$, $SEM =$

1.05) was than the MAE duration when both components were attended alternately (M = 5.15, *SEM* = .63) ($t(31) = -5.87, p < .0001$). Furthermore, none of the four conditions involving a test and an adaptation plaid in different orientations produced MAEs that were significantly different from the zero baseline (heterogeneous, different, first, $p >$ .58; heterogeneous different second, $p > .31$; homogeneous different first, $p > .21$; homogeneous different, second, $p > .4$). However, three of the four control conditions were significantly greater than the zero baseline (heterogeneous, different, first, $p > .11$; heterogeneous different second, $t(10) = 3.04, p < .012$; homogeneous different first, $t(10) = 3.04, p < .012$; homogeneous different, second, $t(10) = 3.23, p < .009$). These findings support a suppression of the MAE when a component of a plaid is oriented differently than the attended component of an adaptation plaid even if the attention is directed to an element of the stimulus in the same visual field.

The third comparison was aimed at investigating the effect of homogeneous versus heterogeneous plaids on the duration of the MAE. Sohn (2004) and von Grünau et al. (1998) found suppression of the MAE for the unattended component of a homogeneous plaid. von Grünau and Faubert found no suppression for the unattended component of a heterogeneous plaid. Therefore, it has been hypothesized that 1) When the test and the attended component are of different orientations, in homogeneous plaids, a suppression of motion processing will be occurring and therefore a weak MAE will be produced for the test in the orientation of the unattended component. In heterogeneous plaids, no suppression of the MAE will be present and therefore a stronger MAE will be produced for the test in the same orientation as the unattended component. 2) No difference will be found in the duration of the MAE between the homogeneous and heterogeneous plaids when the test and the attended component are in the same orientation. 3) When no particular component of a plaid was cued and participants allocated attention equally between both components during the adaptation, no MAE strength difference will be found between homogeneous and heterogeneous plaids. None of the three comparisons was statistically significant. When the test was in the same orientation as the adapted component the MAE produced was of the same strength for homogeneous plaids (M = 6.67, *SEM* = 1.04) as for heterogeneous plaids (M = 7.32, *SEM* = 1.06). When the test was in the orientation of the unattended component, the MAE produced was of the same strength for homogeneous plaids (M = -2.03, *SEM* = 1.24) as for heterogeneous plaids (M = -.60, *SEM* = 1.58). When both components were attended during adaptation, the MAE produced was the same duration for homogeneous plaids (M = 4.07, *SEM* = .90) and heterogeneous plaids (M = 3.13, *SEM* = 1.05). Therefore, contrary to our hypotheses, adapting with a homogeneous plaid does not produce a stronger MAE than adapting with a heterogeneous plaid. In this comparison, adaptation to a first-order component and to a second-order component was merged.

The fourth series of comparisons was aimed at investigating the possible difference between first- and second-order components in the production of the MAE. This analysis consisted of 6 comparisons. The means and the *SEM* for each of the groups compared are found in Appendix K. The MAE duration between a first and a second-order component was compared when the test was in the same orientation as the adapted component in 1) a homogeneous plaid and in 2) a heterogeneous plaid. The MAE duration between first- and second-order components when the test and the adapted components were of different orientation in 3) a homogeneous plaid and 4) a heterogeneous plaid was compared. The MAE duration between first- and second-order components when both components were attended alternately and equally during adaptation in 5) a homogeneous plaid and 6) a heterogeneous plaid was compared. None of these comparisons were statistically significant at the .05 level. Therefore, first- and second-order motion did not produce a significant difference in the duration of the MAE.

Finally a Pearson Correlation was performed between attention and MAE. A significant linear correlation between attention and the duration of the MAE was expected. As expected, the Pearson Correlation coefficient was statistically significant (r (132) = .416 ($p < .01$)) (Figure 10). The lowest MAE duration was produced when the participants were required to attend to a component of a plaid during adaptation but they were tested with a test in the orientation of the unattended component. The largest MAE duration was produced when the participants were required to attend to a component of a plaid and were tested with a test in the same orientation as the attended component. When the participants were required to attend to both components of a plaid during adaptation the MAE duration produced was intermediate as expected.

The participants were slightly better at avoiding the perception of coherence in the control condition of this experiment compared to in the control condition of the preliminary experiment. In the control condition of the preliminary experiment when no cue was given, the percentage of coherence produced was 11.63%. With the new instruction for the control group of the main experiment, the percentage of coherence perceived was 8.17%). The expectation was that the superposition of sine-wave gratings would produce more noise and therefore, it might have been more difficult to differentiate between both components that form the plaid. However, it seems not to be the case considering that the percentages of perceived coherence in the experimental

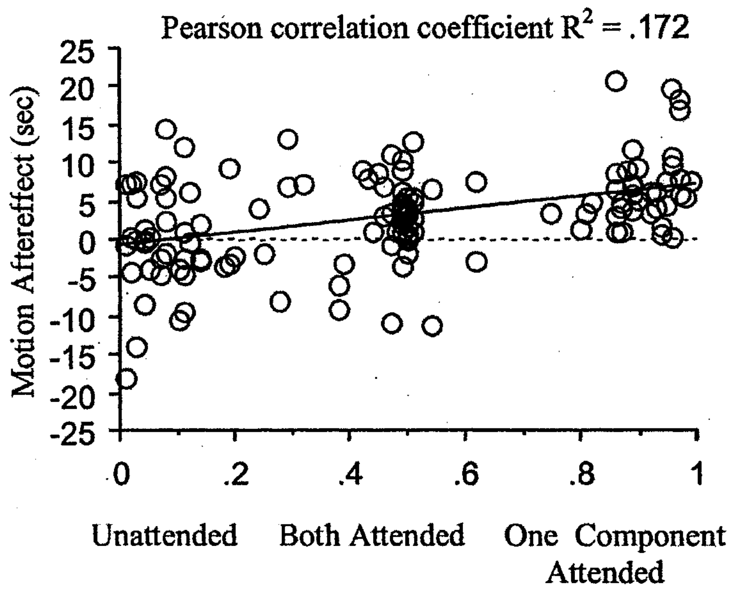


Figure 10. Correlation between the attention ratios and the MAE duration (n = 11).

conditions of both experiments were very similar (preliminary experiment: 3.42%; main experiment: 3.89%).

In these experiments a randomized presentation of the conditions was used. Therefore, when the participants were required to let their attention wonder freely, they were nonetheless aware that they could control their attention. For this reason, it might have been difficult for the participants to let their attention freely alternate between the two components of the plaid in the control condition (similar to the suggestion: "try not to think about a white elephant"). It might have been difficult for the participants to monitor their attention while trying to keep it free of control, since monitoring is a form of control over attention.

It is also unclear what the effect is of an unattended component in the production of the MAE because in this experiment the unattended component was always present. In the unattended experiment, this question will be looked at.

The increase in the MAE duration found when the test and the adaptation component are in the same orientation is in agreement with previous research. These results all show that the MAE is enhanced for a test in the same orientation as the orientation of an element of a complex adaptation stimulus selected by attention (Lankheet & Verstraten, 1995; von Grünau et al. 1998; von Grünau & Faubert, 1998; Watanabe & Miyauchi, 1998).

In von Grünau et al. (1998) superimposed components were used in order to form the plaid. It has been found that the intersection of the two components that form a plaid (called intersection of constraints) produces a perception of motion in a direction other than the direction of each component that forms the plaid. In this study, the direction was downward. A MAE in the direction opposite to the perceived motion of the intersection produces a MAE in the direction opposite to this downward motion. Del Vecchio and von Grünau (2002) showed that MAE in the direction opposite to the combined motion of the plaid was present even when the participants did not attend to this motion but attended to the motion of the components that formed the plaid. The MAE in the direction opposite to the coherent motion of the plaid seems to require less attention than the MAE for the components of the plaid. This demonstrates that the overall motion of a display or a scene is more salient than the motion of its parts. The salience of the motion components of a scene can however be manipulated using active selection.

The MAE produced for the coherent motion of a complex stimulus is processed at a higher level (V5) along the motion pathway than the MAE produced after adaptation to the component of a complex stimulus (V1). Some researchers have not found an MAE for components of a complex stimulus without active selection of a component of the complex stimulus (Lankheet & Verstraten, 1990). In this experiment, It has been shown that active selection is needed in order to produce a strong MAE of the component of a complex motion stimulus. Further, it has been demonstrated that withdrawal of attention further reduces the MAE produced for a component of a complex stimulus. Therefore, motion analyzed at V1 is influenced by attention manipulation.

Conclusion

This experiment suggests that 1) attention increases motion processing of an attended motion. 2) Voluntarily ignoring a motion decreases its processing compared to a baseline. 3) Attention manipulation affects first-and second-order motion in the same manner. The same results as in experiment 1 were found concerning first- and second-order motion therefore, it is difficult to evaluate whether the second-order in the experiment 1 had first-order artifacts.

Experiment 3 : Unattended Component Experiment

This experiment was performed in order to investigate the effect of the presence of an unattended component during adaptation on the processing of an attended component. The MAE duration produced when only the attended component was present during the adaptation (grating stimulus) was compared with instances where the unattended component was also present (plaid stimulus).

Method

Participants

11 participants performed the experiment (6 females and 5 males). The participants were aged between 24-58. All participants had previous experience with psychophysical experiments. Two participants (ASD and MVG) were not naïve as to the purpose of the experiment. All participants had normal or corrected-to-normal vision.

Apparatus and Materials

The same apparatus and material as the one used in the main experiment were used in this experiment.

Stimuli

Mask. The mask stimulus was the same as the one used in the main experiment.

Cue. The cue stimulus consisted of a bar oriented twenty degrees to the left of the vertical indicating to attend to the component moving to the left.

Adaptation Plaids. The adaptation plaids were constructed from sine-wave gratings in the same way as in the main experiment. However, unlike in the main experiment, a first-order grating and a second-order grating were also presented as adaptation stimuli. The gratings were identical to the grating components used to make the plaids.

MAE Test. The test stimuli consisted of the same flickering grating as the one used in the main experiment made-up of two counter phase gratings moving in opposite directions. Two test orientations were presented (20 deg and -20 deg from the vertical).

Procedure

The procedures were the same as in the main experiment. When a grating was presented as the adaptation stimulus, the participants were required to press constantly on the key used to indicate the direction of the grating, which was always in the leftward direction.

Results and Discussion

The results of 9 of the 11 participants who participated in the experiment were included in the group data analysis for attention and the group data analysis for the MAE. Two participants were removed from the group data analysis because they omitted to record the direction of their attention in 35% for the trials. The analysis of the attention results was performed in order to ensure that the participants performed the attention task as required. Therefore it was not possible to know whether these two removed participants performed the attention task as required. Also, no statistical analysis of the attention was possible for these participants using a repeated measures ANOVA.

Attention

For the plaid stimuli, the raw data for attention consisted of the time in seconds the participant attended to the cued component and the uncued component. The raw data for attention were transformed into a ratio. The ratios consisted of 1) the time (sec) the cued component was dominant divided by the sum of all three responses duration. 2) The time that the uncued component was dominant divided by the sum of all three responses duration.

For the grating stimuli, the raw data for attention consisted of the time in seconds the participant attended to the grating. During the presentation of the grating adaptation, some participants did press the key for the other component although the other component was not present during the presentation of the grating. Because of this, a ratio was calculated. The ratio consisted of 1) the duration of time (sec) the motion of the cued component was dominant divided by the total adaptation duration. 2) The duration of time where the motion of the "uncued component" was dominant divided by the total adaptation duration. Because the unattended component was not present, most of the participants attended to the grating for the whole adaptation period. The attention ratio for the grating stimulus was therefore very close to 1 and to 0. Furthermore, almost no variability was present. However, because it was intended to compare the effect of adapting to a grating versus adapting to a plaid, the grating results are included in the data analysis. This will be taken into consideration when interpreting the results.

The participants were presented with one attention cue, three types of adaptation stimulus and two test orientations for a total of 6 different stimulus combinations. Each stimulus combination was repeated 5 times.

A 2 x 3 repeated measures ANOVA was used to analyze the attention performance of the participants as a group. The main effect for the attention (attention directed to a cued component or attention directed to an uncued a component) was statistically significant $F\,(1,8) = 94.87, p < .0001$). This finding suggests that the participants followed the attention instructions. The main effect for the type of stimulus presented during adaptation (homogeneous plaid, heterogeneous plaid or single grating) was not statistically significant ($p > .05$). This finding could suggest that the participants were equally able to attend to a component of a plaid and to a grating; however, the statistically significant interaction shows a different picture of the situation ($F\,(2,16) = 10.61, p < .001$) (Figure 11).

Bonferroni correction was used in order to perform post hoc tests for the statistically significant interaction ($\alpha' = \alpha / k$). Three post-hoc comparisons ($p < .016$) for the interaction were of interest. Post hoc tests showed that the participants were distracted from the attended component when another moving component was present during adaptation (grating: M = .988, *SEM* = .007; plaid: M = .758, *SEM* = .070)

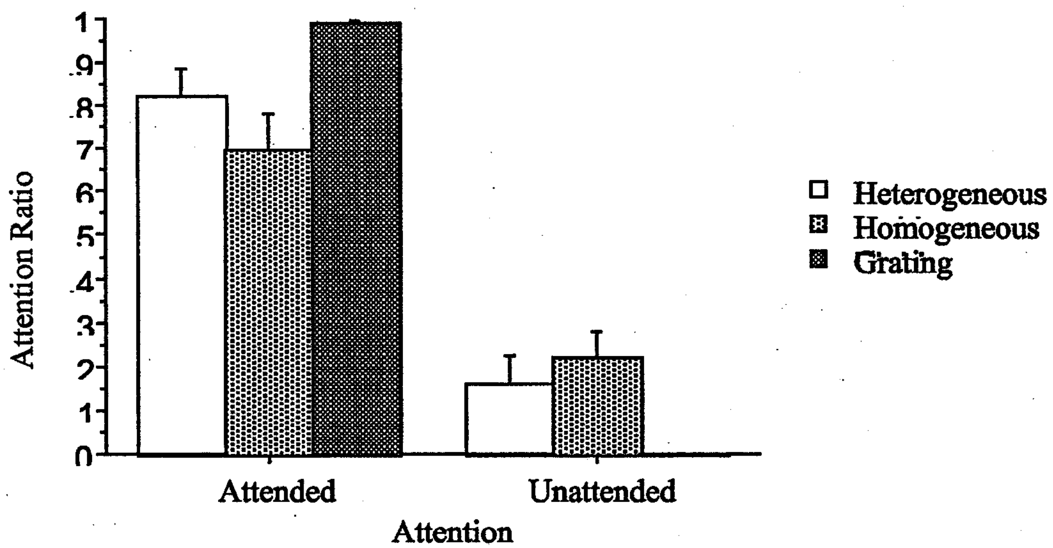


Figure 11. Percentage of time attending or not attending to a component of a plaid or a grating during adaptation in a heterogeneous plaid, a homogeneous plaid and a grating (n = 9).

($\underline{t}$ (8) = -3.10, $p < .0146$). Therefore, this comparison showed that the presence of an unattended component did reduce the duration of time the participants would attend to a required component. Active visual selection of a stimulus is reduced by the presence of other moving stimuli in the same visual field.

Post hoc tests further showed that the participants where better able not to attend to a grating ($\underline{M}$ = .0004, *SEM* = .0004) than not to attend to a component of a plaid ($\underline{M}$ = .189, *SEM* = .05) when required to do so ($\underline{t}$ (8) = -3.74, $p < .0056$). It is not accurate, however, to use this significant interaction between attention and the type of stimulus presented during adaptation to draw conclusions about the effect of ignoring moving components. It is just normal that the participants did not attend to the unattended component of a grating because a grating stimulus has no unattended component. Therefore, to give importance and to draw conclusions using this comparison would be misleading. What can be stated from this result, however, is that the unattended component does grab some of the attention that was supposed to be given to the cued component.

Finally, post hoc tests showed that when a plaid was presented as the adaptation stimulus the participants attended significantly longer to a component of a plaid when required to than when attention was not directed to one particular component as expected. Therefore, the participants were able to follow the instructions ($\underline{t}$ (8) = 5.14, $p < .0009$) (see Appendix L for source table and Appendix M for mean table).

According to these attention results it is expected that 1) the MAE produced when a test is in the orientation of an attended component of a plaid will be shorter than the MAE produced when a test is in the orientation of an attended grating. 2) The MAE produced when a test is in the orientation of an unattended component of a plaid will be larger than the MAE produced when a test is in an orientation in which no grating was presented during adaptation.

MAE

The data included in each cell of the ANOVA were an average of 5 repetitions. A 2 x 3 repeated measures ANOVA was used to analyze the effect of the independent variables on the duration of the MAE. The first independent variable was the type of adaptation stimulus (heterogeneous plaid, homogeneous plaid or single grating). The second independent variable was the correspondence of orientation during adaptation and the test orientation. The test was either in the same orientation as the attended component or in the opposite orientation from the attended component.

The main effect for the type of adaptation stimulus was statistically significant (F $(2,8) = 29.86, p < .0001$). The main effect of the orientation for the cue and test orientation was statistically significant ($F\ (1,8) = 6.63, p < .03$). Using a test in the same orientation as the attended stimulus produced a larger MAE than a test in the opposite orientation. The interaction between the type of adaptation stimulus and the direction of the attention and orientation of the test was also statistically significant ($F\ (2,16) = 18.38$, $p < .0001$) (Figure 12).

To analyze the interaction the Bonferroni correction was used. Four post hoc comparisons ($\alpha' = \alpha / k$) were performed. When the cued and test stimuli were in the same orientation, The MAE duration after adaptation to a grating ($\underline{M} = 11.60$, $SEM = .94$) versus the MAE duration after adaptation to a plaid ($\underline{M} = 7.73$, $SEM = 1.01$) were compared. For this comparison, homogeneous and heterogeneous plaids were averaged. A longer MAE was produced when adapting to a grating compared to adapting to a plaid ($\underline{t}$ (8) = -3.24, $p < .0119$). 2) When the cued and test orientations were different, the MAE duration produced after adapting to a grating ($\underline{M}$ = 10.24, *SEM* = 1.33) versus after adapting to a plaid ($\underline{M}$ = -.37, *SEM* = 2.18) was compared. Longer MAE was produced for adapting to a grating than to adapting to a plaid ($\underline{t}$ (8) = -6.39, $p < .0002$). 3) For plaid adaptation stimuli the MAE produced when the test and the cued stimuli were in the same orientation versus the MAE produced when they were in different orientations were compared. This comparison was statistically not significant ($p > .012$). Longer MAEs were produced when the attended component of the adaptation plaid and the test were in the same orientation. 4) For grating adaptation stimuli the MAE produced when the test and the cue were in the same orientation versus the MAE produced when they were in different orientations was compared. This comparison was not statistically significant ($p > .012$). Therefore, when the unattended component is present the MAE is reduced. Also the reduction is even greater when the test is in the orientation of the unattended component. When the unattended component was not present, rotation in an orientation of the test away from the orientation of the adaptation stimulus (grating) did not reduce the duration of the MAE (see Appendix N for source table and Appendix O for mean table). This latter result is contrary to the orientation tuning of the MAE found in the study of Over, Broerse, Crassini and Lovegrove (1973). von Grünau and Dubé (1992) also found an orientation/direction tuning for local MAE when the adapting stimulus consisted of a plaid and of a grating and the test was presented at the same location as

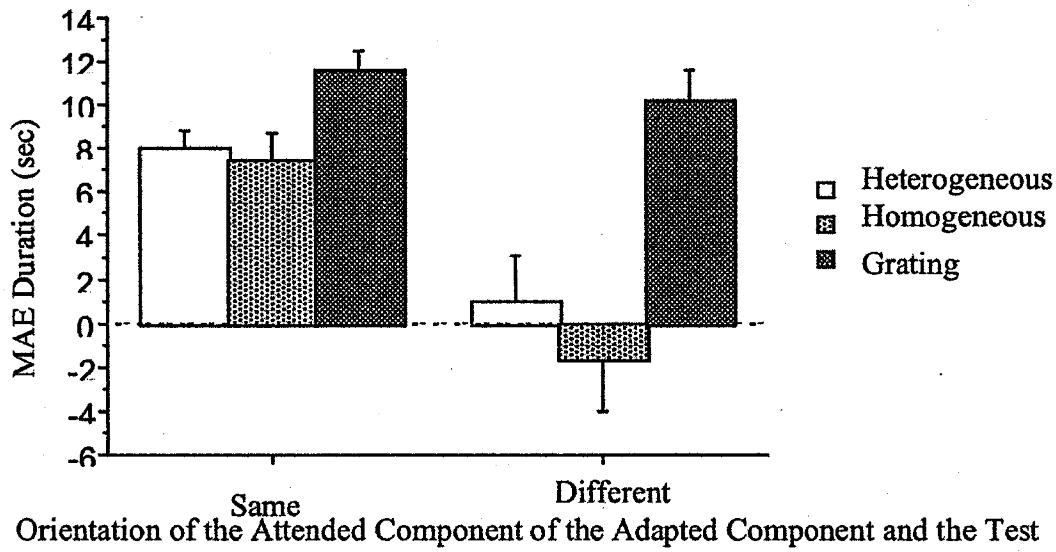


Figure 12. Mean and standard error of measurement of the MAE duration for heterogeneous plaid, homogeneous plaid as well as single grating when the test and the attended component are in the same orientation and when they are in different orientations (n=9).

the adaptation stimulus. However, they did not found such effect on the MAE when the test was presented at a remote location.

The results of this experiment were in accordance with the previous experiments of this thesis. 1) In this thesis, it was shown that allocating attention to one component of a complex stimulus increases the processing of this attended component as compared to the processing of the unattended component. This effect was demonstrated by the difference in the MAE duration produced for the attended component as compared to the unattended component of a plaid. In the main experiment of this thesis, an increase in the duration of the MAE was found for a cued component of a plaid as compared to the control condition. In the preliminary experiment and the main experiment, reduced in duration of the MAE was produced for tests oriented in the same orientation as the unattended component of an adaptation plaid as compared to when attention was not manipulated. This was also true in von Grünau et al. (1998) using only homogeneous first-order plaids. These findings suggest that attention operates via facilitation and suppression.

In the previous experiments of this thesis it was difficult to study directly the effect of the unattended component on the duration of the MAE because the unattended component was always present.

The present experiment showed that having a moving object in the visual field while trying to attend to another moving objects, reduces the attention performance and reduces its processing by the visual motion system. This is demonstrated because the attention performance and the MAE produced for attending to a component of a plaid is weaker than the attention performance and the MAE produced for attending to a grating when being tested with a test in the orientation of the attended component of a grating.

Although some attention is directed to the component of a plaid that is not supposed to be attended during adaptation, this attention is not enough to produce a strong MAE. It is not solely the different orientation of the test that decreases the processing of the unattended component. When the participants are required to attend to a grating in one particular direction and they are tested for MAE with a test in the orientation of the " not present unattended component" the MAE produced is as strong as if the test was in the orientation of the grating. Therefore, the processing of an unattended component is suppressed when attention is allocated to the attended component. If no suppression had occurred when actively ignoring a plaid component, the MAE in a subsequent test with the uncued orientation oriented in the orientation would have been as strong as the MAE produced for attending to a grating and being tested with a test in the orientation of the "not presented" unattended component. The processing of an attended moving object is decreased when another moving object is present in the visual field as compared to when it is not present.

Conclusion

In this experiment, the effect of the unattended component of an adaptation plaid on the duration of the MAE using a different comparison was investigated. This experiment showed that having a moving object in the visual field while trying to attend to another moving object, reduces the attention performance and reduces its processing by the visual motion system.

Experiment 4: Time Experiment

This experiment was performed in order to investigate whether the amount of time the participants allocated their attention to a component of a plaid during adaptation had an influence on the duration of the MAE. The results will be used to determine whether the weaker MAE in the control condition of the preliminary and the main experiments, as compared to the MAE of the experimental condition, was the result of having been adapted to the stimulus for a shorter time or a direct effect of the attention manipulation.

Method

Participants

11 participants performed the experiment (6 females and 5 males). The participants were aged between 22-56. All participants had previous experience with psychophysical experiments. Two participants (ASD and MVG) were not naïve as to the purpose of the experiment. All participants were required to have normal or corrected-to-normal vision.

Apparatus and Materials

The same apparatus and material as the one used in the main experiment were used in this experiment.

Stimuli

The cue stimuli were the same as in the main experiment. Only heterogeneous plaids were used in this experiment. The adaptation stimuli consisted of the same sine-wave heterogeneous plaids used in the main experiment. Each adaptation stimulus was presented for 20 seconds, as in the main experiment, or for 40 seconds. The test stimuli consisted of the same flickering counter phase gratings as the ones used in the main experiment.

Procedure

The procedure was the same as in the main experiment.

Results and Discussion

Attention

The raw data for attention consisted of the time in seconds the participant attended to 1) the cued component and 2) the conditions where the participant was required to attend to both components of the plaid alternately. The raw data for attention were transformed into a ratio. The ratios consisted of 1) the time (sec) that the motion of the cued component was dominant divided by the sum of the duration of time where each component and the coherent motion dominated. 2) The time that the motion of the uncued component was dominant divided by the sum of the duration for the cued and uncued component and the coherent motion. 3) For the conditions in which both directions were cued (circle), half of the ratios consisted of the time (sec) during which the component moving to the right was dominant over the time when the left and the right components and the coherent motion were dominant. The other half of the ratios consisted of the amount of time (sec) during which the component moving to the left was dominant over the amount of time the left and the right components and coherent motion were dominant.

Each stimulus was repeated 5 times. The conditions were: 1) attention to a first-order component for 20 seconds, 2) attention to a first-order component for 40 seconds, 3) attention to both components alternately for 20 seconds, 4) attention to a second-order component for 20 seconds, 5) attention to a second-order component for 40 seconds, 6) attention to both components alternately for 40 seconds. Because in the preliminary and the main experiments no effect for the type of component attended (first-order; second-order) was found, the data points for these two conditions were averaged together in the statistical analysis. In this experiment, both types of component produced similar amount of MAE (first-order: M= 6.72, *SEM* = 1. 09; second-order: M= 7.11, *SEM* = .78) ($p >$ .05). Therefore first- and second-order components "saturate" with the same time course.

A two way repeated measures ANOVA was used to analyze the attention results. The two independent variables were 1) adaptation time (20 or 40 seconds), 2) attention manipulation during the adaptation (one attended component, both components attended). The 2 x 2 repeated-measures analysis of variance indicated a statistically significant main effect for attention $F(1,10) = 64.55$, $p < .0001$. None of the other main effects and interactions were statistically significant (Figure 13) (See Appendix P for means and *SEM*s and Appendix Q for the source table). The participants performed the attention task as required. They allocated their attention for a longer time to a cued component than when no attention cue was given. The not significant main effect for time indicated that the attention performance of the participant did not drop as the adaptation period increased in time.

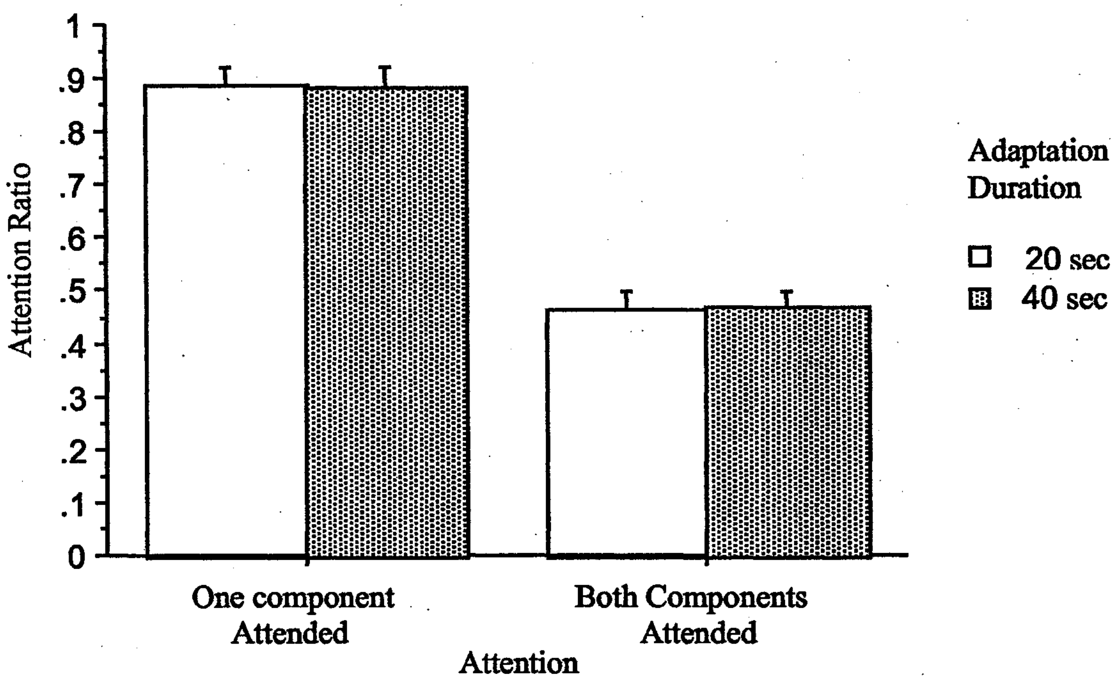


Figure 13. Mean and standard error of measurement of the attention ratio for heterogeneous plaids when adapting for 20 seconds and 40 seconds to one component or to both components of the plaid (n=11).

MAE

The data of the 11 participants were included in the group data analysis. The raw data consisted of the duration and the direction of the perceived motion in a counterphase test stimulus. The MAE duration (sec) and the direction were included in the statistical analysis. A negative duration for the MAE means that in the test a motion in the direction of the attended component of the adaptation plaid was perceived.

A 2 x 2 repeated measures ANOVA was used to analyze the MAE results. The first independent variable was time (the duration of the adaptation stimulus) either 20 second or 40 seconds. The second independent variable was the instruction of attention. The participants were required to attend to one component during the whole adaptation period or to let their attention free to alternate between both components of a plaid during the adaptation.

The main effect for attention was statistically significant. Attending to only one component of a plaid produced a longer MAE than when attention was free to alternate between both components of the plaid during adaptation ($F\,(1,10) = 5.95, p < .035$). The main effect for time was not statistically significant. The MAE duration did not increase as the adaptation time increased. The interaction between time and attention was not statistically significant (Figure 14) (see Appendix R for means and *SEM*s and Appendix S for source table).

This experiment tells us that the participants are equally good at attending for 20 sec as for 40 sec. The finding that doubling adaptation duration from 20 to 40 sec, for either a one-component or two-component plaid, leads to roughly equivalent MAE durations, suggests the following: 1) Since MAE duration has previously been found to

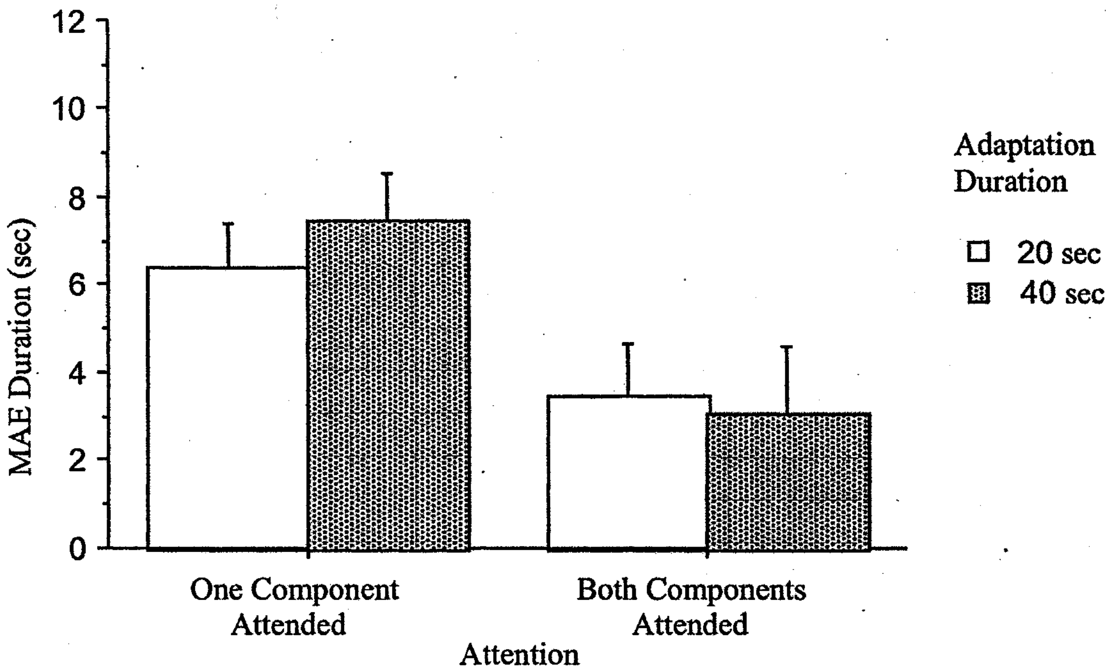


Figure 14. Mean and standard error of measurement of the MAE duration for heterogeneous plaids when adapting for 20 seconds and 40 seconds to one component, or to both components of a plaid alternately (n=11).

increase with increasing adaptation duration (Hershenson, 1989; Kwas, 1999), but in a decelerating fashion, adaptation seems to have leveled off in the present situation after the relatively short time of 20 seconds. 2) The finding in the preliminary experiment and the main experiment, that MAE was longer in the experimental (with specific attention) than in the control (with attention switching) condition, is unlikely to be the result of the longer attentional selection of the tested grating in the experimental condition at least for the range of durations used in this study.

The second finding of this experiment was that the same adaptation times led to MAEs twice as long an MAE when there was only one component cued than when there were two. When there was one component cued, attention remained on that component for practically the entire adaptation time, with only very brief interruptions. When there were two components cued, observers switched attention between the two components, so that the overall adaptation duration with attention for each component was only half as long as in the equivalent one-component situation. Together with the first finding above, this can explain the shorter MAE for the 20 sec adaptation time in the two-component case, but not the equally short MAE for the 40 sec adaptation duration for the same case.

Switching attention during adaptation can have two effects: it might simply withdraw attention from the unattended component or it might actively suppress processing of the unattended component. It has been found that attention is required to produce an MAE for a component of a complex stimulus (Lankheet & Verstraten, 1995; Sohn, 2004), thus a time without attention will not add to the duration of the MAE. Kwas (1999) found that using a unidirectional grating as adaptation stimulus, interrupting the adaptation period with five blank episodes did not significantly reduce the strength of a subsequent MAE. In her experiment, the adaptation time was statistically the same for the two conditions. Thus interrupting adaptation by simply withdrawing attention cannot explain our second finding.

The conclusion is that active suppression of the unattended component must take place to explain our findings. This conclusion is the same as proposed by von Grünau et al., (1998) to explain the results of their MAE experiment.

Conclusion

This experiment tells us that the participants are equally good at attending for 20 sec as for 40 sec. Increasing the adaptation duration of one component or of both components does not proportionally increase the MAE. Therefore, in the main experiment and in the preliminary experiment, it is not the longer duration that the participants adapted to a component of a plaid that increased the MAE for the experimental condition as compared to the control. Attending to one component of a plaid produced almost twice as much MAE than attending to both components alternately. Therefore, active suppression of the unattended component must take place in the control condition because even if the participants adapted for the same duration in the experimental and the control condition, switching components during adaptation produced smaller MAE duration.

One of the possibilities is that the 20 and 40 s durations leaded to the same amount of MAE because the adaptation effect was maxed out. Therefore, it would have been important to test 10 s duration as well.

The results of this experiment support our previous conclusion that active suppression of the unattended component occurs when attention is switched between the two components during adaptation. And this suppression determines the duration of the observed MAE.

General Discussion

The main findings of this thesis are as follows: 1) Participants are able to attend to a component of a complex moving stimulus and this equally well whether the component comprises first-order motion or second-order motion. Furthermore, the performance of attending to a component of a complex moving stimulus is the same whether the unattended component and the attended component are made up of the same type of motion or of different types of motion. Attending to a component of a complex stimulus is not affected by the adaptation duration. Although participants are able to attend to a cued component of a plaid more than 80 % of the time, the unattended moving component occasionally "grabs" attention. 2) Attending to a component of a moving stimulus increases the MAE for this component as compared to when attention is not actively directed to a specific component of a complex moving stimulus during adaptation. 3) Actively not attending to a component of a complex moving stimulus reduces the MAE for this component as compared to when attention is not actively directed away from a specific component of a complex moving stimulus during adaptation. 4) Increasing the adaptation time does not increase the MAE duration. This is true when attention is allocated to one component of a plaid and when attention is allocated to both components of the plaid during adaptation. 5) The MAE produced when a component of a plaid is actively attended is roughly twice as much as the MAE produced when both components were attended equally. Even when adaptation duration to one component of a plaid (experimental condition) is the same as the adaptation duration to one component of a plaid in the situation where both components are attended but no component is specifically cued (control condition), the MAE produced in the control condition remains approximately half as strong as the MAE produced in the experimental condition (experiment 4). 6) Attending to a first- and a second-order motion during adaptation produces the same amount of MAE in a subsequent dynamic test. Actively ignoring a first- or a second-order motion during adaptation produces the same amount of suppressive effect on the MAE in both homogeneous and heterogeneous plaids.

Voluntary Control of Attention

In a stimulus involving two motions that are overlap in space but move in different directions, participants can direct attention to one of the motions (Cullam et al. 2000; Lankheet & Verstraten, 1995) or to the overall motion of the stimulus. von Grünau et al. (1998) using a plaid made-up of two first-order gratings found that attention could be directed to one of the two components of a transparent plaid. von Grünau and Faubert (1998) arrived at the same conclusion as von Grünau and al. (1998) using transparent plaids comprising first- and second-order gratings. In this thesis, the participants were also able to attend to a component of a plaid equally well when the plaid comprised two first-order motions, two second-order motions or a mixture of a first- and second-order motion. Attending to a component of a plaid was not influenced by the adaptation duration. For instance, increasing the adaptation duration from 20 to 40 sec did not decrease the percentage of time the participants attended to the cued component. The participants were able to attend to the cued component of a plaid more than 80 % of the time during adaptation. Nevertheless, the unattended component "grabbed" the attention of the participant on some occasion during the adaptation. The involuntary shift in attention suggests that all moving stimuli in a display involving many motions are salient stimuli (Treisman & Gelade, 1980) and exogenously moving stimuli such as the other uncued component of the plaid attracted attention on some occasions. This involuntary shift in attention is highly adaptive in the real world. It might be essential for the survival of individuals to shift attention to other moving stimuli around us in order to avoid collisions with them. In this thesis, It has been noticed that this involuntary shift of attention occurs for the same amount of time during an adaptation period whether the attended component is a first-order or a second-order motion and whether the unattended component was a first- or a second-order motion. This finding suggests that the attentional system does not privilege one type of motion over the other.

Attention Modulates Motion Processing

In this thesis, the MAE was used to study the effect of attention on motion processing. Although Wohlgemuth (1991) did not find an effect of attention on the MAE, it has been well documented in the more recent literature that: 1) Attention increases the duration of the MAE when directed to a moving stimulus (Sohn, 2005; von Grünau et al. 1998). 2) Attention modulates the direction of the MAE (Cavanagh, 1992; Lankheet & Verstraten, 1995; Watanabe & Miyauchi, 1998). For instance, Cavanagh (1992) demonstrated that attention could determine the direction of a perceived motion and its subsequent MAE. He presented two opposite motions defined by color or luminance to the participants at the same spatial location. He found that directing attention to one motion component biased the perception of the overall motion in that direction and produced a MAE in the opposite direction as the direction of the perceived motion during adaptation. 3) Attention directed away from the moving adaptation stimulus decreases the duration of the MAE (Chaudhuri, 1990; Georgiades & Harris, 2000, 2002; Rees, et al. 1997; Rezec et al. 2004; Shulman, 1991, 1993; Takeuchi & Kita, 1994;). It has been consistently found within the experiments of this thesis that attention has enhancing and suppressing effects on motion processing.

Attention Directed to a Moving Component of a Complex Stimulus

As hypothesized, an enhancement in the duration of the MAE when attention is directed to the motion of a component of a plaid compared to when attention is not directed to one specific component of the plaid and the percept is of two overlapping transparent motions in different directions was found. This finding is in agreement with the results of many studies which also showed that attention selectively increases the duration of the MAE for a moving component of a complex moving stimulus when directed to this component during adaptation (Del Vecchio, Faubert & von Grünau, 2001; Del Vecchio & von Grünau, 2002; Lankheet & Verstraten, 1995; Mukai & Watanabe, 2001; Sohn, 2005; von Grünau et al. 1998). This enhancement in the MAE occurs whether the motion of the adaptation stimulus is made up of two first- (Mukai & Watanabe, 2001; von Grünau et al. 1998;) or two second-order motions as demonstrated in this thesis (Lankheet & Verstraten, 1995). Therefore, the results of this thesis support the hypothesis that attention enhances the processing of a selected moving object in the visual field and this, independently of the type of motion attended. The models of motion extraction are silent on the attentional modulation of motion. Our experiments, however, shows that passive extraction of motion energy such as modeled in the Reichardt type model might not be enough to explain motion processing by the visual system. The results of the experiments of this thesis and other studies on the modulation of motion by attention (e.g. Chaudhuri, 1990; Lankheet & Verstraten, 1995; von Grünau & al., 1998) suggest that extraction of motion energy can be affected by attention in both directions (enhanced or reduced).

In the main experiment the increase MAE durations following active selection of one component of a plaid found in von Grünau et al. (1998) and von Grünau and Faubert (1998) was replicated. This increase in the duration of the MAE was present when the adaptation plaid was made-up of first-order components, second-order components and when it was made up of a mixture of a first-and a second-order components. However, although the result was in this direction, they were not replicated in the preliminary experiment. This might be due to the small number of participants or the extra task required after adaptation to allow the measurement of the MAE. Furthermore, the results of this thesis show that motion processed higher in the visual motion pathway (second-order motion) is not modulated differently by attention compared to motion processed at a lower level (first-order motion). Also no difference was found in the MAE production when the unattended component of a plaid was made up of the same type of motion as the attended component or of a different type. This latter finding suggests that attention acts at both levels in similar ways to influence the processing of motion. Attention does not privilege one type of motion over the other, at least when a dynamic test is used.

Attention Directed Away from a Moving Component of a Complex Stimulus.

It has been repeatedly demonstrated in the literature that attention directed away from the moving adaptation stimulus decreases the MAE (Chaudhuri, 1990; Georgiades & Harris, 2000, 2002; Rees, et al. 1997; Rezec et al. 2004; Shulman, 1991, 1993; Takeuchi & Kita, 1994). In these studies, however, the distractor was not in the same visual field as the attended moving stimulus. The window of attention for the distractor was much smaller than the window of attention for the adaptation stimulus. It has also been demonstrated that not attending to one component of a complex moving stimulus that involves two motions in different direction but at the same spatial location removes the increase in MAE that would have occurred had the participants been instructed to attend to one component of the complex stimulus (Verstraten & Lankheet, 1995; Watanabe & Miyauchi, 1998). In these studies, the attended and unattended components are in the same visual field. However, it is not clear whether the processing of the unattended component is actually suppressed or the processing remains similar to the situation where the participant is attending to the whole complex stimulus (Fox, 1994; Johnston & Dark, 1986; Kinchla, 1992;).

It has been demonstrated that when attention is directed to one motion of a plaid during adaptation, the processing for the other motion of the plaid decreased as compared to the baseline (Del Vecchio, Faubert & von Grünau, 2001; von Grünau et al. 1998). In the experiments constituting this thesis, results similar to the one just described were found. A smaller MAE for the unattended component of the plaid compared to the attended component has been consistently found across all experiments of this thesis. Also, a smaller MAE for the unattended component of the plaid compared to the MAE produced in the control condition in which none of the components of the plaid were specifically cued was found. This latter finding suggests that the unattended component is more than just unprocessed, it is suppressed when attention is directed to another component of a complex moving stimulus. The results of this thesis suggest an active inhibition of the unattended component. This is in agreement with Miller (1991) and Tipper and Cranston (1985) and against the argument that unattended stimuli in a visual field remain unprocessed (Johnston & Dark, 1982).

von Grünau et al. (1998) using a plaid as the adaptation stimulus found suppression of the MAE for the unattended component of a complex homogeneous first-order stimulus. Using the same method but heterogeneous plaids made up of one first-order component and one second-order component, von Grünau and Faubert (1998) found no suppression of the MAE when the test was oriented in the orientation of the unattended component. Taking these results they concluded that first- and second-order motion are processed at different levels along the motion pathway. However, the results found in the experiments of this thesis consistently demonstrated that there is a suppression of the processing of the unattended component of a complex moving stimulus and this suppression is equally strong in homogeneous and heterogeneous plaids. It is unclear why von Grünau and Faubert (1998) arrived at a different conclusion about the suppressive effect of the unattended component in heterogeneous plaid. The same stimulus and methodology were used in the study of von Grünau and Faubert

(1998) and in the experiments of this thesis. Both studies used two spatially superimposed but temporally interleaved sine-wave gratings as the adaptation plaid. Also, the second-order motion stimulus in von Grünau and Faubert (1998) was made up of the same type of second-order motion as the one used in the experiments of this thesis: modulation of texture. Therefore, it is difficult to explain the different results found between von Grünau and Faubert (1998) and our results. Unfortunately, von Grünau and Faubert's (1998) study was a preliminary study using a limited number of participants. Since only three participants were used including the two experimenters, it might be the case that the lack of suppressive effect occurred by chance or was the result of a lack of power. In their pilot study, the data were in the direction of a suppressive effect. The results could also be attributed to another unsuspected and unknown extraneous variable due to the results of the statistical analysis (faliure to reject the null hypothesis).

The results of the experiments presented in this thesis consistently demonstrate that the processing of an unattended component of a complex moving stimulus is suppressed and this is true whether the unattended component is of the same or different type as the attended component. Other evidence also suggests a suppression of the MAE in homogeneous and heterogeneous plaids. This evidence is highlighted in the results of the specific experiments and will be discussed in the next section.

Adaptation Time

In the experiments of this thesis a larger MAE when one component was attended as compared to when two components were attended during the adaptation has been consistently found. One could argue that on average a participant attended twice as much to a cued component than to one component when attention was not specifically directed to it during adaptation. This could account for the smaller MAE in the control condition as compared to in the experimental condition. However, It has been found that increasing the adaptation time did not increase the MAE duration. This is true when attention is allocated to one component of a plaid and when attention is allocated to both components of the plaid during adaptation. Furthermore, the MAE produced when a component of a plaid was actively attended was roughly twice as much as the MAE produced when no particular component of a complex stimulus was attended. This effect is independent of the adaptation time to one stimulus because when the adaptation time was increased in order to have equal amounts of adaptation time in the experimental and the control condition, the MAE for the attended component remained twice as large as the one for the control condition. Even when the adaptation time to one component of a plaid (experimental condition) was the same as the adaptation time to one component of a plaid in the situation where both components were attended (control condition), the MAE produced in the control condition remained approximately half as long. Therefore, it is not the adaptation time as such that reduced the duration of the MAE in the control condition but an active suppression caused by the unattended component that occurred when attention was switched between the two components during adaptation. This conclusion is supported by the finding that the MAE for a grating was larger than the MAE for an attended component of a plaid.

Is our Second-Order Motion Really a Second-Order Motion?

What constitutes a pure second-order motion stimulus has been debated in the literature. Ledgeway (1994) argued that contrast modulated static noise may not be an appropriate second-order stimulus because it may contain first-order artifacts. Ledgeway and Hutchinson (2005) and Smith and Ledgeway (1997) proposed using dynamic noise in order to reduce first-order elements in the stimulus. However, Verstraten et al. (1996) argued that the stimulus becomes less visible due to the dynamic noise, which may in fact become an extraneous variable when using dynamic noise. In agreement with Verstraten et al. (1996), using fMRI Seiffert et al. (2003) showed that dynamic contrast modulated noise produced more activation than contrast modulated rings, which were static. Benton and Johnston (1997) also disagree with the use of dynamic noise in order to reduce the first-order artifact of a second-order stimulus as proposed by Ledgeway (1994).

Another way to reduce the first-order artifact in a second-order motion might be to use small elements of noise. Gurnsey, Fleet and Potechin (1998) and Smith and Ledgeway (1997) suggested using small noise elements in order to reduce the first-order artifact in an image. Gurnsey et al. (1998) stated that the first-order elements decrease and second-order elements increase as a function of the size of the noise element in a contrast modulated noise pattern.

In this thesis, a modulation of texture where the luminance remains stable was used as a second-order stimulus. I was aware of the difficulty involved in producing a pure second-order motion. In order to decrease the first-order contamination in the second-order stimulus, these steps were used. First, second-order stimuli were presented interleaved instead of superimposed on first-order stimuli. Second, small noise elements were used. Third, the viewing distance was kept stable by using a chin rest. Fourth, the participants were encouraged not to blink their eyes during the presentation of the adapting stimuli and test stimuli because it has been found that blinking the eyes or changing the viewing distance can reintroduce the first-order artifact in an image (Bowns, 2002; Savoy, 1987).

Where Along the Motion Pathway Does Attention Exert its Effect on Motion Processing?

The motion of both plaid components is analyzed at lower levels in the motion pathway and both motions are integrated at V5 (higher). It has been consistently demonstrated that a strong MAE was produced in the direction opposite to the integrated motion and this independently as to whether the participant perceived coherent motion or transparent motion (Wenderoth et al., 1988; Burke & Wenderoth, 1993). This strong MAE was also present in transparent plaids made up of gratings alternating in time (Del Vecchio et al., 2001; Del Vecchio & von Grünau, 2002; von Grünau & Dubé, 1992). Finally a strong MAE in the direction opposite to the coherent motion of a plaid was also present when the participants directed attention to one component of a plaid during adaptation (Del Vecchio & von Grünau, 2002). Therefore it seems that the integration of motion processing is independent of whether the attention is directed or not to a component of a plaid. However, the processing of the motion component of a complex motion is strongly affected by attention modulation using a dynamic test.

The MAE literature tells us that the processing of the individual motions of a complex stimulus requires attention (Lankheet and Verstraten, 1995). Without attention the MAE of two fields of dots moving in opposite directions is cancelled out. In order for the motion of the individual component to be processed attention is needed on one of the fields of dots (Lankheet & Verstraten, 1995). Also no, or very little, MAE is produced for a plaid component when attention is not specifically directed to it during adaptation (von Grünau et al., 1998).

In the experiments of this thesis similar results were found. Attention to a component of a plaid produced a strong MAE. Attention not directed to a component of a plaid, but not directed away from it either, produced an intermediate MAE, attention directed away produced almost no MAE.

What does this tell us about where along the motion pathway attention exerts its effect on motion processing? In order to access the processing of the individual component of a complex motion with the MAE, attention needs to be directed to the individual component during the adaptation. Therefore, attention seems to modulate the processing of motion at low and high levels in the motion pathway using a dynamic test, which is known to pick up motion processing at the different levels along the motion pathway.

Another way to investigate where along the motion pathway attention exerts its effect is to look at the effect of attention on different types of motion known to be processed at least initially by different mechanisms situated at different levels along the motion pathway. Lankheet and Verstraten (1995) demonstrated using a second-order complex stimulus consisting of two sheets of dots moving in opposite directions that a MAE is produced only if the participants attend to one field of dots. If attention is not directed to a particular field of dots, the opposite motions cancel out the MAE. von Grünau et al. (1998) studied the benefit and cost of directing attention to one component of a complex first-order stimulus using a plaid as an adaptation stimulus. von Grünau et al. (1998) were able to bias the direction of the MAE by directing attention to one component of this complex stimulus. Therefore, attention enhances the processing of first- and second-order motion at the low and high level in the motion pathway.

The experiments of this thesis also showed that attention could be directed with the same efficiency to a first-order motion and to a second-order motion of a complex moving stimulus. Attending to one component of a complex moving stimulus increased the processing of this component and decreased the processing of the other unattended component in the same visual field. This effect was present independently whether the components of the adaptation plaid were made-up of first- or second-order motions or a mixture of a first- and a second-order motions. Therefore, in this thesis it has been shown that luminance and contrast modulation of texture motions are affected by attention in the same manner. This suggests that the effect of attention on motion processing is the same at the levels where first-order and second-order motions are integrated.

Conclusion

Attention can alter the processing of motion at low levels within the motion pathway. Attention has enhancing and suppressing effects on the low level motion processing. Different types of motion known to be processed at least initially by different mechanisms and at different locations along the motion pathway (first- and second-order motion) are affected in the same way by attention.

In the future the effect of attention manipulation on the modulation of the overall motion aftereffect (with a test in the orientation of the motion generated by the combination of the two motions of the plaid) could be investigated. For instance the participants could be instructed to attend to one component of a plaid and ignore the other. The same plaid as the one used in this experiment could be used. The test in the orientation of the overall motion can tap the MAE produced for the integrated motion. This is a motion that is believed to be analyzing at a higher level than the motion of the individual components that compose the plaid. This experiment could give information about the effect of the allocation of attention to a motion analyzed at a low level on the integrated motion processing of a scene. Del Vecchio and von Grünau (2002) did this experiment but they used square-wave gratings, therefore, the differential effect between first- and second-order motions could not be investigated due to the high possibility to have introduced first-order artifacts in the second-order motion. Nevertheless, they found that the integration of different motions known to be achieved higher than the processing of each individual motion along the motion pathway (MT and higher) seems less affected by attention than the modulation of attention at lower levels (Del Vecchio and von Grünau, 2002).

Other types of second-order motions could also be investigated using exactly the same paradigm and method used in this thesis. Cavanagh (1995) has found that different types of second-order motion produce different results. Therefore, perhaps not all types of second-order motion are analyzed at the same level in the motion pathway. Does attention act the same way on different types of second-order motion? Cavanagh and Anstis (1991) found that texture-defined moving stimuli and color-defined motion interfere with the first-order motion in the nulling task. Also, Stoner and Albright (1992) found that a second-order grating and a texture-defined grating in a plaid cohere and may be perceived as one motion under the right conditions. However, no nulling occurs for luminance-defined motion and stereo-defined second-order motion and no coherence occurs between a texture-defined motion and a stereo-defined grating. Finally, Cavanagh (1992) found that when participants were asked to attend to the motion of a grating in an inner annulus while also asked to report the motion in an outer annulus, the participants' performance is degraded for outer annulus motion defined by stereo-defined gratings but not for color-, texture-, or luminance-defined gratings, suggesting that motion perception for the former type of motion is processed higher than luminance and texture based stimuli. Cavanagh (1995) argues that research evidence suggests that low-level motion detectors exist for equi-luminant color-defined motion (Cavanagh & Anstis, 1991) and texture-defined motion (Cavanagh, 1995) but not for stereo-defined motion (Cavanagh, 1995). Therefore, it would be relevant to redo the experiments of this thesis using a different type of second-order motion such as a stereo-defined motion.

The results of this thesis can have implications in everyday situations where active attention is crucial. For instance, the results suggest that the increasing presence of moving stimuli such as moving advertising displays or billboards, navigators that use motion signals and other devices that generate motion signals reduces performance on tasks with attention demands when needed such as when driving or operating heavy machinery.

The results of this thesis also suggest that humans can choose to direct or sustain our attention to a moving stimulus in the presence of other moving stimuli. This decision influences the way the motion will be processed. Although, attention will switch involuntary to unattended moving object in the same visual field, the attended motion will remain the main processed motion. This involuntary switch of attention permits us to react to objects that could potentially move toward us and, allow us to avoid colliding with the object. However, if the switch of attention is produced by an irrelevant moving stimulus such as other moving stimuli described above that divert attention of a driver, the consequences might be devastating.

In common situations, there may be an advantage to choosing which stimulus or stimuli to which to attend. Sometimes, an organism might be advantaged at not attending to one particular motion in order to be able to process more accurately many motions may be the best choice, such as when trying to find a small lost object on a carpet with a lot of details. In other situations, it might be better to focus our attention on one motion at the disadvantage of the processing of other motions such as while driving.

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APPENDIX A

Equating First- and Second-Order Motion

Equating First- and Second-Order Motion

Blaser, Sperling and Lu (1999) stated that equating first- and second-order motion stimuli properly is important. It is important that first- and second-order motion be equally likely to be dominant during adaptation. von Grünau and Faubert (1998) used a counterphase grating method in order to equate the first-order and the second-order motion stimuli used in their MAE experiment. The counterphase method for equating a first- and a second-order motion consisted of presenting a series of counterphase gratings (a mixture of first- and second-order stimuli), with variable luminance contrast for the first-order stimulus. Luminance contrast was adjusted to correspond to the 50 % threshold for perceived direction of the overall stimulus. von Grünau and Faubert (1998) showed that after having equated a first- and a second-order motion with a counterphase grating method, without selective attention indications, participants spontaneously switched their attention between the first- and the second-order components of a heterogeneous plaid resulting in their attending to each component 50 % of the time. This finding suggests that the method of counterphase gratings used by von Grünau and Faubert (1998) to equate the dominance of both components was adequate. However, some research findings suggest that counterphase gratings might not be adequate to equate first- and second-order motion components making up the plaids.

First, contrary the effects obtained using counterphase gratings made-up of two first-order gratings, motion cancellation cannot be obtained with counterphase gratings made-up of a combination of first- and second-order motion component moving in opposite directions (Ledgeway & Smith, 1994). Motion cancellation consisted of the abolition of the perception of transparency by locally balancing the motion signal (Qian, Anderson & Adelson, 1994). Using two fields of dots moving in opposite directions Qian et al. (1994) demonstrated that the perception of transparency could be eliminated by the cancellation of opposing motions. They explained the effect of oppositely-drifting dots falling into the same receptive fields resulting in no motion signal arising because the motion signal cancelled each other out at the receptor level. Ledgeway (1994) and Ledgeway and Smith (1994) used the cancellation test in order to investigate the difference in first- and second-order motion mechanisms. Their stimuli consisted of a series of counterphase gratings made-up of either two first-order components or a mixture of first- and second-order components, with variable luminance contrast for the first-order stimulus. They found that when two first-order components were presented at a particular level of luminance contrast the motion in opposite directions could be cancelled out. However, Ledgeway (1994) and Ledgeway and Smith (1994) found that when a mixture of a first- and a second-order component formed the counterphase grating, no cancellation could occur. The fact that cancellation is not possible using two types of motion might suggest that they are processed differently by the visual system and therefore cannot be equated (Scott-Samuel & Smith, 2000).

Second, counterphase grating stimuli differs from that of the plaids presented in the experiment of von Grünau and Faubert (1998) and from the plaids of this thesis. The plaids are presented for a prolonged period of time but the counterphase gratings were presented for a few hundred milliseconds only. It has been shown that direction of perceived motion can change after prolonged exposure with a bidirectional moving stimulus (Derrington, Badcock & Hennig, 1993). This finding suggests that observation duration could influence the threshold for equating the salience of the first- and second-order motion of a plaid.

Third, the difference between the counterphase stimuli and the plaids used in von Grünau and Faubert (1998) is that both components of the plaid were perceptible independently (transparent), although this was not the case in the counterphase grating method used to equate first- and second-order motion. A second difference between the counterphase grating method of equating first- and second-order stimuli and the stimuli presented in this thesis was that in the counterphase grating method cells that are tuned to the same orientation but opposite direction were stimulated. The first-order component was moving in the direction opposite to the direction of the second-order component. However, the plaid stimuli presented in the experiments of this thesis, contained first-order and second-order components that were moving in directions that differed by 140 degrees. In this experiment which method for equating the first- and the second-order motion stimuli should be used in the experiments of this thesis will be investigated: a plaid or a grating method.

In order to further increase the similarity between the stimuli presented during adaptation and the stimulus used to equate the first- and the second-order components, a method that uses plaid was developed. A mixture of temporally interleaved components made-up a first- and a second-order grating that formed a plaid was presented for several seconds of and the participants were asked to continuously monitor which grating appeared in front. The plaids formed by these components were identical to the heterogeneous plaids presented to the participants in subsequent experiments of this thesis. The contrast of the first-order stimulus was varied to obtain the 50% threshold corresponding to equal perceived cumulative time for both components.

Our aim was to find the luminance contrast for the first-order stimulus that allowed a participant to perceive the motion of the overall stimulus in the direction of the first-order grating 50% of the time. At this luminance contrast, it was assumes that both components were equated for their likelihood to be dominant. The counterphase grating method has the advantage to be a fast pre-test to administer. In this experiment, the counterphase method was compared to a method that took longer to administer but that was more similar to the stimuli presented in the subsequent experiments of this thesis.

First, the presentation time was different. The counterphase grating was presented for 800 ms in von Grünau and Faubert (1998). In this experiment, the adaptation stimulus was presented for 20 seconds. The presentation time difference might have an effect on the threshold of perceived direction. For instance, Derrington et al. (1993) demonstrated that a type of second-order motion (a beat stimulus) produced consistently higher threshold elevation compared to a first-order luminance grating at presentation times lower than 200 ms, but not for longer periods. In this experiment, two participants were required to discriminate the direction of motion in beats and first-order gratings. The authors attributed this discrepancy to the hypothesis that the second-order visual mechanisms, which analyze the motion of the beat stimulus, are slower than the mechanisms that analyze first-order motion. They stated that this difference in threshold might reflect a more severe low-pass temporal filtering required for the processing of second-order motion compared to first-order motion. Thus, with longer presentation times, such as during adaptation, the threshold might change for the second-order component as compared to counterphase gratings.

To further increase the similarity between the adaptation stimuli used in this thesis and the stimuli used to equate the first- and the second-order components, another aspect of the equating stimuli was also tested. The second-order grating in the experiments of this thesis consists of contrast modulation. This gave rise to the perception of texture in the second-order motion stimulus while the first-order stimulus was perceived as being smooth. Random noise can be added to the first-order component in order to increase the similarity of both gratings. It has been hypothesized that the noise elements included in the first-order stimulus that are used to make it more similar to the second-order stimulus may reduce the clarity of the first-order stimulus. Therefore, a smaller reduction in the luminance of the first-order stimulus may be required to "equate" both stimuli.

Finally, since in the subsequent experiments of this thesis, both square-wave and sine-wave gratings were used, whether the equation of components leads to similar luminance contrast of the first-order component when a sine-versus a square-wave is used in order to make the gratings that formed the plaids was also investigated.

Method

Participants

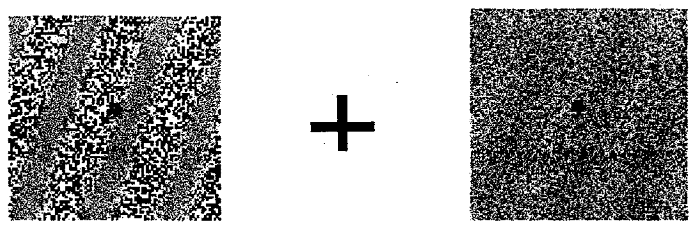
Thirteen observers participated in this study (8 females and 5 males). Ten observers had previous experience in psychophysics experiments. Two participants (ASD and MVG) were familiar with the purpose of the experiment. All participants had normal or corrected-to-normal vision.

Apparatus and Materials

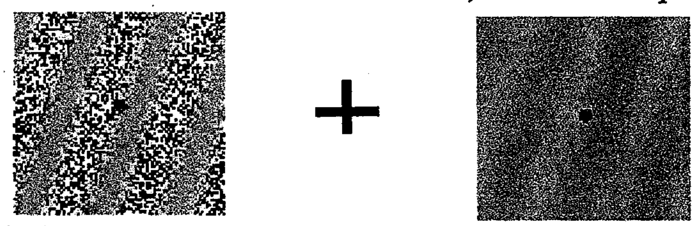
The stimuli were presented on a Power Macintosh 7300/180 computer. The VPixx 1.4 program developed by Peter April (http://www.vpixx.com/) was used to create and present the stimuli. The stimuli were displayed on an 17-inch Apple studio monitor with a refresh rate of 75 Hz. The screen resolution was 800 x 600 pixels. The color depth was set at 256 levels. A chin rest was used to stabilize the participant's head position during testing. Color calibration and luminance readings were taken using a Minolta CS-100 Chroma Meter colorimeter. A 25 watts light bulb in a funnel type lamp was used to dimly light up the testing room during testing.

Stimuli

The twelve stimuli used in this experiment can be seen in Figure 1. Four stimuli were sine-wave counterphase gratings. In two of the counterphase gratings the first-order motion was moving toward the right. One of them included noise in the first-order grating while the other one did not. In two other counterphase gratings the first-order motion was moving toward the left. One of them included noise in the first-order grating while the other one did not. Eight stimuli were plaids made-up of one first- and one second-order component. Four stimuli were plaids made-up of one first- and one second-order sine-wave component. The other four stimuli were plaids made-up of one first- and one second-order square-wave component.



Grating method with noise: First- and second-order, sine-wave components



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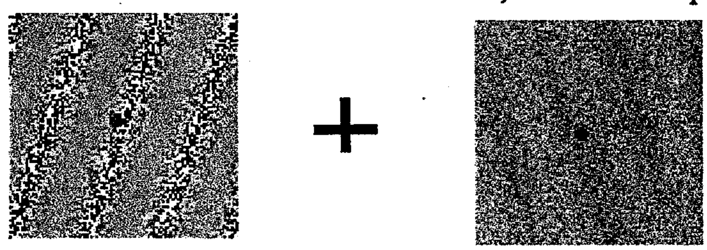
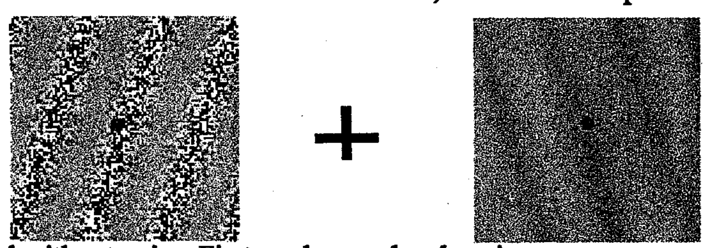
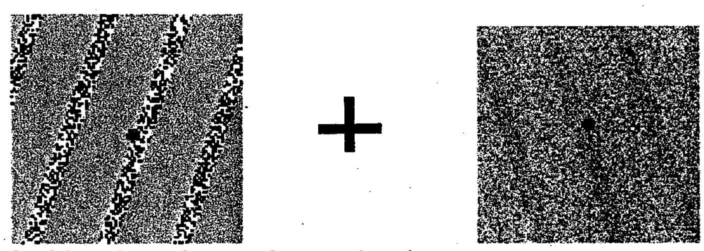


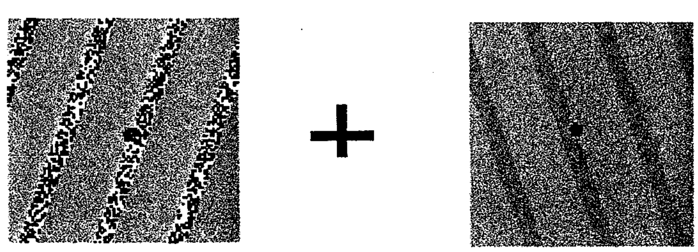
Plaid method with noise: First- and second-order, sine-wave components



Plaid method without noise: First- and second-order, sine-wave



Plaid method with noise: First- and second-order, square-wave components



Plaid method without noise: First- and second-order, Square-wave components

Figure 1. Types of gratings used to construct the counterphase gratings and the plaids used in this experiment.

Display for the grating stimulus. The counterphase grating stimulus presented to the participants consisted of two spatially superimposed but temporally alternating sine-wave gratings moving in opposite directions. Both gratings were interleaved every frame. A frame lasted 13.3 msec because the computer was set at 75Hz. The gratings were tilted 20 degrees to the right of the vertical to match the orientation of the plaid stimuli. The stimuli were presented within a 12-degree circular aperture. At the center of the circular aperture, a red fixation point was present throughout the presentation of the display. The two gratings that formed the counterphase grating had a spatial frequency of .5 cycles/degree. The symmetry of the wave was .5. The gratings were oriented either 20 or –20 degrees away from the vertical. The gratings oriented 20 degrees from the vertical were moving toward the right and the gratings oriented –20 degrees from the vertical were moving toward the left. The temporal frequency of the motion was 7.7 cycles/sec. One temporal cycle of the gratings consisted of 5 static presentations of the grating shifted by 1/5 of a cycle each time. The duty cycle of the gratings was .5. A noise component was included in the first-order grating of the counterphase grating stimulus. In one version of these gratings with noise in the first-order grating, the first-order component was moving toward the left and in the other version the first-order component was moving toward the right. The other two gratings only differed from the first two in that the first-order component did not contain noise.

Display for the Plaids. The plaid stimuli consisted of two spatially superimposed but temporally alternating square-wave or sine-wave gratings moving in directions differing by 140 degrees. The plaids consisted of one first-order and one second-order grating. The spatial frequency of the gratings was 0.5 cycles per degree and their temporal frequency was 7.7 cycles/sec. One temporal cycle for each grating consisted of 5 static presentations of the grating shifted each time by 1/5 of a cycle. Both gratings that composed the plaids were temporally interleaved every frame. A frame lasted 13.3 msec. There was no luminance difference at the intersections of the two gratings because they were not presented together in time. The duty cycle of the gratings was 0.75. The mean luminance was both 12.4 cd/m^2 for the second-order grating, and for the first-order grating. The luminance of the light and dark bars of the first-order motion varied from trial to trial depending on the contrast. However, the luminance of the dark strips for the first-order component varied from trial to trial depending on the contrast. A mask consisting of a white and black dynamic checkerboard pattern was used between each trial to prevent earlier stimuli from influencing the outcome for subsequent stimuli. The mask lasted 160 frames or 1.68 seconds.

Second-order stimulus. The second-order stimulus used for the direction-identification threshold tasks and the plaid task was a contrast-defined noise sine-wave grating. The grating had a spatial frequency of .5 cycles/degree. The equation that defined the luminance profile at each point on the x and y axes was:

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

This formula is adapted from Bertone (1999). L_{mean} is 12.4 cd/m^2, the mean luminance of the display. m_{env} is the modulation depth of the envelope. f is the spatial frequency of the envelope. m_{car} is the contrast of the carrier. R(x, y) is the carrier made of static noise of 1 pixel * 1 pixel, measuring approximately 2.24 arc min. The grayish colored, static carrier was formed using a sinusoidal modulation. The luminance of each dot was determined by the function of sin(x), where the luminance of x ranged from 0 to

2π for the sine-wave gratings and ranged from 0 to 1 for the square-wave grating. Fixed noise elements (the carrier) were multiplied with the sine-wave grating (the envelope) in order to form the second-order stimulus. The symmetry of the wave was .5. The second-order grating was oriented either 20 or –20 degrees away from the vertical. The temporal frequency of the motion was 7.52 cycles/sec. One temporal cycle of the second-order grating consisted of 5 static presentations of the grating shifted each time by 1/5 of a cycle. The duty cycle of the grating was .75.

First-order stimulus. The first-order stimulus was a luminance-modulated sine- or square-wave grating. The symmetry of the first-order stimulus was identical to the symmetry of the second-order stimulus. The motion of the grating was oriented 20 degrees away from the vertical. The temporal frequency of the first-order grating, as well as its duty cycle, was identical to those of the second-order grating. A uniform sheet of noise was added in one condition but not the other condition. Ten luminance contrasts of the first-order stimulus were used in this experiment (.08, .1, .12, .14, .16, .18, .2, .25, .3, and .4).

Procedure

The participants were tested individually in a laboratory room. Prior to the experiment they read a consent form in which the requirements as well as the instructions for the experiment were indicated. They signed the consent form if they agreed to participate in the experiment. Procedural instructions were repeated verbally to the participants before each of the eight conditions. The whole experiment lasted approximately 80 minutes, each session lasting 10 minutes. Experimental conditions were administered in a random order. Each counterphase grating trial lasted approximately 770 msec. Twenty-five replications of the 10 contrast luminance stimuli were administered within a condition. Each plaid trial lasted approximately 20 seconds. Ten luminance contrast variations of the plaid conditions were presented within a condition. This condition was performed twice and the results obtained in two repetitions were averaged. The monitor surface was at a distance of 57 cm from the chin rest. The participants viewed the display binocularly.

During the counterphase grating presentation, the participants were asked to fixate at the fixation point. At the end of each trial, the participants were required to indicate their perceived direction of the overall motion of the stimulus. They were required to press the left arrow if they perceived the motion going to the top left and the right arrow if they perceived the motion going to the bottom right.

During the plaid presentation, the participants were also asked to fixate at the fixation point. During each trial, the participants were required to indicate the direction of the predominant grating. They continuously pressed the left arrow when they perceived the motion of the predominant grating as moving to the bottom left and the right arrow when they perceived the motion of the predominant grating as moving to the bottom right. If they perceived a motion going in the direction of the coherent motion, they pressed the "c" key.

Results

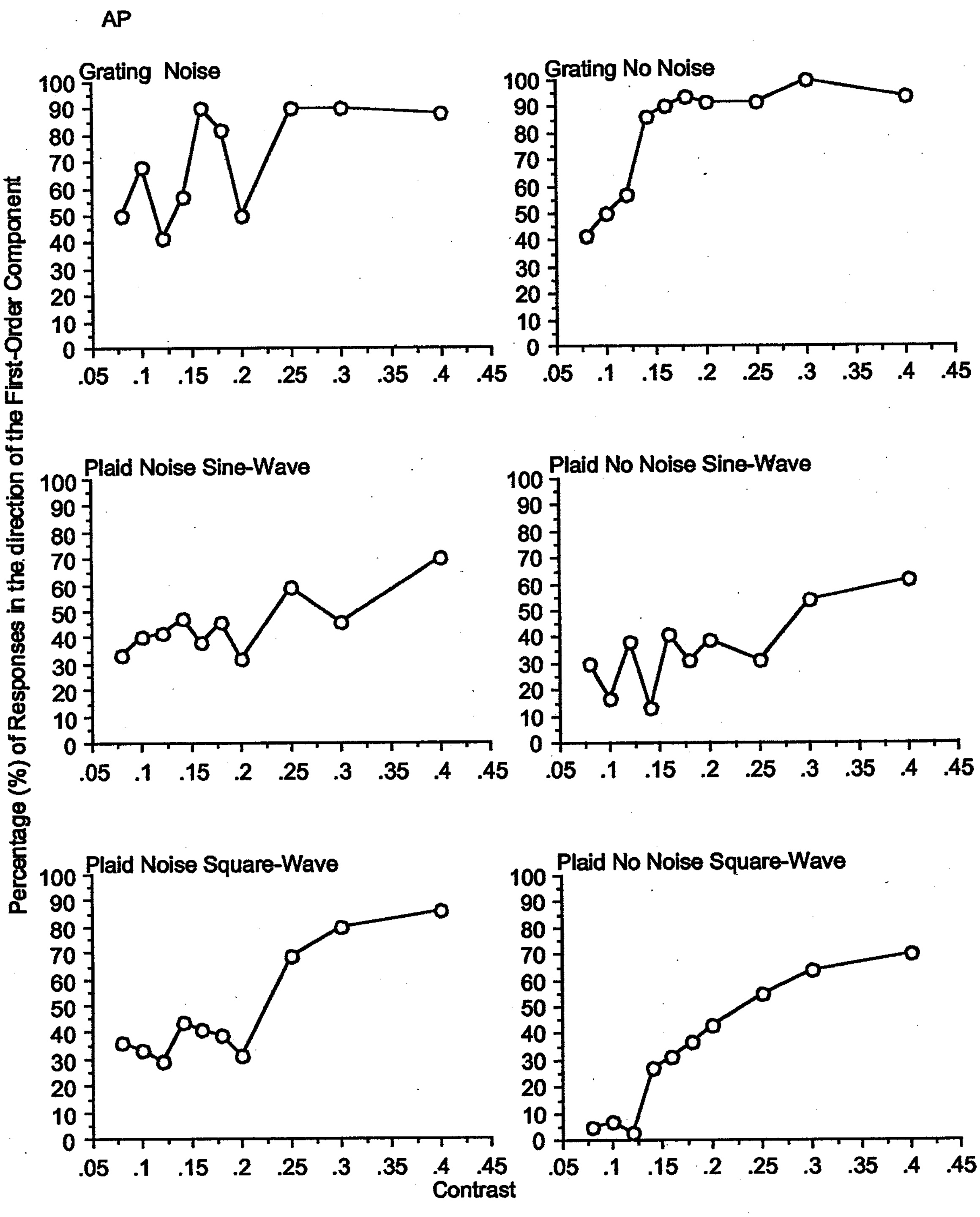
Grating. The raw data represented the number of trials out of 25 trials in which the observer reported the motion as moving in the direction expected if they were attending to the first-order component. The results obtained for the first-order grating moving to the left and the first-order grating moving to the right were added together for a total of 50 repetitions for each luminance contrast. The number of the responses for each luminance contrast of the first-order component was fitted to a curve and the 50% threshold was computed using Bootstrap v2.1 computer software. Figure 2 shows the percentage of motion in the direction of the first-order component as the luminance contrast of the first-order component is increased. The results of each participant are presented separately.

Tables A and B show the 50% luminance contrast threshold for each participant when a grating was presented with 1) no noise and 2) noise added, respectively.

Plaid. The raw data for the plaids represent the number of time (s) that the participant attended to the first-order, the second-order or both components during a 20 second trial. The results obtained for trials where the first-order grating was moving to the left and the duration for trials where the first-order grating was moving to the right were added together. The raw data for attention were transformed into a ratio. The ratio consisted of the amount of time the first-order motion was dominant, divided by the total adaptation time. These ratios were converted into percentages. They were fitted to a curve to find the 50% luminance threshold. Table C and D show the 50% luminance contrast threshold for each participant when they were presented with a sine-wave plaid with no noise and with noise added, respectively. Table E and F show the 50% luminance contrast threshold for each participant when they were presented with a square-wave grating plaid with no noise and with noise added, respectively.

Figure 3 illustrates the effects of noise (noise versus no noise) and type of stimulus (plaid vs. grating (square- and sine-wave)) on luminance contrast for the first-order

Figure 2. Percentage of responses indicating motion perception consistent with the direction of the first-order component as a function of the luminance contrast in the first-order component. The results for each participant are shown separately.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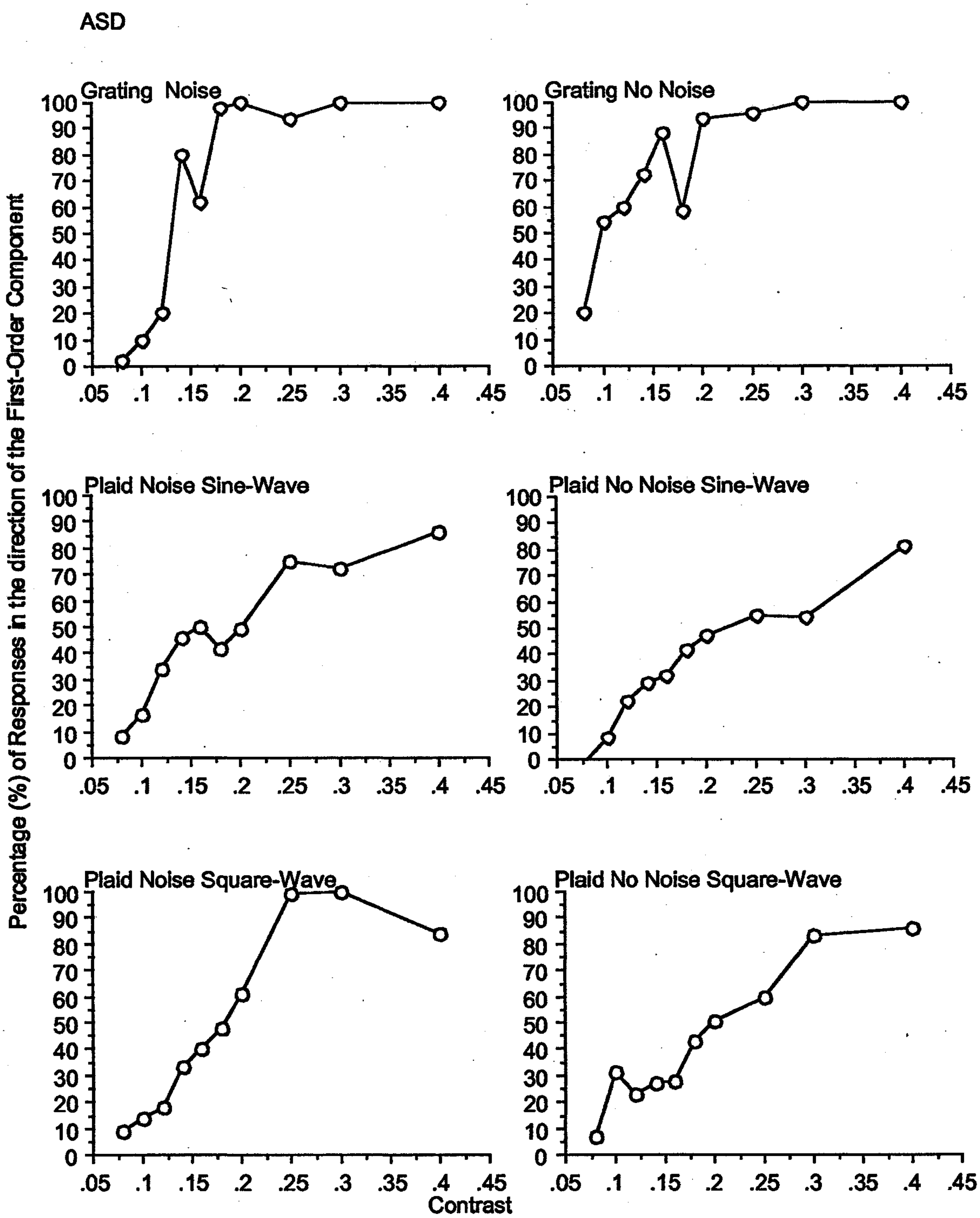
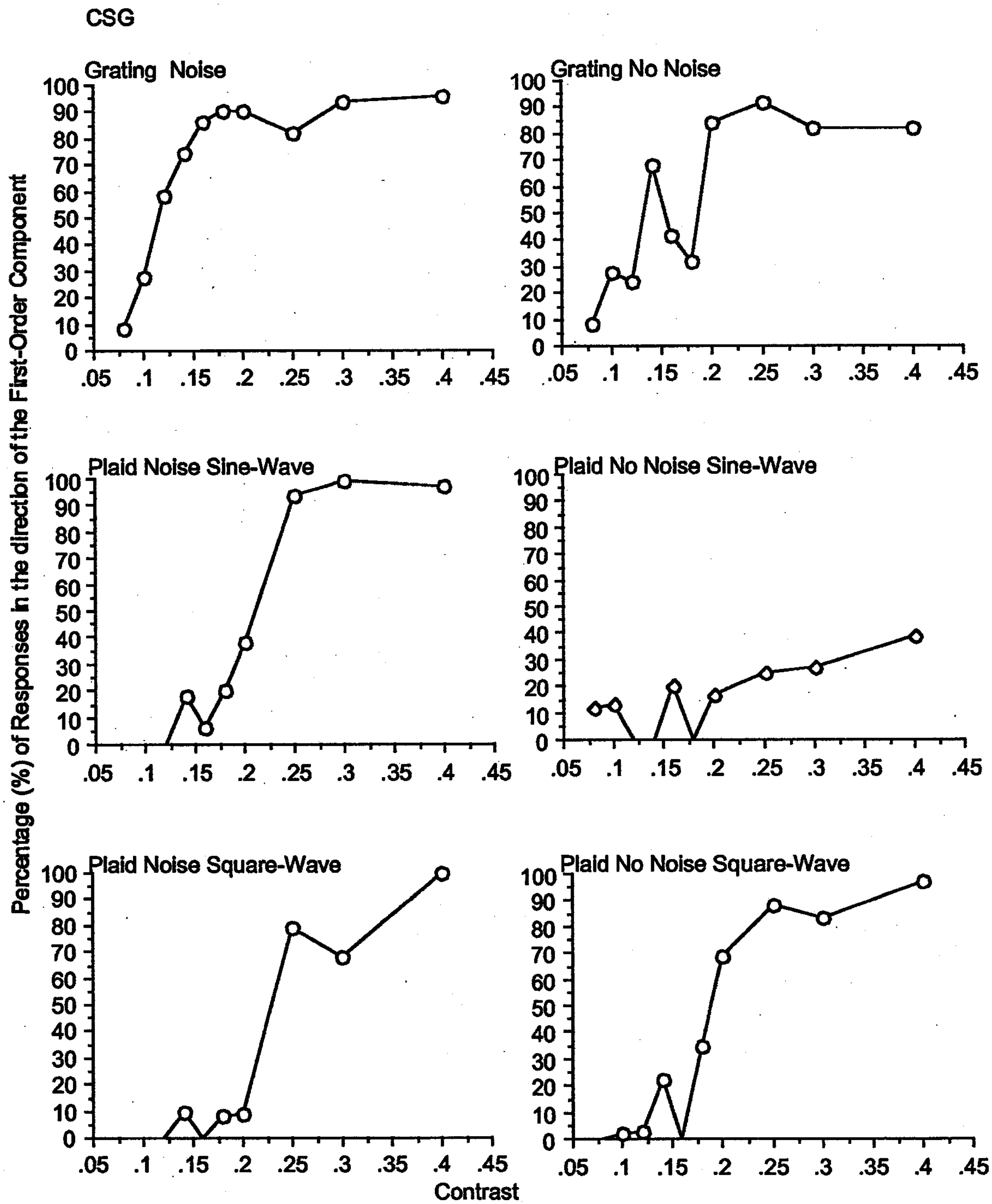
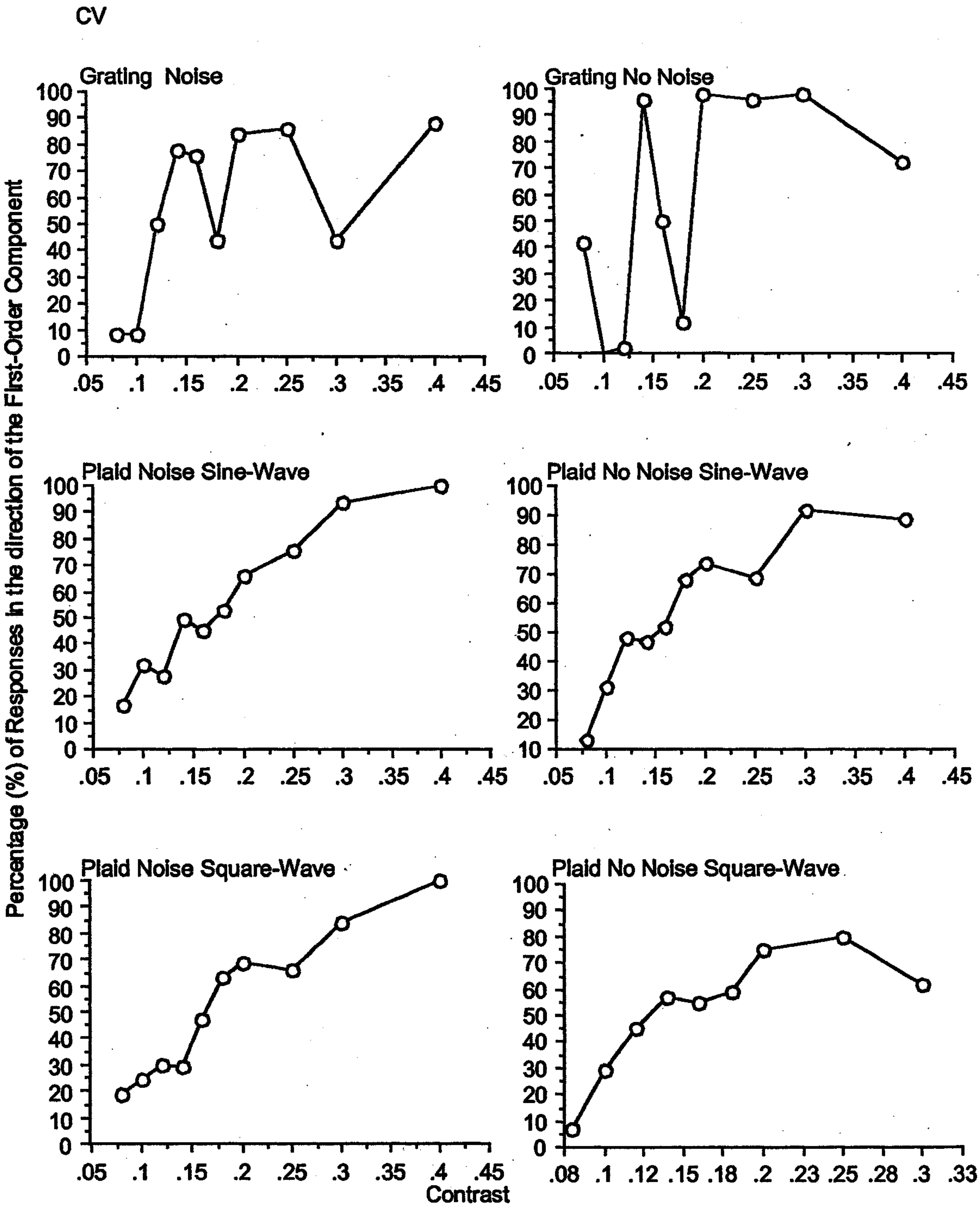
Plaid Noise Sine-Wave
Plaid No Noise Sine-Wave
Plaid Noise Square-Wave
Plaid No Noise Square-Wave
Percentage (%) of Responses in the direction of the First-Order Component
Contrast
0 10 20 30 40 50 60 70 80 90 100
.05 .1 .15 .2 .25 .3 .35 .4 .45

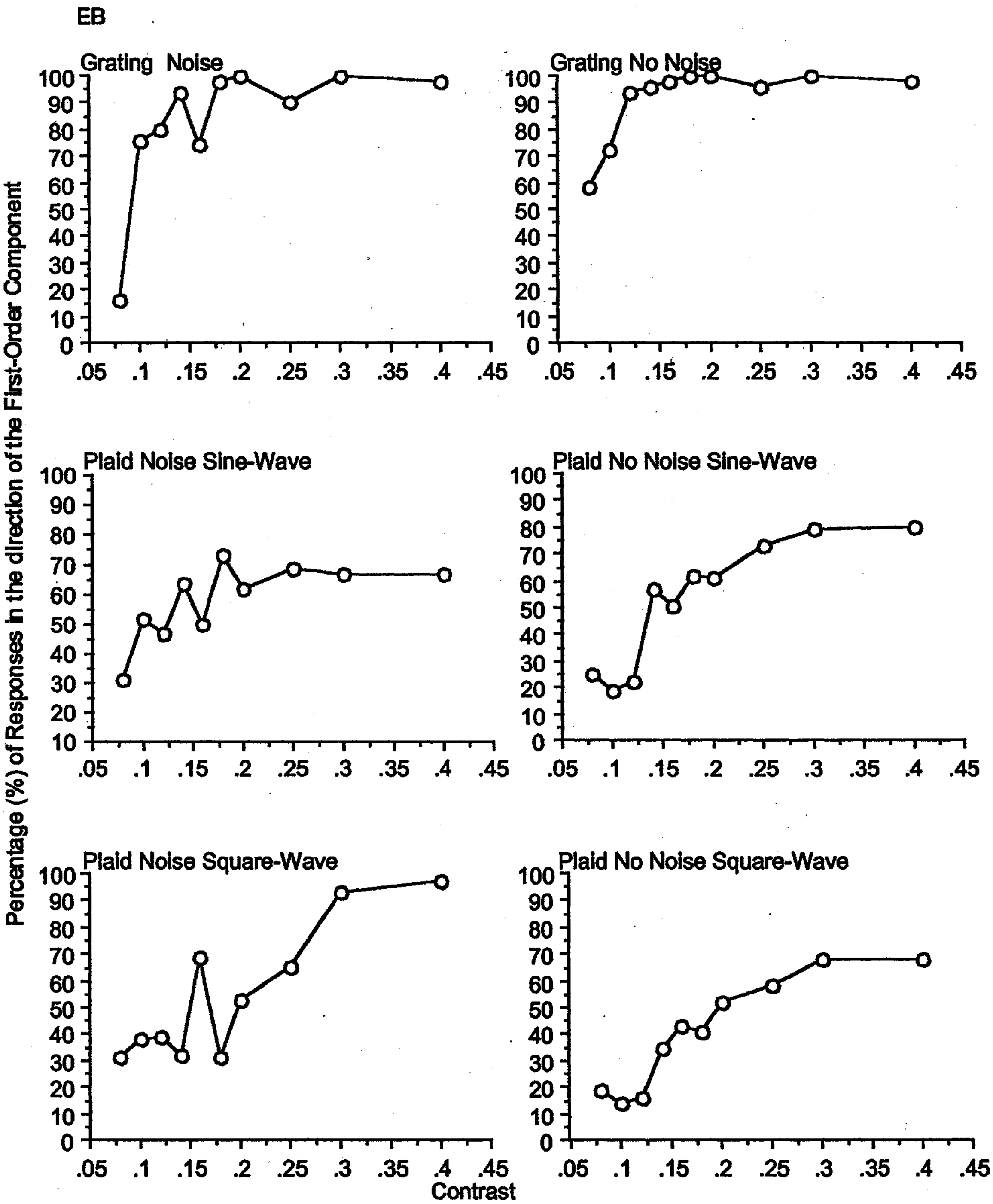


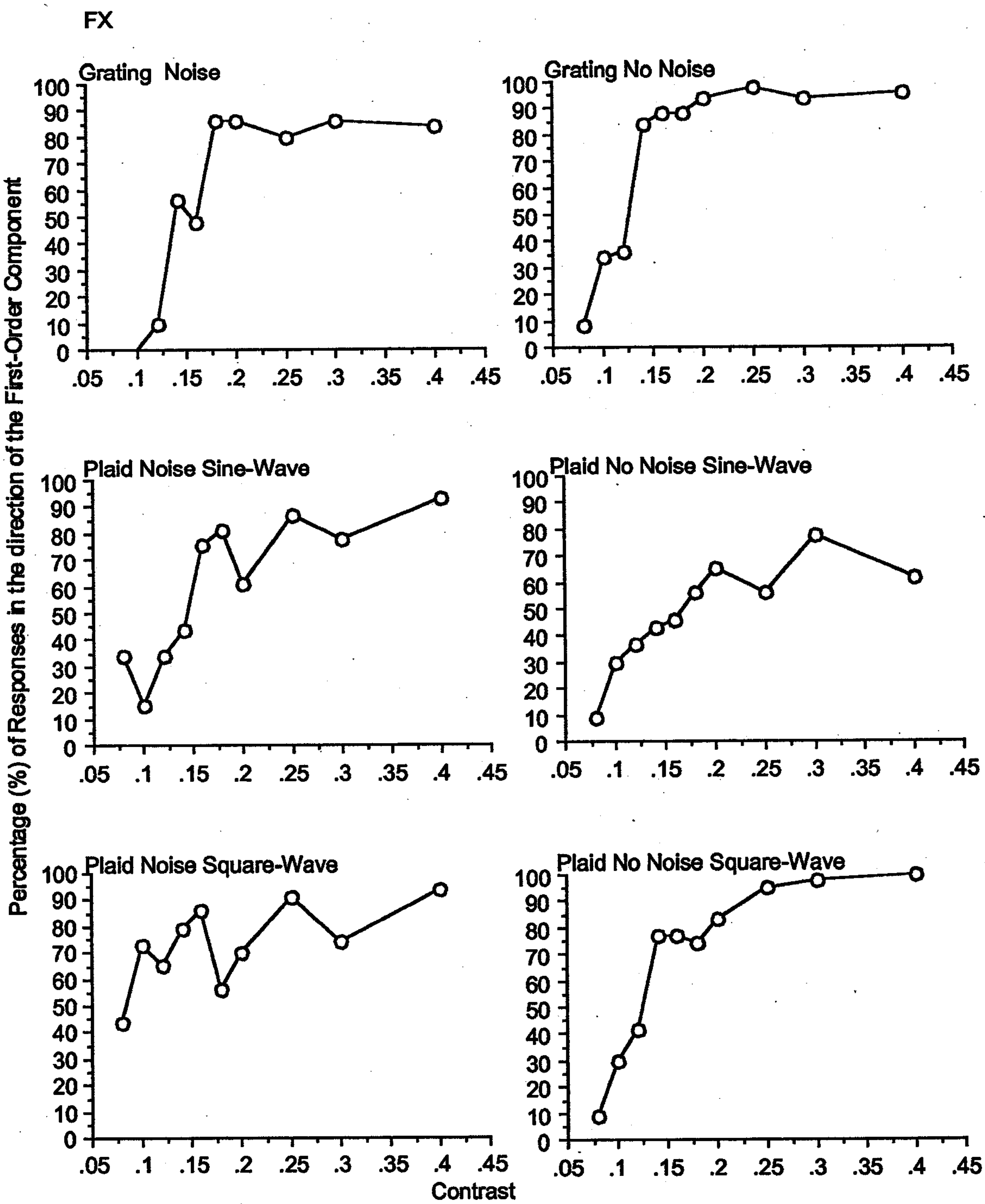
ASD
Grating Noise
Grating No Noise
Plaid Noise Sine-Wave
Plaid No Noise Sine-Wave
Plaid Noise Square-Wave
Plaid No Noise Square-Wave
Percentage (%) of Responses in the direction of the First-Order Component
Contrast
0
10
20
30
40
50
60
70
80
90
100
.05
.1
.15
.2
.25
.3
.35
.4
.45



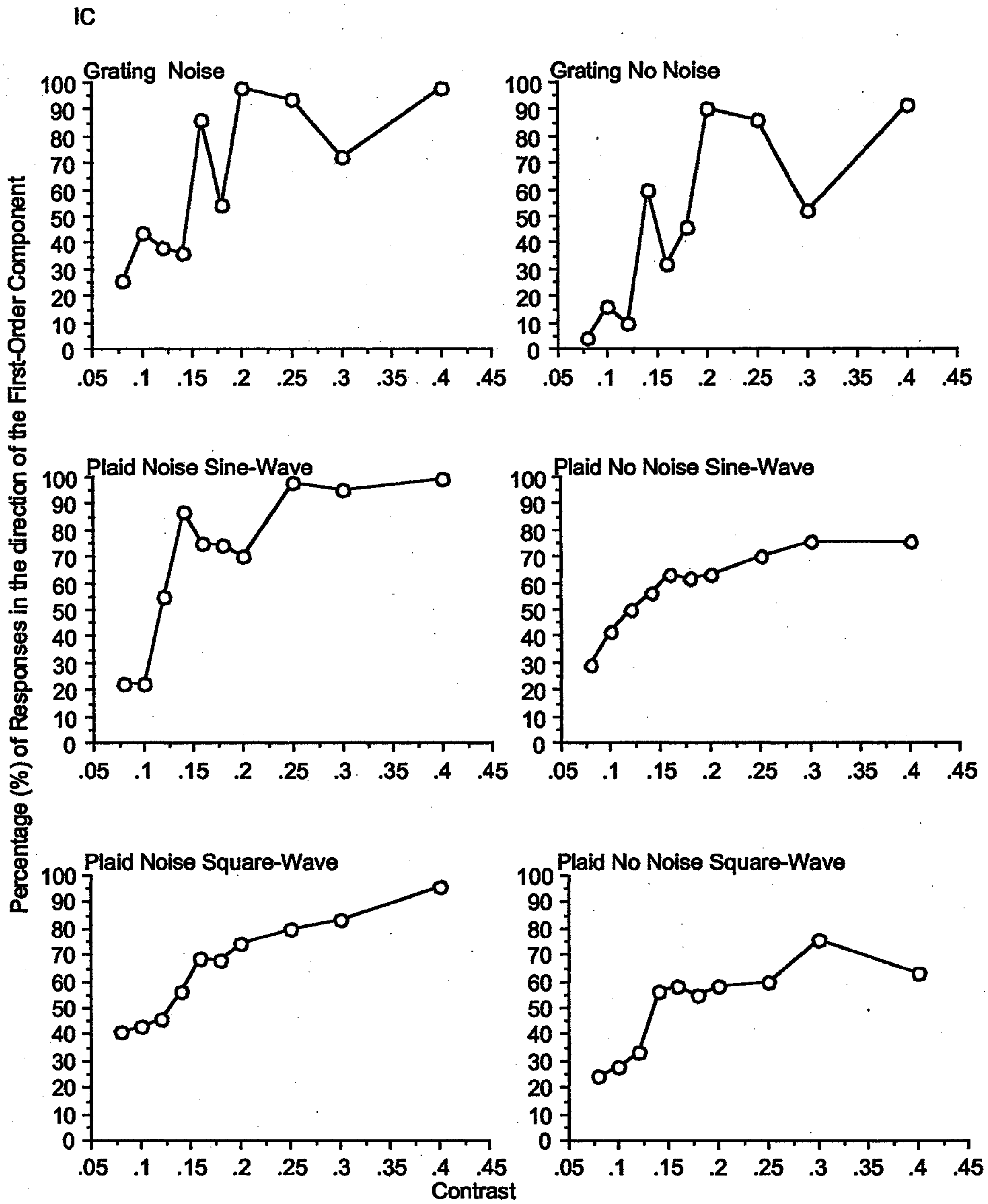
CSG
Grating Noise
Grating No Noise
Plaid Noise Sine-Wave
Plaid No Noise Sine-Wave
Plaid Noise Square-Wave
Plaid No Noise Square-Wave
Percentage (%) of Responses in the direction of the First-Order Component
Contrast

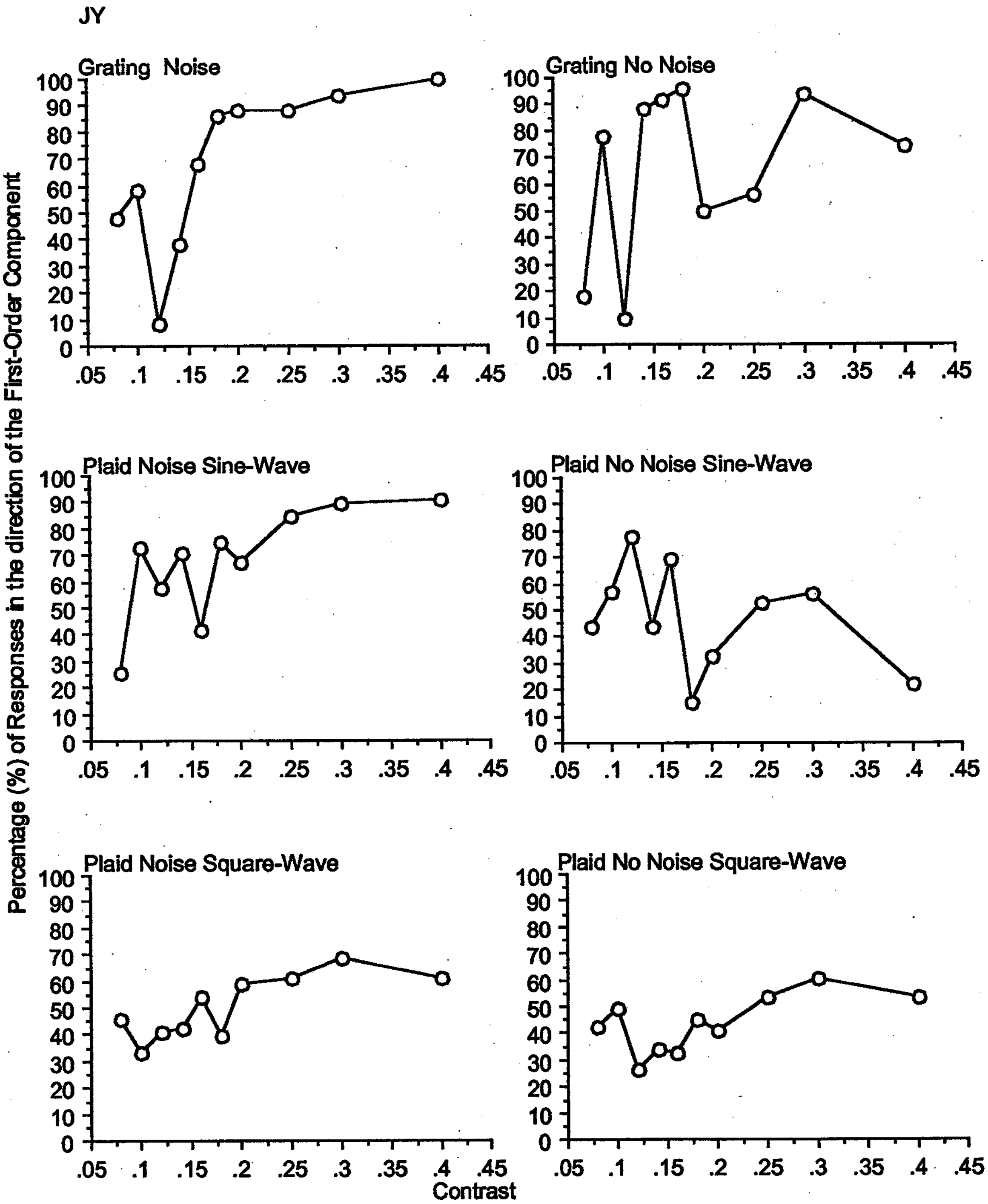

CV
Grating Noise
Grating No Noise
Plaid Noise Sine-Wave
Plaid No Noise Sine-Wave
Plaid Noise Square-Wave
Plaid No Noise Square-Wave
Percentage (%) of Responses in the direction of the First-Order Component
Contrast


EB
Grating Noise
Grating No Noise
Plaid Noise Sine-Wave
Plaid No Noise Sine-Wave
Plaid Noise Square-Wave
Plaid No Noise Square-Wave
Percentage (%) of Responses in the direction of the First-Order Component
Contrast
.05 .1 .15 .2 .25 .3 .35 .4 .45
0 10 20 30 40 50 60 70 80 90 100

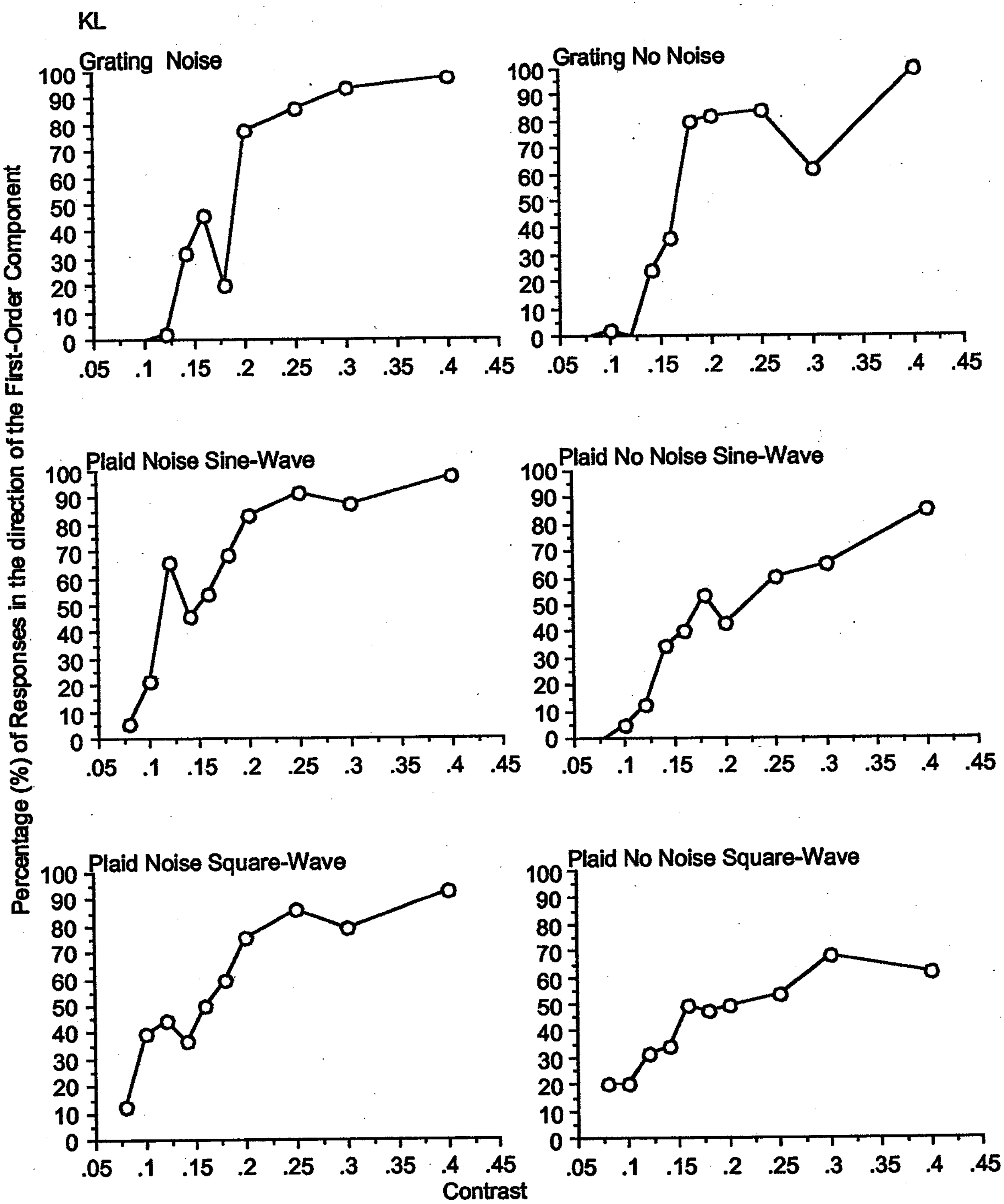


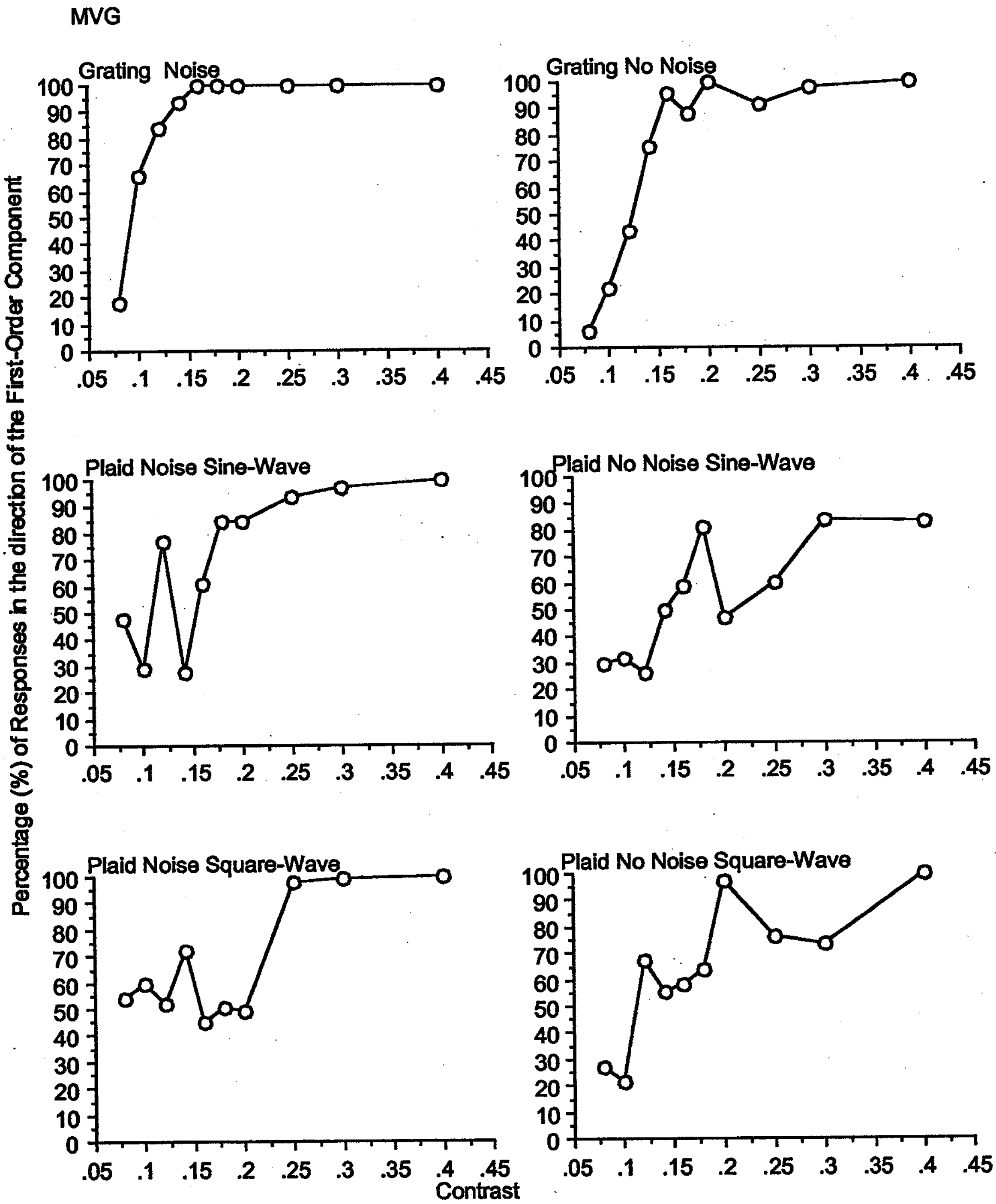
FX
Grating Noise
Grating No Noise
Plaid Noise Sine-Wave
Plaid No Noise Sine-Wave
Plaid Noise Square-Wave
Plaid No Noise Square-Wave
Percentage (%) of Responses in the direction of the First-Order Component
Contrast
100
90
80
70
60
50
40
30
20
10
0
.05
.1
.15
.2
.25
.3
.35
.4
.45


IC
Grating Noise
Grating No Noise
Plaid Noise Sine-Wave
Plaid No Noise Sine-Wave
Plaid Noise Square-Wave
Plaid No Noise Square-Wave
Percentage (%) of Responses in the direction of the First-Order Component
Contrast
0
10
20
30
40
50
60
70
80
90
100
.05
.1
.15
.2
.25
.3
.35
.4
.45

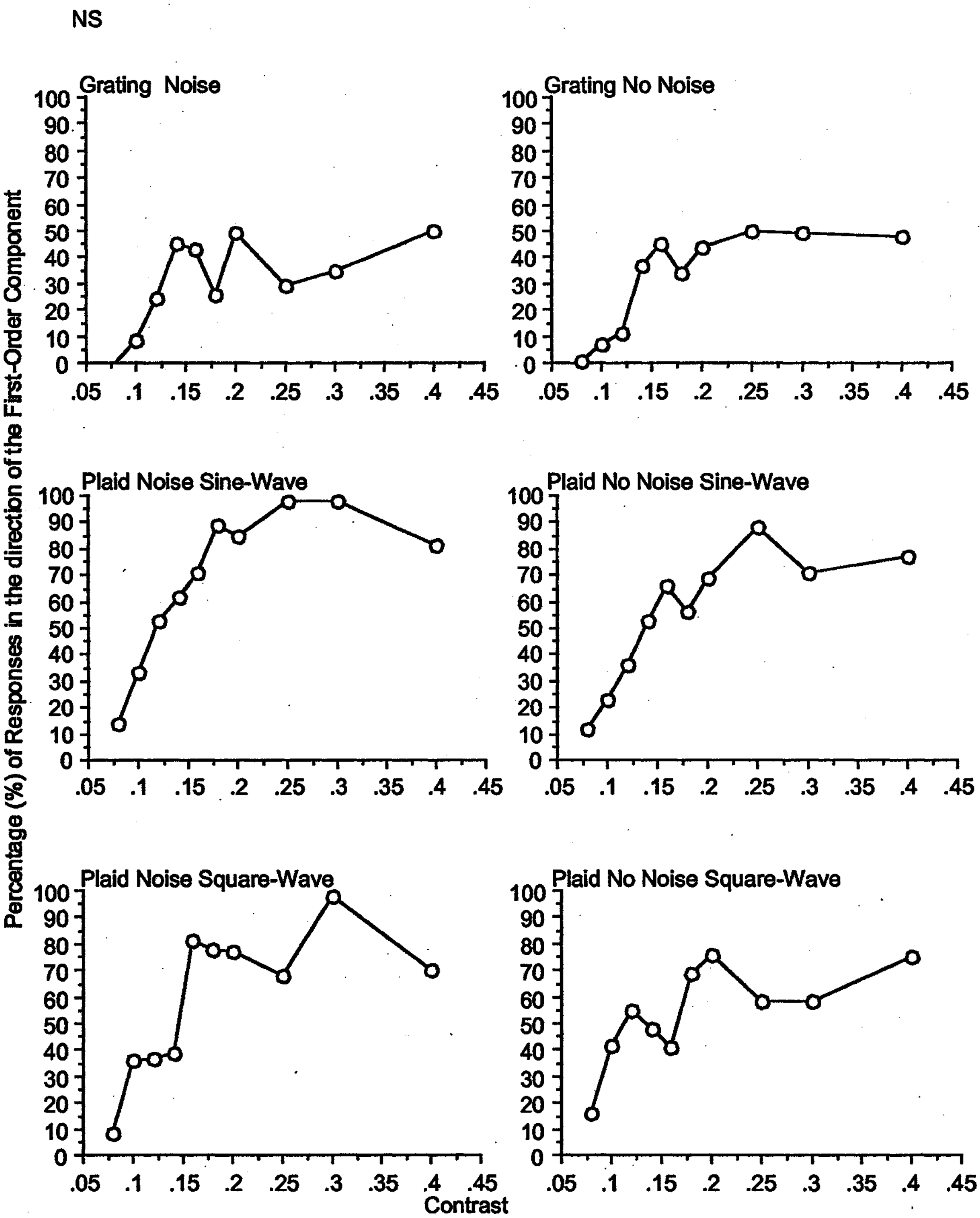


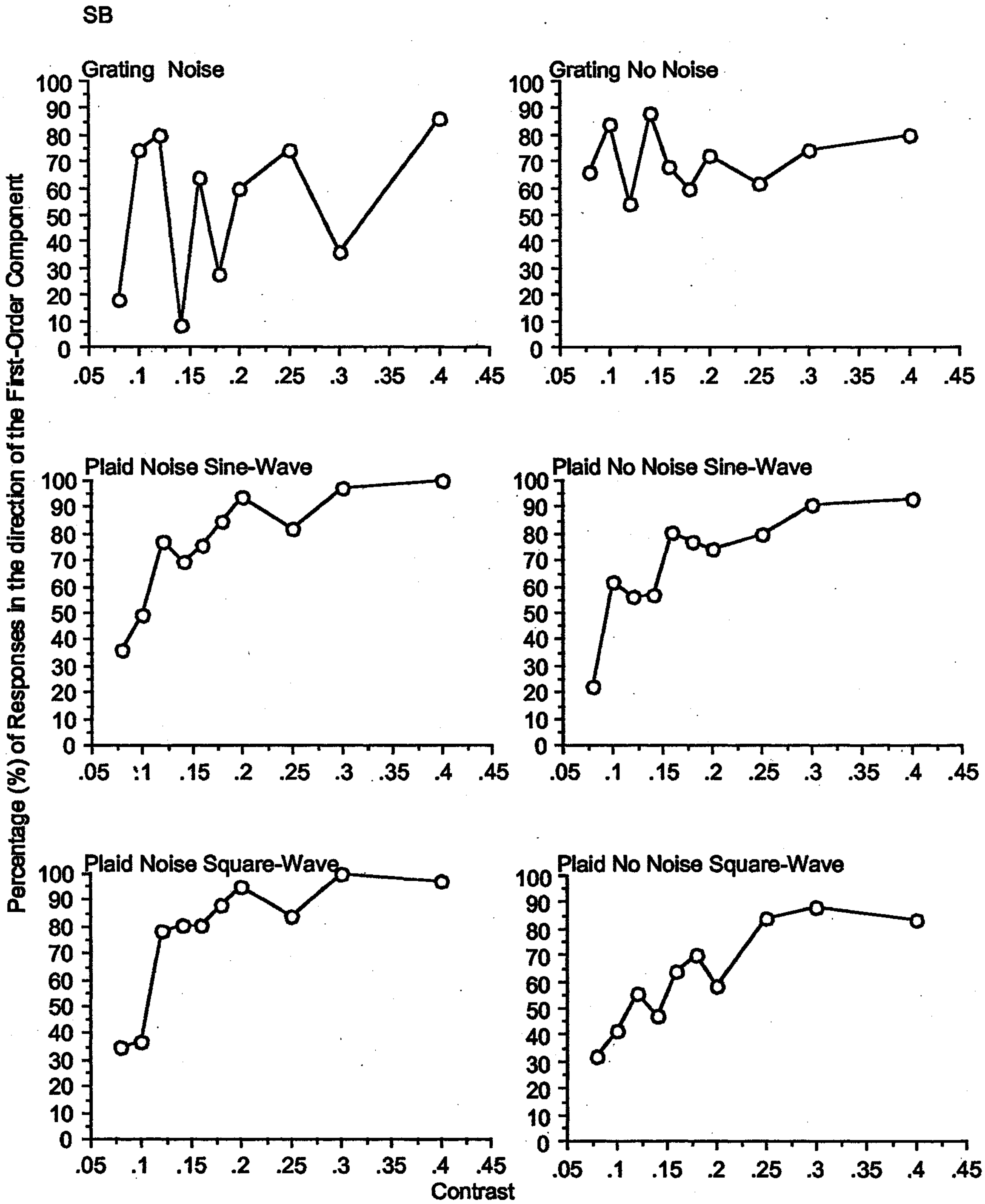
JY
Grating Noise
Grating No Noise
Plaid Noise Sine-Wave
Plaid No Noise Sine-Wave
Plaid Noise Square-Wave
Plaid No Noise Square-Wave
Percentage (%) of Responses in the direction of the First-Order Component
Contrast
0 10 20 30 40 50 60 70 80 90 100
.05 .1 .15 .2 .25 .3 .35 .4 .45


KL
Grating Noise
Grating No Noise
Plaid Noise Sine-Wave
Plaid No Noise Sine-Wave
Plaid Noise Square-Wave
Plaid No Noise Square-Wave
Percentage (%) of Responses in the direction of the First-Order Component
Contrast
0
10
20
30
40
50
60
70
80
90
100
.05
.1
.15
.2
.25
.3
.35
.4
.45



MVG
Grating Noise
Grating No Noise
Plaid Noise Sine-Wave
Plaid No Noise Sine-Wave
Plaid Noise Square-Wave
Plaid No Noise Square-Wave
Percentage (%) of Responses in the direction of the First-Order Component
Contrast
0
10
20
30
40
50
60
70
80
90
100
.05
.1
.15
.2
.25
.3
.35
.4
.45


NS
Grating Noise
Grating No Noise
Plaid Noise Sine-Wave
Plaid No Noise Sine-Wave
Plaid Noise Square-Wave
Plaid No Noise Square-Wave
Percentage (%) of Responses in the direction of the First-Order Component
Contrast
100
90
80
70
60
50
40
30
20
10
0
.05
.1
.15
.2
.25
.3
.35
.4
.45


SB
Grating Noise
Grating No Noise
Plaid Noise Sine-Wave
Plaid No Noise Sine-Wave
Plaid Noise Square-Wave
Plaid No Noise Square-Wave
Percentage (%) of Responses in the direction of the First-Order Component
Contrast
0
10
20
30
40
50
60
70
80
90
100
.05
.1
.15
.2
.25
.3
.35
.4
.45

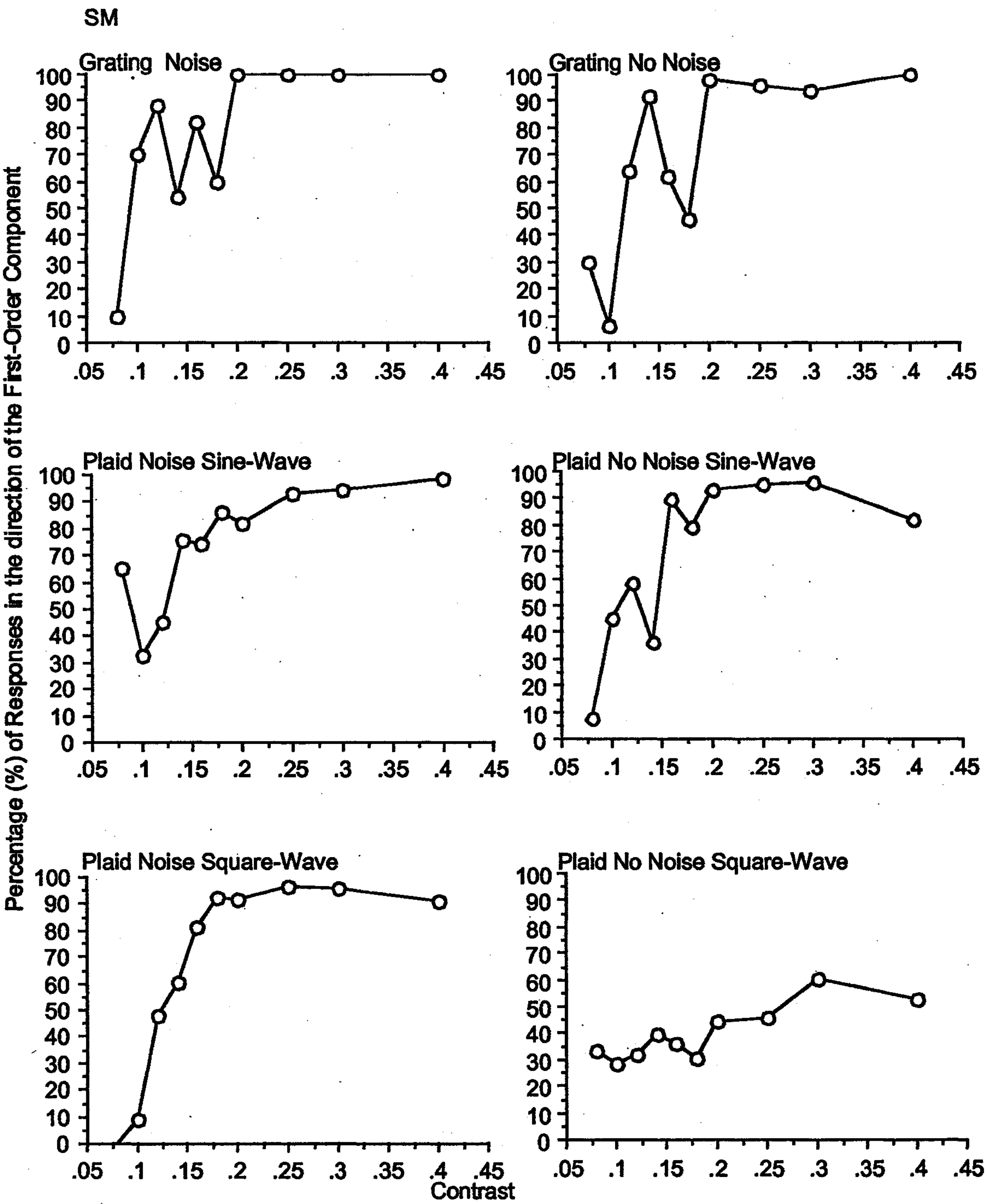

SM
Grating Noise
Grating No Noise
Plaid Noise Sine-Wave
Plaid No Noise Sine-Wave
Plaid Noise Square-Wave
Plaid No Noise Square-Wave
Percentage (%) of Responses in the direction of the First-Order Component
Contrast
100
90
80
70
60
50
40
30
20
10
0
.05
.1
.15
.2
.25
.3
.35
.4
.45

Table A

Threshold Luminance Contrast for Each Participant When the Stimulus Consisted of a Grating without Noise

Participant	Replications	Luminance Contrast
ap	50	.090
asd	50	.141
cv	50	.161
eb	50	.073
fx	50	.123
jy	50	.068
mvg	50	.129
sb	50	.081
sm	50	.125
csg	50	.142
kl	50	.194
ic	50	.194
ns	50	.139

Note. A higher score indicates a darker first-order.

Table B

Threshold Luminance Contrast for Each Participant When the Stimulus Consisted of a Grating with Noise

Participant	Replications	Luminance Contrast
ap	50	.059
asd	50	.136
cv	50	.156
eb	50	.083
fx	50	.176
jy	50	.124
mvg	50	.097
sb	50	.204
sm	50	.106
csg	50	.116
kl	50	.189
ic	50	.129
ns	50	.141

Note. A higher score indicates a darker first-order.

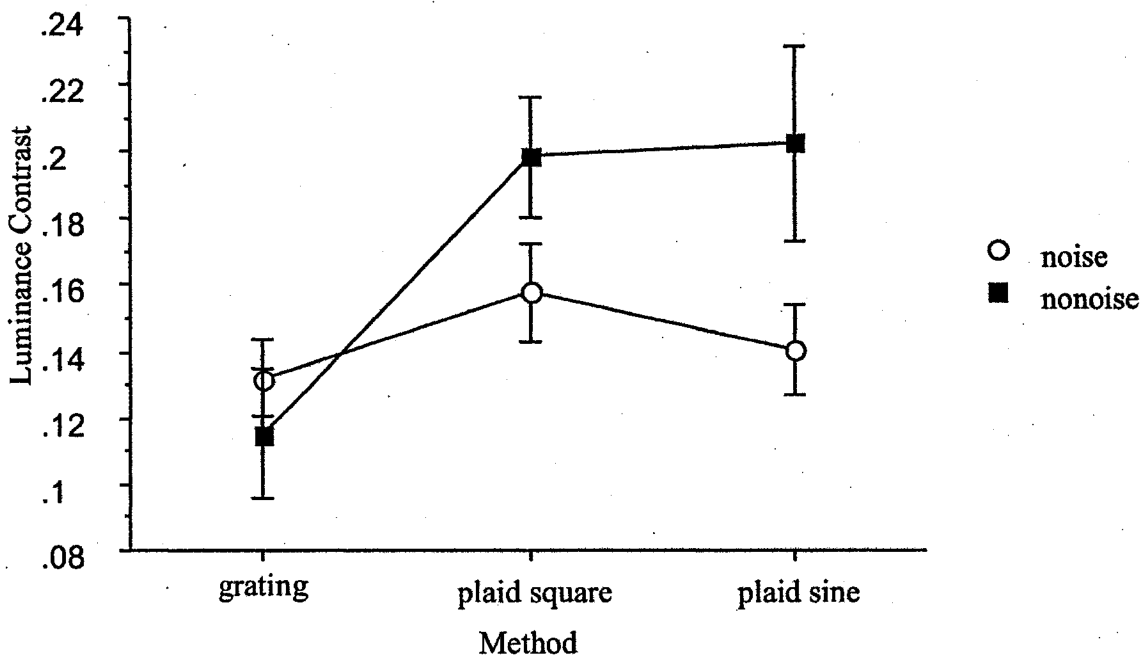


Figure 3. Threshold luminance contrast of the first-order component as a function of the type of tests used (plaid or grating, sine and square) and noise (noise or no noise) (n = 13).

Table C

Threshold Luminance Contrast for Each Participant When the Stimulus Consisted of a Sine-Wave Grating Plaid without Noise

Participant	Replications	Luminance Contrast
ap	2	.314
asd	2	.248
cv	2	.154
eb	2	.176
fx	2	.204
jy	2	.155
mvg	2	.162
sb	2	.097
sm	2	.111
csg	2	.487
kl	2	.228
ic	2	.128
ns	2	.165

Note. A higher score indicates a darker first-order.

Table D

Threshold Luminance Contrast for Each Participant When the Stimulus Consisted of a Sine-Wave Grating Plaid with Noise

Participant	Replications	Luminance Contrast
ap	2	.244
asd	2	.199
cv	2	.164
eb	2	.101
fx	2	.146
jy	2	.094
mvg	2	.116
sb	2	.080
sm	2	.112
csg	2	.192
kl	2	.145
ic	2	.122
ns	2	.111

Note. A higher score indicates a darker first-order.

Table E

Threshold Luminance Contrast for Each Participant When the Stimulus Consisted of a Square-Wave Grating Plaid without Noise

Participant	Replications	Luminance Contrast
ap	2	.262
asd	2	.213
cv	2	.113
eb	2	.238
fx	2	.130
jy	2	.282
mvg	2	.130
sb	2	.121
sm	2	.305
csg	2	.211
kl	2	.228
ic	2	.185
ns	2	.162

Note. A higher score indicates a darker first-order.

Table F

Threshold Luminance Contrast for Each Participant When the Stimulus Consisted of a Square-Wave Grating Plaid with Noise

Participant	Replications	Luminance Contrast
ap	2	.196
asd	2	.243
cv	2	.174
eb	2	.167
fx	2	.100
jy	2	.185
mvg	2	.119
sb	2	.067
sm	2	.135
csg	2	.249
kl	2	.157
ic	2	.114
ns	2	.144

Note. A higher score indicates a darker first-order.

Table G.

<u>Means and standard error of measurements for the ratio of luminance contrast that yield 50% threshold for the counterphase grating method and the plaid method when noise is present or not in the first-order component (n = 13).</u>

	Attention and Test		
First-Order Grating Luminance Contrast	Grating	Plaid Square-Wave	Plaid Sine-Wave
Noise			
<u>M</u>	.13	.16	.14
SEM	.01	.02	.01
No Noise			
<u>M</u>	.12	.20	.20
SEM	.02	.02	.03

Table H.
Source table

Source	df	SS	MS	F-Value	p
Subject	12	.104	.009		
Noise	1	.016	.016	6.16	.03
Noise * Subject	12	.031	.003		
Method	2	.046	.023	4.86	.02
Method * Subject	24	.113	.005		
Noise * Method	2	.021	.011	3.55	.04
Noise * Method * Subject	24	.072	.003		

component that corresponds to the 50% threshold. The 2 X 3 repeated measure ANOVA revealed a significant effect for type of stimulus ($F(2, 24) = 4.86$, $p < .02$), a significant main effect for noise ($F(1, 12) = 6.16$, $p < .03$) and a significant interaction for noise x type of stimulus ($F(2, 24) = 3.55$, $p < .05$) Table G shows the mean and *SEM* for each conditions. Table H shows the source table for the analysis of variance. When noise was included in the first-order component, the 50 % thresholds for the component were not statistically different for the plaids (square-wave: M = .16, *SEM* = .02; sine-wave: M = .14, *SEM* = .02) and the grating methods (M = .13, *SEM* = .02). The grating method without the noise in the first-order component was also equivalent (M = .12, *SEM* =. 02). Only the plaid method (square- and sine-wave) without noise in the first-order component required significantly higher luminance contrast for the first-order component to match the second-order component (square-wave: M = .20, *SEM* = .02; sine-wave: M = .20, *SEM* = .03).

Discussion

Equivalent salience between the first- and the second-order components was important because these two types of motion will be used to form different types of plaids. The effect of selective attention to the components of the plaids and its effect on a subsequent MAE will be measured. It is important that no perceptual bias toward one type of grating be present in order to measure the effect of selective attention. In this experiment, as the luminance contrast of the first-order component increased, the frequency of the perceived motion in the direction of the first-order component increased, indicating that the first-order motion was overriding the second-order motion perception.

It was expected that a first-order component without noise would produce lower luminance contrast thresholds, since the introduction of noise decreased the visibility of the first-order grating. This was what happened with the plaid method. However, with the grating method, the luminance contrast threshold was not reduced when noise was excluded in the first-order grating. Because in the counterphase gratings both gratings occupied the same visual space, this could have resulted in an increase in noise in the first-order component even when no noise was included specifically within the first-order component. The results of this experiment show that when no noise was introduced in the first-order component of a plaid, the counterphase grating method for equating the two components of the plaid might not be appropriate because it would suggest too little luminance in the first-order component. This would give more salience to the second-order component compared to the first-order component during the adaptation.

This is not the case when noise was added in the first-order stimulus of the counterphase grating. The grating method and the plaid method yielded comparable contrast thresholds when noise was added to the first-order component. Because in the experiment of this thesis noise was added to the first-order component to make it more similar to the second-order component, both equating methods are adequate to equate the salience of the first- and second-order components of a plaid. An advantage at using the counterphase grating method instead of the plaid method is that the administration is faster.

von Grünau and Faubert (1998) used the counterphase method in their study. In von Grünau and Faubert (1998), no noise was added to the first-order component and the counterphase grating method was used to equate the first- and the second-order components. This may have resulted in an inflated contrast for the first-order component, which could in turn have influenced the results because the second-order component might have been more salient than the first-order component in the adaptation plaid. It is surprising that considering this difference in salience between first- and second-order components, they did not find attentional and MAE differences between first-order and second-order component in the MAE.

In accordance with the results of the studies by Ledgeway (1994) and Ledgeway and Smith (1994), the motion in one direction did not cancel the motion in the opposite direction using the grating method when heterogeneous components were used. Participants always perceived motion when first- and second-order motions formed the counterphase grating. This inability to cancel the motion could have been due to the nature of the first- and the second-order motions being different. This is an important observation although it was not the main focus of this experiment.

Conclusion

The plaid method was more face valid because it used stimuli identical to the stimuli used in the subsequent MAE experiment of this thesis. However, this experiment showed that the counterphase grating method yielded identical luminance contrasts when noise is added to the stimulus and has the advantage to be administered faster. For this reason, the counterphase grating method was used in the experiments of this thesis.

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APPENDIX B

Consent form to participate in the preliminary experiment

Consent Form to Participate in the Preliminary Experiment

This is to state that I agree to participate in a program of research being conducted by Anne-Sophie Del Vecchio of the department of Psychology at Concordia University, in conjunction with her doctoral thesis, under the supervision of Dr. Michael von Grünau.

1) PURPOSE

I have been informed that the purpose of the research is to investigate how the brain processes visual information and that the research is being conducted to partially fulfill the requirements for a doctoral degree in Psychology.

2) PROCEDURES

I have been informed that the experiment involves the following procedures: On a computer screen, I will be presented two types of stimuli; a grating or a plaid.

The grating will tilted 20 degrees to the right and will appear to move either to the right or to the left. My task will be to fixate at the fixation point and to record the motion direction of the grating by pressing the appropriate key after the grating has disappeared. When the grating moved to the left, I press on the pink and left arrow (x key) and when the grating moved to the right, I press of the pink and right arrow (z key). I will initiate each trial by pressing on the space bar.

The plaid will be made-up of two gratings moving in opposite directions. One grating will be oriented 20 degrees to the left and the other grating will be oriented 20 degrees to the right. My task will be to fixate at the fixation point and to monitor which grating is dominant. A dominant grating is defined as a grating that appears in front of the other grating. When the grating moving to the left is dominant, I press on the pink and left arrow (x key) and when the grating moving to the right is dominant, I press of the pink and right arrow (z key). I continuously press on one of these two keys during the presentation of the plaid. I will initiate each trial by pressing on the space bar. Prior each grating I will be presented with a mask made-up of black and white dots.

The completion of the experiment will take about 80 minutes. There is no deception involved in the experiment and I will not be required to do any task other than that described above. I have been informed that my age, gender and handedness will be recorded and that my name may be associated with my data in the experiment. I understand that otherwise my participation in the experiment, and the information and data that I provide, will be kept confidential.

3) CONDITIONS OF PARTICIPATION

a) I understand that I am free to decline to participate in the experiment without negative consequences.

b) I understand that I am free to withdraw my consent and discontinue my participation at anytime without negative consequences.
c) I understand that my participation in this study in confidential (i.e., the researcher will know, but will not disclose my identity).
d) I understand that the data from this study may be published.
e) I understand the purpose of this study and know that there is no hidden motive of which I have not been informed.

I HAVE CAREFULLY STUDIED THE ABOVE AND UNDERSTAND HIS AGREEMENT. I FREELY CONSENT AND AGREE TO PARTICIPATE IN THIS STUDY.

NAME (please print) ______________________________________

SIGNATURE ______________________________________

WITNESS SIGNATURE ______________________________________

DATE ______________________

Instructions:

A)Open Experiment 6 Folder
B)Run in random order:
1) sensit grat 1/2 noise
2) sensit grat 1/2 nonoise
3) sensit grat 2/1 noise
4) sensit grat 2/1 nonoise
5) sensit plaid 1/2 nonoise
6) sensit plaid 1/2 noise
7) sensit plaid 2/1 noise
8) sensit plaid 2/1 nonoise
C) Save in Experiment 6 folder.
D) Add your initials to the excel file.

Age:______
Gender:_______
Handedness:________

Thank you for your participation in my experiment.

Anne-Sophie

APPENDIX C

Mean and standard error of measurement for the attention ratio of the preliminary experiment for 5 participants.

<u>Mean and standard error of measurement for the attention ratio of the preliminary experiment for 5 participants.</u>

	Attention cue		
Attention Ratio	Attended	Unattended	Both
First-Order Component			
Type of Plaid			
Homogeneous			
<u>M</u>	.817	.137	.392
SEM	.046	.024	.084
Heterogeneous			
<u>M</u>	.841	.072	.281
SEM	.036	.029	.082

Attention Ratio	Attention cue Attended	 Unattended	 Both
Second-Order Component			
Type of Plaid			
Homogeneous			
M	.690	.107	.320
SEM	.087	.025	.114
Heterogeneous			
M	.919	.160	.571
SEM	.030	.037	.105

APPENDIX D

ANOVA for the attention ratio of the preliminary experiment for the group analysis (n=5).

<u>ANOVA for the attention ratio of the preliminary experiment for the group analysis (n=5).</u>

Source	df	SS	MS	F-Value	p	eta^2
Subject		4	.256	.064		
Type of Plaid	1	.061	.061	2.737	.1734	.406
Type of Plaid * Subject	4	.089	.022			
Type of Component Attended	1	.021	.021	.797	.4224	.166
Type of Component Attended * Subject	4	.107	.027			
Attention	2	4.950	2.475	74.14	.0001	.949
Attention * Subject	8	.267	.033			
Type of Plaid * Type of Component Attended	1	.196	.196	6.485	.0635	.619
Type of Plaid * Type of Component Attended * Subject		4	.121	.030		
Type of Plaid * Attention	2	.044	.022	3.112	.1001	.438
Type of Plaid * Attention * Subject		8	.057	.007		
Type of Component Attended *						

Attention	2	.045	.023	1.957	.2033	.329
Type of Component Attended * Attention * Subject	8	.093	.012			
Type of Plaid * Type of Component Attended * Attention	2	.038	.019	2.161	.1777	.351
Type of Plaid * Type of Component Attended * Attention * Subject	8	.071	.009			

APPENDIX E

Mean and standard error of measurement of MAE duration (sec) of the preliminary experiment for homogeneous and heterogeneous plaid (n = 5).

Mean and standard error of measurement of MAE duration (sec) of the preliminary experiment for homogeneous and heterogeneous plaid (n=5).

	Attention and Test		
Attention	Same	Different	Both
Attention homogeneous plaid			
First-order			
M	6.14	.36	4.94
SEM	.72	2.40	1.29
Second-order			
M	5.44	-.11	4.51
SEM	1.00	2.52	1.77

	Attention and Test		
Attention	Same	Different	Both
Attention heterogeneous plaid			
First-order			
M	4.41	2.65	3.77
SEM	.82	1.58	1.55
Second-order			
M	6.35	.08	4.17
SEM	1.05	1.89	1.34

APPENDIX F

ANOVA for the MAE duration (sec) of the preliminary experiment for the group analysis (n = 5).

ANOVA for the MAE duration (sec) of the preliminary experiment for the group analysis (n = 5).

Source	df	SS	MS	F-Value	p	eta^2
Subject	4	167.34	41.84			
Plaid	1	.005	.005	.0003	.987	.000
Plaid * Subject	4	63.22	15.81			
Component	1	1.38	1.38	.23	.6585	.054
Component * Subject	4	24.30	6.08			
Selection and Test	2	253.14	126.57	7.86	0130	.663
Selection and Test * Subject	8	128.88	16.11			
Plaid * Component	1	.786	.786	.56	.4958	.123
Plaid * Component * Subject	4	5.61	1.40			
Plaid * Selection and Test	2	11.41	5.71	.279	.7634	.065
Plaid * Selection and Test * Subject	8	163.46	20.43			
Component * Selection and Test	2	12.14	6.07	2.37	.1558	.372
Component * Selection and Test * Subject	8	20.52	2.57			
Plaid * Component * Selection and Test	2	14.34 7.17	1.64	.2526		.291
Plaid * Component						

Selection and Test			
* Subject	8	34.93	4.36

Dependent Variable: MAE duration (s)

APPENDIX G

Consent form to participate in the main experiment.

Consent form to participate in the main experiment

This is to state that I agree to participate in a program of research being conducted by Anne-Sophie Del Vecchio of the department of Psychology at Concordia University, in conjunction with her doctoral thesis, under the supervision of Dr. von Grünau.

4) PURPOSE

I have been informed that the purpose of the research is to investigate how attention modulate visual motion perception and that the research is being conducted to partially fulfill the requirements for a doctoral degree in Psychology.

5) PROCEDURES

I have been informed that the experiment involves the following procedures: On a computer screen, I will be presented with a mask made-up of black and white dots. The mask will be followed by a probe which will consist of either a line oriented 20 degrees to the left, 20 degrees to the right, or a circle for few milliseconds. Then, a plaid made-up of two gratings moving in opposite direction will be presented to me, one grating will be oriented 20 degrees to the left and the other grating will be oriented 20 degrees to the right. Finally, a test counter-phase dynamic grating will be presented to me. My task will first be to attend to the component of the plaid oriented in the direction specified by the probe or to monitor my attention to attend to both component of the plaid alternatively avoiding the perception of coherence (merging of both component) if the probe is a circle. During adaptation I will monitor my attention by pressing the "z" key when I attend to the component of the plaid moving to the left, the "x" key when I attend to the component of the plaid moving to the right. When I perceive both component binding together I will press of the "c" key. During the test, I will press the left arrow key if I perceive a motion to the left, the right arrow key if I perceive a motion to the right during test. If I perceive no motion or when the direction of the perceived motion become ambiguous, I will press the "0" key.

The completion of the experiment will take about 2 hours. There is no deception in the experiment and I will not be required to do any task other than that described above. I have been informed that my age and gender and handedness will be recorded but that, my name will not be associated with such information.

6) CONDITIONS OF PARTICIPATION

f) I understand that I am free to decline to participate in the experiment without negative consequences.

g) I understand that I am free to withdraw my consent and discontinue my participation at anytime without negative consequences.

h) I understand that the data from this study may be published.

i) I understand the purpose of this study and know that there is no hidden motive of which I have not been informed.

I HAVE CAREFULLY STUDIED THE ABOVE AND UNDERSTAND ITS AGREEMENT. I FREELY CONSENT AND AGREE TO PARTICIPATE IN THIS STUDY.

NAME (please print) ______________________________

SIGNATURE ______________________________

WITNESS SIGNATURE ______________________________

DATE ____________________

Modulation of Motion Aftereffect by Attention

Instructions:

1- Open the experiment folder.
2- Open the folder titled with your name.
3- Open a vpixx file in a random order.
4- Go to constant stimuli
5- Press on run test
6- Remove the date and add your initials and the trials number to the file name before saving (e.g. first order.asd3)
7-Click on "Start experiment"
8- Press the spacebar to start each trial.
9- Attends to the component of the plaid oriented in the direction specified by the probe.
10- During adaptation monitor your attention by pressing the "z" key when you attend to the component of the plaid moving to the left, the "x" key when you attend to the component of the plaid moving to the right and the "c" key when you perceive coherent motion.
12- Press the left arrow key if you perceive a motion to the left, the right arrow key if you perceive a motion to the right during test. If you perceive no motion press the "0" key.
13- When the perceived motion becomes ambiguous, press the "0" key.
14- Press the space bar to assess another trial.
15- Circle the trial done on this sheet.

First order:
1 2 3 4 5

Second order:
1 2 3 4 5

First and second:
1 2 3 4 5

Second and first:
1 2 3 4 5

APPENDIX H

Mean and standard error of measurement for the attention ratio of the main experiment for 11 participants.

Mean and standard error of measurement for the attention ratio of the main experiment for 11 participants.

Attention Ratio	Attention cue		
	Attended	Unattended	Both
First-Order Component			
Type of Plaid			
Homogeneous			
M	.794	.155	.467
SEM	.056	.043	.018
Heterogeneous			
M	.885	.103	.451
SEM	.032	.047	.039

	Attention cue		
Attention Ratio	Attended	Unattended	Both
Second-Order Component			
Type of Plaid			
Homogeneous			
M	.789	.101	.436
SEM	.025	.034	.032
Heterogeneous			
M	.891	.118	.474
SEM	.046	.032	.038

APPENDIX I

ANOVA for the attention ratio of the main experiment for the group analysis (n=11).

ANOVA for the attention ratio of the main experiment for the group analysis (n=11).

Source	df	SS	MS	F-Value	p	eta^2
Subject		10	.311	.031		
Type of Plaid	1	.030	.030	4.336	.0639	.302
Type of Plaid * Subject	4	.069	.007			
Type of Component Attended	1	.002	.002	.160	.6977	.016
Type of Component Attended * Subject	4	.115	.011			
Attention	2	11.449	5.724	78.202	.0001	.887
Attention * Subject	8	1.46	.073			
Type of Plaid * Type of Component Attended	1	.017	.017	7.266	.0225	.421
Type of plaid * Type of Component Attended * Subject		4	.023	.023		
Type of Plaid * Attention	2	.078	.039	2.172	.1400	.178
Type of Plaid * Attention * Subject		8	.358	.018		
Type of Component Attended *						

Attention	2	.003	.001	.734	.492	.068
Type of Component Attended * Attention * Subject	8	.036	.002			
Type of Plaid * Type of Component Attended * Attention	2	.005	.003	1.692	.2095	.145
Type of Plaid * Type of Component Attended * Attention * Subject	8	.030	.002			

Dependent Variable: Attention

APPENDIX J

Plan of the planned comparisons performed in the Main Experiment for the MAE.

Plan of the planned comparisons performed in the Main Experiment for the MAE.

1. Orientation of the attended component and test: (to test MAE)

A) Same VS Different + Both

2. To test the suppressive effect

B) Different VS Both

3. Type of plaid: (to test the effect of the type of unattended component)

C) Hetero VS Homo

1) Hetero VS Homo

E) Hetero VS Homo

4. Type of component attended: (to test the effect of first- and second-order motion)

F) 1st VS 2nd

G) 1st VS 2nd

H) 1st VS 2nd

I) 1st VS 2nd

1) 1st VS 2nd

2) 1st VS 2nd

APPENDIX K

Mean and standard error of measurement for MAE duration (sec) for the main experiment (n=11).

Mean and standard error of measurement for MAE duration (sec) for the main experiment (n=11).

	Attention and Test		
MAE duration (sec)	Same	Different	Both
Heterogeneous plaid			
First-order			
M	7.27	1.22	3.08
SEM	1.68	2.15	1.75
Second-order			
M	7.38	-2.43	3.19
SEM	1.38	2.26	1.91

MAE duration (sec)	Attention and Test		
	Same	Different	Both
Homogeneous plaid			
First-order			
<u>M</u>	7.31	-2.78	3.99
SEM	1.49	2.05	1.31
Second-order			
<u>M</u>	6.21	-1.27	4.16
SEM	1.50	1.45	1.29

APPENDIX L

Mean and standard error of measurement for the attention ratio of the unattended experiment (n = 9).

Mean and standard error of measurement for the attention ratio of the unattended experiment (n = 9).

	Adaptation Stimulus		
Attention Ratio	Heterogeneous	Homogeneous	Grating
Attention			
Attended Component			
M	.821	.695	.988
SEM	.067	.085	.007
Unattended Component			
M	.158	.220	.004
SEM	.065	.059	.004

APPENDIX M

ANOVA for the attention ratio of the unattended experiment for the group analysis (n =9).

ANOVA for the attention ratio of the unattended experiment for the group analysis (n=9).

Source	df	SS	MS	F-Value	p	eta^2
Subject	8	.113	.014			
Adaptation Stimulus	2	.015	.007	.468	.6345	.055
Adaptation Stimulus * Subject	16	.248	.016			
Attention	1	6.782	6.782	94.86	.0001	.922
Attention* Subject	8	.572	.071			
Adaptation Stimulus * Attention	2	0604	.302	10.606	.0012	.570
Adaptation Stimulus * Attention * Subject	16	.456	.028			

Dependent Variable: Attention

APPENDIX N

Mean and standard error of measurement for the MAE duration (sec) of the unattended experiment for 9 participants.

Mean and standard error of measurement for the MAE duration (sec) of the unattended experiment for 9 participants.

	Type of Adaptation Stimulus		
MAE Duration (s)	Heterogeneous	Homogeneous	Grating
Cue and Test Orientation			
Same			
M	8.02	7.44	11.60
SEM	.85	1.28	.940
Different			
M	.95	-1.69	10.24
SEM	2.14	2.28	1.33

APPENDIX O

ANOVA for the MAE of the unattended experiment for the group analysis (n =9).

ANOVA for the MAE of the unattended experiment for the group analysis (n=9).

Source	df	SS	MS	F-Value	p	eta^2
Subject	8	265.43	33.18			
Adaptation Stimulus	2	652.73	326.37	28.86	.0001	.783
Adaptation Stimulus * Subject	16	180.94	11.31			
Cue and Test Orientation	1	462.43	462.43	6.63	.0329	.453
Cue and Test Orientation* Subject	8	557.82	69.73			
Adaptation Stimulus * Cue and Test Orientation	2	145.58	72.79	18.38	.0001	.697
Adaptation Stimulus * Cue and Test Orientation * Subject	16	63.36	3.96			

APPENDIX P

Mean and standard error of measurement for the attention ratio of the time experiment (n = 11).

Mean and standard error of measurement for the attention ratio of the time experiment (n = 11).

	Attention cue	
Attention Ratio	Attended	Both
Adaptation Time		
20 seconds		
M	.884	.462
SEM	.038	.038
40 seconds		
M	.879	.468
SEM	.040	.032

APPENDIX Q

ANOVA for the attention ratio of the time experiment for the group analysis (n=11).

ANOVA for the attention ratio of the time experiment for the group analysis (n=11).

Source	df	SS	MS	F-Value	p	eta^2
Subject	10	.293	.029			
Adaptation Time	1	1.45E-6	1.45E-6	.002	.9625	.000
Adaptation Time * Subject	10	.006	.001			
Attention	1	1.912	1.912	64.55	.0001	.866
Attention * Subject	10	.296	.030			
Adaptation Time * Attention	1	3.27E-4	3.27E-4	.767	.4018	.072
Adaptation Time * Attention * Subject	10	.004	4.27E-4			

Dependent Variable: Attention

APPENDIX R

Mean and standard error of measurement for the MAE duration (sec) of the time experiment (n = 11).

Mean and standard error of measurement for the MAE duration (sec) of the time experiment (n = 11).

	Component Attended During Adaptation	
MAE Duration (s)	One Component	Both Components
Adaptation Time		
20 seconds		
M	6.38	3.44
SEM	1.02	1.18
40 seconds		
M	7.41	3.05
SEM	1.08	1.58

APPENDIX S

ANOVA for the MAE of the time experiment for the group analysis (n=11).

ANOVA for the MAE of the time experiment for the group analysis (n=11).

Source	df	SS	MS	F-Value	p	eta^2
Subject	10	351.58	35.16			
Time	1	1.17	1.17	.375	.5539	.036
Time * Subject	10	31.16	3.12			
Attention	1	148.44	148.44	5.95	.0349	.373
Attention * Subject	10	249.41	24.94			
Time * Attention	1	5.9	5.9	1.54	.2425	.134
Time *Attention * Subject	10	38.24	3.82			

Dependent Variable: MAE