DISSERTATIONES PSYCHOLOGICAE UNIVERSITATIS TARTUENSIS

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INTERACTION OF OBJECT PERCEPTION AND VISUAL ATTENTIONAL SELECTION PROCESSES

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II Bachmann, T., **Luiga, I.**, & Põder, E. (2005). Variations in backward masking with different masking stimuli: I. Local interaction versus attentional switch. *Perception*, *34(2),* 131–137.

III Bachmann, T., **Luiga, I.**, & Põder, E. (2004). Forward masking of faces by spatially quantized random and structured masks: On the roles of wholistic configuration, local features, and spatial-frequency spectra in perceptual identification. *Psychological Research-Psychologische Forschung, 69(1–2),* 11–21.

IV Bachmann, T., **Luiga, I.**, & Põder, E. (2005). Variations in backward masking with different masking stimuli: II. The effects of spatially quantised masks in the light of local contour interaction, interchannel inhibition, perceptual retouch, and substitution theories. *Perception*, *34(2),* 139–153.

V Bachmann, T., Põder, E., & **Luiga, I.** (2004). Illusory reversal of temporal order: the bias to report a dimmer stimulus as the first. *Vision Research*, *44(3),* 241–246.

VI **Luiga, I.** & Bachmann, T. Luminance processing in object substitution masking. (submitted)

INTRODUCTION

The topic of this thesis seems quite astonishing for people outside the field of psychology. Common belief is that there is nothing to study about visual object perception and attention — if you want to see something or pay attention to somebody, you just look that way. Of course, we may look more closely at some things than at others, which is ordinarily meant by "paying attention", but most of the time it seems that we see nearly everything in our view. The type of attention that involves eye movements is named overt attention. Research on attention is done mostly on covert attention that refers to specific information processes in the brain and does not involve eye movements (see any book on visual attention e.g., van der Heijden, 1992; Jenkin & Harris, 2001).

Researchers of human visual perception know already for at least 50 years that we do not explicitly perceive everything that falls onto our retina. Perception can be broadly divided into two "subsystems": pre-attentive and attentive (to name a few who layed the foundation of the two staged processing view: Broadbent, 1958; Neisser, 1967; Eriksen & Collins, 1969; Treisman & Gelade, 1980). Indeed, pre-attentive system is assumed to have unlimited processing capacity and it analyses simple visual features all over visual field. This means that simple features (e.g. color, brightness, orientation, size, spatial frequency, movement, curvature) are processed in parallel and with equal efficiency in "lower" cortical areas (also including primary visual area in human cortex). However, we do not perceive those simple features of objects separately from objects. In order to perceive objects as a whole, those simple features are put together in "higher" cortical areas. This is far more complex task for our perceptual system than encoding simple features. Our mental capacity is limited hence we have a "subsystem" that helps us to use our perceptual resourses wisely. It is possible to select attentively only a small part of visual field or a single visual object (or maybe a few simple visual objects) at once (e.g. Tresiman & Gelade, 1980). The basic function of attention is to *select* either a location/a sensory stimulus ("bottom up" process) or the objects/features we have knowingly determined to find ("top down" process). The third function that is remotely related to selection is maintaining alert attentive state (Posner, 1995).

Although most of the data of visual attention studies point to the two stages of perception – pre-attentive and attentive, it is not clear where the pre-attentive stage ends and attentive stage begins. Debate is about whether the attentive processing involves early stages of object perception or is the selection taking place in late stages. Early stage attentional selection upholders think that the object is selected due to a pre-tuned "spotlight" or a "zoom" lens that is turned to the object location when either a sensory or mentally pre-determined cue is encountered (e.g. Posner, 1980; Eriksen & St. James, 1986; Shulman & Wilson, 1987). This spotlight "illuminates" the object in selected location and it can be processed more effectively than the less illuminated objects. Also, moving the spotlight or in other words, shifting attention to another location takes time (e.g. Tsal, 1983). When the spotlight is moved, all objects between old location and new location become illuminated too (Shulman, Remington & McLean, 1979). The spotlight was initially thought to be generally fixed in size (Eriksen & Eriksen, 1974) and not dividable between two locations (Eriksen & Yeh, 1985). However, there is also evidence for the opposite conclusions, namely that the size of spotlight is variable (Eriksen & St.James, 1986) and that it can be split to separate spatial locations (Awh & Pashler, 2000; Müller et al., 2003). The "zoom lens" idea was integrated into "spotlight" idea after Shulman & Wilson (1987) found that after seeing either huge or small stimulus subjects needed time to adjust their "zoom lens" to the following different spatial frequency resolution. The way spatial attention can be focused depends also on cognitive load (Lavie, 2005).

Late selection is thought to happen when unattended objects have been processed up to the identification (e.g. Allport, Tipper & Chmiel, 1985) and attention may be needed for response selection, memory encoding or conscious awareness.

However, what are "illuminated", locations or objects? The logic of one group of researchers assumes that features of the objects have to be analyzed to a certain level in order to bind them into coherent objects. Processing the features of objects is spread out over many cells in retina and receptive fields in brain. This processing is strictly tied to the locations in the visual field. At higher levels, cells become more specialized in the attributes that they are involved in processing (Zeki, 1978). Different systems encode color, motion, depth, etc. How this scattered information is put back together is called a binding problem. According to Treisman (1998) and Treisman and Gelade (1980), features from the perceptual world are parsed into individual objects through the act of attending to them. Attention is the "glue" that combines together the features of the object. The logic of another group of researchers says that attention is probably selecting objects of which features are going to be processed (Duncan, 1984; Egly et al., 1994; Webber et al., 1997; Moore et al., 1998; Brown et al., 2006). For example, Egly et al. (1994) used two bar stimuli next to each other. On valid trials the target appeared at the location of the cue (brightening of one end of a bar). On invalid trials it appeared at a nearby location. In half the invalid trials the target appeared at the opposite end of the bar requiring a shift of attention within the object, in the other half the target appeared in a nearby bar requiring a shift of attention between objects. The stimuli were configured so that the cue-to-target spatial distance was the same for both types of invalid trials. A purely location based account predicts that targets should be detected equally fast because whether attention shifts within or between objects, the physical distance between the cue and the targets is the same. However, as they and many others have found, targets are responded to faster when they appear in the same object as the cue rather than in an adjacent object. Many researchers agree that selection can occur at multiple stages. Effects of attention have been observed at nearly all levels of sensory processing (e.g. Motter, 1993; Riesenhuber & Poggio, 1999; Pasupathy & Connor, 2002; Itti, Rees & Tsotsos, 2005).

The aim of the studies of this thesis is to get more information about attentional selection in object perception using two different approaches. On the one hand, it is questioned how *different ways of directing attention* influence target object selection and perception in our visual field when other objects are present. On the other hand, it is explored how the *different features* (e.g. spatial arrangement of object parts, contrast, spatial frequency) of the object that is seen either briefly before or after the target, influence attentional selection of the target object.

Psychopsysical experiments with voluntary human subjects (mostly students) have been conducted to accomplish these aims. The experiments are all specifically programmed (in Qbasic or Visual Basic) for each study to present different visual stimuli on a computer screen in the controlled way and environment.

1. VISUAL MASKING

Having a representation of the visual object in our brain is not all we need for to perceive it; at some point in the process we also have to become consciously aware of that object. Visual masking is a widely used method to research the stages of object processing and to manipulate perceptual awareness of the target. It involves briefly displayed target stimulus that is either preceded (forward masking) or followed (backward masking) by a mask, or presented simultaneously with a mask. The mask is another stimulus (in the studies relevant to this thesis, a briefly displayed stimulus) that is degrading the perceiver's ability to discriminate the target. If a target stimulus is presented without a mask it has an unlimited processing time, making it difficult to draw conclusions about the dynamics of the processing of objects. The mask imposes constraints on the processing of the target. These constraints can be controlled by the physical attributes and timing of the mask in order to interfere with the object perception processes selectively. For example, the earlier the mask is introduced relative to a target the earlier ("lower level") object processing stage can be influenced. There are mainly four types of masking used in object perception and conciousness studies: metacontrast masking, pattern masking, lateral masking and substitution masking. The first two are supposedly more low-level masking and the last two are more high-level, attention dependent masking. I have probed the effects of metacontrast and substitution masking in my studies. However, it should be mentioned that the mask types are often not so clearly distinguishable and those hypothetical explanations can be combined depending on the features and spatial location of the mask and also timing of the mask.

The term lateral masking is used whenever identification of isolated objects in the periphery of visual field is better than identification of equidistant objects situated near other objects. Among the contemporaries, Bouma (1970) and Bouma and Leigen (1977) demonstrated the lateral masking effect. In their seminal studies (Bouma & Leigen, 1977, 1980, cited in Pernet et al. 2006), subjects had to focus on a fixation cross and name target letters located in parafoveal vision. Subjects' naming was both more accurate and faster for isolated letters than for flanked letters.

Pattern masking is the most common type of masking, where a pattern that is covering the area of the target stimulus is shown either briefly before or after the target (for reviews of all types of masking see Breitmeyer, 1984; Bachmann, 1994; Breitmeyer & Ögmen, 2000, 2006).

Metacontrast masking is a special case of visual backward masking that refers to the reduction of the visibility of a briefly flashed stimulus (the target) by the second stimulus (the mask) that flanks or surrounds the target. It is different from pattern masking because there is no spatial overlap of mask and target. The masking effect can be seen best when the contours of the target and mask are close, the mask follows the target onset by 30–100 ms (Turvey, 1973; Bouma, 1970; Breitmeyer, 1984; Bachmann, 1994; Enns & Di Lollo, 1997), and the contrast polarity of the target and mask is similar (Becker & Anstis, 2004). This type of masking is typically attributed to low-level, preattentive interactions described in such models as the inter-channel inhibition model offered by Breitmeyer and Ganz (1976), the perceptual retouch theory by Bachmann (1984) and the boundary contour system by Francis (1997). According to perceptual retouch theory (Bachmann, 1984, 1994, 1999), an explanation of the backward masking results would be that the long-latency boost of facilitative modulation through the non-specific thalamus which is evoked by the first stimulus arrives at cortical sites of specific stimulus-representations right at the time when the newly arrived fast signals from the second stimulus specify the sensory contents of the second stimulus. The specific signals of the first stimulus processed by respective driver neurons (Crick & Koch, 2003) have decayed somewhat already. However, the signal-to-noise ratio of specific second stimulus information encoded by second stimulus drivers is higher than that for the fist stimulus when the delayed modulation boost arrives in the form of pre-synaptic excitatory potentials from non-specific thalamus. Consequently, relative saliency of the second stimulus is increased and the second stimulus will be prioritized for explicit representation, resulting in replacement of the fist stimulus.

Substitution masking phenomenon has been found by Enns and Di Lollo (1997) and has grown out from metacontrast masking studies. It occurs when the emerging representation of the target object comes into conflict with the emerging representation of the mask object at the same visual field location. Substitution masking differs from metacontrast masking because there is no close spatial adjacency of the target and mask contours and two separate sources for this type of masking are hypothesized. The first, *camouflage* masking, refers to degradation in the representation of a target through the addition of noise from the mask (since the target and the mask are presented simultaneously). The second source of masking is *interruption.* The mask appears (or is presented after the image of simultaneous target and mask) when the target has been fully processed and represents a competition for higher-level mechanisms involved in object recognition. Enns and DiLollo (1997) prefer the term substitution masking instead of interruption masking since the mask does not simply interrupt the processing of the target but appears to become the new focus of attentional object recognition mechanisms (see also Bachmann & Allik, 1976). Moreover, effective rejection of the target from perception seems not to be all-or-none, but it can be partial, depending on what is the property of the target to be reported (Gellatly et al., 2006). A necessary precondition for substitution masking to occur is that attentional contact with the target has to be delayed, either by location uncertainty or simultaneous presentation of distractors similar to the target (Enns & Di Lollo, 1997; Di Lollo, Enns & Rensink, 2000).

Attention can also be delayed by increasing the distance between the fixation and the target (Jiang & Chun, 2001). If the offset of the mask is simultaneous with the offset of the target, there is little impairment of target visibility when using Enns and Di Lollo type of mask (see, however, Lleras & Moore, 2003). When the mask offset is delayed relative to the target offset, the result depends on attentional conditions. When distractor items are presented with the target in order to compete for attentional resources, discrimination performance drops rapidly, with maximum impairment obtained at offset delays of around 100–150 ms (performance drops to an asymptotic value). When no distractors are present, there is no masking (see **Studies I, VI**). The main assumption of Computational Model of Object Substitution (CMOS) (Di Lollo, Enns & Rensink, 2000) is that perception is based on the activity of hierarchically arranged three-layer-modules arrayed over the visual field. The model employs an iterative loop (re-entrant activity) aimed at noise reduction and hypothesis verification, establishing the most plausible perceptual interpretation of the incoming stimulus. In CMOS attention is modeled as the time for making contact with the target (t_c), being a linear function of set size.

Several other resent studies have proved involvement of higher-level attentional processes in visual masking. Ramachandran and Cobb (1995) found that adding stimuli to the display that enabled to group the stimuli reduced metacontrast masking. In accord with that finding Shelley-Tremblay and Mack (1999) had noticed in their studies of inattentional blindness that a few highly meaningful stimuli resisted inattentional blindness and were seen even under conditions of inattention. They conducted experiments with masked happy faces and subjects' names and found that those resisted metacontrast masking, indicating that attention also has a role in metacontrast masking. The authors assume that masked targets are deeply encoded although unavailable to consciousness. The highly meaningful stimuli draw attention faster/better and the masking effect is eliminated.

In **Study II** it was hypothesized that the relative spatial positioning of the target and mask may be the key to differentiate the local contour/sensory interaction based masking effects from the attentional selection based masking. It is common practice that the mask is used as something that interrupts the processing of the target, therefore manipulating the target and the time interval between the target and the mask would enable to interfere with different target perception stages. However, manipulations with the mask may give us information about the interruptive processes of masking, especially when a range of mask temporal delays is utilized. In other words, by systematically changing the mask in **Studies II, III** and **IV** we explored not just the target object perception but the processes of target and mask interaction in more detail. In **Study II**, the idea of Francis and Herzog (2004) research is elaborated. They showed that the size of the mask had an enormous effect on masking although that part of the mask that was overlapping with the location of the target was kept invariant. Small mask produced strong U-shaped masking and large mask (consisting of the same elements as the small mask) did not have any masking effect. The results were attributed to different attentional selection processes involved in feature binding stage of object processing. We noticed that the masks differed in number of elements, confounding the results with different mask processing speed (larger objects processed faster or objects consisting of more elements processed slower). This confound could be overcome by using two flanking letters as a mask of a single letter target, or two adjacent letters as a mask on one side of the single letter target. The mask was presented as a forward mask on half of the trials, and as a backward mask on other half of the trials. The subject had to identify the target and mask letters to ensure equal processing of the mask and target. Therefore, the stimuli were not named a target and a mask but mutually masking targets S1 (the stimulus that is shown first) and S2 (the stimulus that is shown after the first stimulus). Our hypotheses and results were: 1) Changing the spatial arrangement of the mask varies the extent of local contour interaction and, therefore, single letter targets displayed *between* flanking letters would not be identified as well as single letter targets displayed adjacently to one side. When stimulus onset asynchrony was short, this hypothesis was supported, but depending on the timing of stimuli. When stimulus onset asynchrony (SOA) was increased the effect of spatial positioning of single letter S1s decreased, reaching an equal level of correct recognition of about 40% for flanking and flanked S1s when SOA=100 ms. It was inferred that the masking depended on local contour interaction (Francis, 1997) in short SOA conditions but on substitution or interruption processes in long SOA conditions (Bachmann & Allik, 1976; Di Lollo et al., 2000); 2) attentional selection dependent object substitution masking or interruption masking should be seen from relatively higher identification rates of S2, independently of the stimulus type. The results confirmed that.

2. ORIENTING OF ATTENTION

As mentioned in the introduction, according to Posner's view attentional selection can occur as a result of two different processes that can be observed using certain types of visual cues. Attentional responses to the cue depend on the location, informativeness and purpose of the cue. First option is orientation towards sensory properties of a stimulus cue, particularly locations in visual space ("bottom up"). This type of cueing is variously termed exogenous (Posner, 1980) or automatic, reflexive or peripheral cueing (see review by Egeth & Yantis, 1997). It means that we can attend to the location where the cue is presented in visual space and respond more rapidly to events occurring at that location. Attended events give rise to enhanced cortical electrical activity (evoked potentials), and can be reported at lower thresholds (Posner, 1995). In addition, the ability to correctly discriminate targets in the immediate surround of the stimulus that is in the focus of attention (cue), is improved (Kröse & Julez, 1989; Nakayama & Mackeben, 1989; Kirschfeld & Kammer, 2000).

Second option of attentional selection occurs when endogenous (Posner, 1980), in other words voluntary (Jonides, 1981; Müller & Rabbit, 1989) or central cue is used. This enables detection of the target, whether sensory or from memory ("top down"). The cue is only neccesary as a "conceptual" landmark of a location and the cue's physical parameters are irrelevant. In fact, the cue can be omitted if we can maintain fixation of the covert attention at the mentally designated area in our visual field. Focusing without the physical cue can create a focus of attention and improve the accuracy of responses dramatically (Nakayama & Mackeben, 1989).

In **Study I** we manipulated attentional selection in substitution masking conditions using the central and periferal cues. Our aim was to find out whether the substitution masking model presented in Di Lollo et. al. (2000) was adequate claiming that object perception in those specific masking conditions depended on general attention directing time (manipulated by the number of distracters) and mask delay. As introduced above, Posner (1980) has shown that attention can be directed to a target at least in two ways: endogenously and exogenously. Therefore, substitution masking should also be influenced either by exogenous or by endogenous cues. However, from substitution masking theory we predicted that when no pre-cue is displayed before the target-mask and distractors display, attentional selection takes time and strong substitution masking occurs. Pre-cueing should attenuate or eliminate the masking effect (meaning that in all mask offset delay conditions results similar to simultaneous mask offset condition would be achieved) because it would shorten the time to direct attention to target location.

We found that when attention was shifted to the target location exogenously (using a local peripheral pre-cue, four-dots around the location of the target), masking was attenuated. The typical substitution masking result (target identification would decrease with longer mask offset delays) was not observed with exogenous pre-cue. Responses to the centrally pre-cued (an arrow pointing to one of the four possible target locations) or not pre-cued conditions revealed typical substitution masking effect. Therefore, this study showed that exogenous pre-cueing of attention attenuates substitution masking whereas endogenous pre-cueing does not. The reasons could be that only exogenous, sensory type of cue (compared to symbolic, top-down controlled pre-cue) is shortening the *time to contact* with the target. The computational model of object substitution masking (Di Lollo et al. 2000) should be revised accordingly. The effect of increasing sensory saliency of the stimulus at the locus of the pre-cue should perhaps also be considered (**Study II**; Bachmann, 1988; 1994). These attentional enhancing effects could be based on bottom-up mode of sensory modulation preceding the target. This modulation can be thought of as local pre-cue processing facilitating sensory processing of the following target image. According to this reasoning, the model describing substitution masking could be feed-forward as well as re-entrant. Re-entrant reasoning would be that the speeding up of processing may improve the segregation of the target and mask images before the re-entering mask-alone image signals replace the target plus mask signals.

3. HYPOTHETICAL PROCESSING STAGES OF OBJECT PERCEPTION

Pre-attentive and attentive processes are implemented in the hypothetical stages of object (scene) processing. Neurobiological studies have shown that there are several levels of processing that analyze visual properties from the simplest through intermediate to complex natural objects (e.g. Riesenhuber & Poggio, 1999; Pasupathy & Connor, 2002; Motter, 1993). Different researchers name those stages differently and for some researchers the division is different. The most popular understanding of object perception stages comes from the theoretical framework introduced by David Marr (1982) and his colleagues. Palmer (1999, pp. 85) labels those stages: the image based, surface-based, object-based and category based stages of perception.

The image-based stage

The image-based stage includes retinal processing (see for overview Palmer, 1999, pp. 147–150; Schiller, 1986) and processing in sensory pathways: ON-OFF pathways (Schiller 1982, 1984, 1992; Bilotta et. al. 1995; Dvorak and Morgan, 1983; Bowen, 1997, 1995) and M-S pathways (e.g. Shapely & Perry, 1986). These pathways lead signals from retina to the cortex and process simple features in primary visual areas of cortex. Marr thought that initial images that are the outcome of this processing stage are two-dimensional and specified within the retinal frame of reference (coordinate system where principal axes are aligned with the eye). One image is supposedly a "raw primal sketch" and includes the results of elementary detection processes that locate edges, bars, blobs, and line terminations. Spatial frequency theory has been developed for understanding these elementary detections. The other image is so called "full primal sketch" and includes also global grouping and organization among the local image features.

The assumptions of spatial frequency theory have been put into use also in experiments reported in this thesis (**Study III, IV**). The essence of spatial frequency theory is the idea that the representation of any image is an assemblage of many primitive spatial "atoms". They can be envisaged as spatially extended patterns of sinusoidal gratings. Each primitive sinusoidal grating can be characterized by its spatial frequency, orientation, amplitude, and phase. Every scene or picture or object we encounter may be summed to a set of sinusoidal gratings using a method called Fourier analysis and its reversal – Fourier domain synthesis. It can be shown, using Fourier's theorem, that low spatial frequencies carry the coarse spatial structure of the image (large dark and bright areas) and high spatial frequencies carry the fine spatial structure (the sharp edges and small details). This spatial frequency analysis is supposedly carried out by a large number of overlapping psychophysical channels of different spatial frequencies and orientations. Each of these hypothetical spatial frequency channels is maximally sensitive to a certain spatial frequency and orientation of the grating. The physiologically close match to those hypothetical channels could be cells that are selective to orientation, initially found by Hubel and Wiesel (1963) in the cortex of kittens. These cells may also perform a local spatial frequency analysis of incoming images. They work like small patches of sinusoidal gratings that are multiplied by a bell-shaped Gaussian envelope. The receptive field structure that results from this is called a Gabor function. There is also a great deal of empirical evidence to infer that our unconscious visual perception is functioning like the spatial frequency theory depicts it (Palmer, 1999, pp. 158–170; Blakemore & Campbell, 1969; Blakemore & Nachmias, 1971; Graham & Nachmias, 1971; De Valois, Albrecht & Thorell, 1982). Spatial frequency filtering (either low or high frequencies are filtered out from the images) is often used in object perception studies.

We also used a spatial quantization (Harmon & Julez, 1973) method for studying perception of face stimuli (**Study III, IV**). This method enables one to manipulate parametrically the spatial distances and proportions of features that form the configural structure of the elements of facial images. Increasing the quantization level by enlarging the square-shaped blocks (within which the local intensity values of the original image is averaged) introduces more distortion into the original configuration of the image. This systematic manipulation of masker images (image that is shown shortly before or after the target image) enabled us to interfere selectively with various levels of target object recognition to different extents. However, it is important to note that the reasoning is based on the hypothesis that the object processing stages working on coarse and detailed levels of the image structure are executed in a successive manner. Using mask images that have either the same or a different visual identity compared to the target image, supportive/facilitative effect or interruptive/masking effect could be observed accordingly. The mentioned effects also depend on the perceptual processing stage when the mask is introduced. The mask appearing before the target would start influencing the target processing in early stages and the mask appearing after the target would influence the late stages; the more so, the larger the time delay. (The results of the studies **III**, **IV** will be dealt with in part 4.)

Research of ON-OFF pathways also contributes to the understanding of image-based stage of object perception. Whenever luminance increments and decrements have to be detected, ON and OFF pathways are in work. Luminance increments are detected by ON channels and decrements by OFF channels that transmit signals from retina to cortex. These signals remain isolated at least up to primary cortical areas as has been shown by Schiller (1982; 1984; 1992), Bilotta et al (1995) and Dvorak and Morgan (1983). Trained monkeys in which the ON channel is blocked with 2-amino-4-phosphonobutyrate (a neurotransmitter analogue), have difficulty in detecting stimuli that are made visible

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by virtue of light increment, but have no difficulty with detecting light decrement. Those monkeys also show a significant loss in contrast sensitivity but not in colour discrimination, acuity, motion detection and stereopsis (Schiller, 1986). Bowen (1995; 1997) has done psychophysical experiments on humans, manipulating contrast polarity (positive and negative) of base contrast mask and added contrast target. Bowen concluded from his results that on cortical level ON- and OFF-pathways probably interact. However, Becker and Anstis (2004) reported opposite results (metacontrast masking) that allow inferring isolation of ON- and OFF pathways also on cortical level.

How objects are attentionaly selected when the influence of ON- and OFF-pathways on object perception is manipulated, is a question asked in **Study VI**. It has been shown by Becker and Anstis (2004) that metacontrast masking is diminished when a target and a surrounding mask have opposite contrast polarity values. We were interested in how lower level features such as luminance increments and decrements influence object perception in relatively higher level, attention dependent substitution masking. Results of our two experiments showed that contrast polarity of the target and the mask had an effect on substitution masking. A target was generally identified better when surrounded by an opposite polarity mask compared to a same polarity mask on a gray background. Opposite contrast polarity of mask stimuli decreased the effect of distracters. Therefore, opposite polarity mask that also functioned as a spatial cue influenced the time of directing attention to a target. Also, opposite contrast polarity mask decreased masking with delays longer than 100.2 ms, showing that re-entrant processes could be influenced either by isolated processing in ON-OFF pathways that process luminance or by color/luminance processing that enables faster formation of separate target and mask representations.

An increase in intensity and contrast of the stimulus improved performance near the spatial cue probably due to decrease in visual latency (Breitmeyer, 1984; Hirosaka et. al. 1993; Stromeyer & Martini, 2003; Kirschfeld & Kammer, 2000) and attentional set (Shore et al. 2001). Attentional set is a pre-activated knowledge about the properties of the stimulus. The aim of **Study V** was to explore temporal discrimination process by varying relative luminance contrast of two temporally successive stimuli. When two objects are presented in rapid succession, observers find it difficult to discriminate their temporal order. Below certain limit (e.g., 20–70 ms), the rate of correct temporal order judgment is reported to be about 50% (i.e., close to chance level). We hypothesized that temporal order discrimination of two stimuli improves if relative luminance contrast is increased for the first stimulus and decreased for the second stimulus (because of the decrease of visual latency). We controlled attentional set of temporal position by not telling to subjects to attend to one of the two stimuli but to attend to both temporally successively displayed stimuli and evaluate their temporal order (Experiments 1 and 2). It was made clear that the stimuli may differ in contrast. Subjects did not know that trials with synchronous presentation of the stimuli were included (Experiment 2). In our experimental setup the temporal order discrimination was not improved as expected. The dimmer stimulus that was presented as the second was reported as the first at short (< 33.4 ms) SOAs. We inferred that from the stimulus conditions where veridical order discrimination dropped significantly below chance level, which meant perceptual illusion of order reversal. To observe the order reversal effect it is necessary that the stimuli are very brief, spatially overlapping, clear-cut backward and forward masking is absent, stimulus onset asynchronies are very short, and luminance contrast of the following stimulus is considerably lower than luminance contrast of the first stimulus. The higher the contrast ratio, the stronger is the order reversal effect. However, because also in the conditions where the two stimuli were presented synchronously, the dimmer target was perceived as the first, the effect should be attributed to some implicit bias that enforces subjects to regard a more contrasted stimulus as the one that appears after the less contrasted stimulus.

Although image based properties are central in this thesis, it is also important to introduce shortly the other processing stages of object perception.

The surface-based stage

The surface-based stage is for recovering the intrinsic properties of visible surfaces (spatial layout in three dimensions) in the external world that might have produced the features that were discovered in the image-based stage. The end product of this stage processing was named 2.5-D sketch by Marr (1978) to emphasize that it lies between the true 2-D structure of image-based and true 3-D structures of object based representations. Primitive elements in this stage are local patches of 2-D surface at some particular slant located at some distance from the viewer within 3-D space. Therefore, it is a first step of recovering the third dimension from two-dimensional image.

The object-based stage

The object-based stage includes hidden assumptions about natural world that enable us for example perceive a coffee cup cylindrically and not cut off from the backside that we do not see from our viewpoint. This stage includes our knowledge about whole objects. The scene representations and known representations are merged into one. There are two possible approaches to how the merging could happen. Boundary approach says that the objects in the view are extended according to known representations. Volumetric approach says that scene representations are perceived as arrangements of some set of primitive 3-D shapes (Marr & Nishihara, 1978).

The category based stage

The category-based stage is about recovering functional properties of objects (which would aid us to survive in our adaptation to environment). Two operations are involved, first an object is classified according to visual properties and second, this identification allows access to a large body of stored information about this type of object, including practical meaning (e.g. what one can do with the object).

4. PROCESSING OF THE FACE STIMULUS

What processes of what stages are most important in face identification? The early stages of object processing could be interfered and studied by introducing the quantized mask various time intervals before the target (**Study III**). The interference effects provide valuable information of what processes are specific to identifying a face and to specific subcomponents of this activity. The predictions of what processes could influence face identification in **Study III** had three sources: local feature processing, spatial frequency processing, and microgenetic emergence of object configuration (mutual distances and proportions of individual features) in successive stages. All those processes start in the early stages and first two also end in the early object processing stage, configural processing continues until later stages (object-stage, categorical stage).

Microgenetic processing idea (see for overview, Bachmann, 2000) supports the assumptions that when two spatially overlapping images (e.g., faces) are presented in rapid succession and the first image (S1) is identical to the second (S2) the facilitative/supportive effect to all aspects of processing of S2 should be maximal. When S1 and S2 are different faces, the interruptive/masking effect of S2 processing is achieved. When random broadband Gaussian noise is quantized and used as S1, it degrades the processing of local features and spatial frequency of S2 but not directly its configural processing. The aspects of image processing affected in **Study III** would be: 1) integration of the local sensory signals and overall configuration of features of S2 is enhanced and signal-to-noise ratio is reduced with finely quantized same-face S1. Intermediately quantized same-face S1 has an early effect of noise-masking on local sensory signals but not on identity-related configuration. Coarsely quantized same-face S1 does not have an influence on robust configuration of S2. Different-face or noise S1 would slow down the local feature and spatial frequency processing of S2 when S1 is finely or intermediately quantized, coarse quantization of S1 would not have the impairing effect on robust configuration processing of S2; 2) the search for general perceptual category of the object (i.e., face) is initiated by S1 and therefore becomes redundant for the S2, independently of the quantization scale of S1 in the same-face or different-face S1 conditions. Different-face S1 would initiate the search of the correct general category, but wrong identity cues when quantized finely or intermediately, slowing down initiation of the specific visual identity processing of S2. Coarsely quantized different-face S1 would not have an interfering effect on general visual category level, but may have an effect on visual identity based level; 3) independently of quantization scale, same-face or noise S1 captures attention, increasing perceptual saliency and processing speed of S2. Different-face S1 captures attention and increases the attentional threshold for S2 when S1 is finely or intermediately quantized. Results showed that same-face masks had virtually no masking effect at any of the quantization values. Different-face masks had strong masking effects only with fine-scale quantization, but led to the same efficiency of recognition as in the same-face mask condition with the coarsest quantization. Moreover, compared with the noise-mask condition, coarsely quantized different-face masks led to a relatively facilitated level of recognition efficiency. The masking effect of the noise mask did not vary significantly with the coarseness of quantization. Therefore, microgenetic process, where generalized visual category related configuration is established before the identity level, may have the utmost importance in early stages of face stimulus recognition. This is because quantized forward masks enhance it in predictable ways. The conclusion was made from our data because the refinement of the values of the configural metrics of a perceived face took place at the later stages of microgenesis and manipulation of the local level features of the mask did not affect S2 identification results.

How later stages of face identification are influenced by the quantized masks that are either locally noise-masking for features, or influencing configuration processing, or disrupting the spatial frequency analyses, or tapping attentional capacity, was explored using backward quantized masks (the masks appearing after the target) in **Study IV.** The masks used were same-face, different-face and quantized noise (see also **Study III**). Different backward-masking theories were compared as the possible explanations of the outcomes. The theories compared were: transient-on-sustained inhibition theory (Breitmayer and Ganz, 1976; Breitmayer, 1984; Breitmeyer & Ögmen, 2000), perceptual retouch theory (Bachmann, 1984, 1994), attentional object substitution theory (Di Lollo et al. 2000), and local-contour-interaction theory (see Francis 1997 for overview). Transient and sustained channels are sensitive to the spatial frequency content of the stimuli. Low-frequency stimuli are effective input for transient channels and high-frequency stimuli for sustained channels (at short or intermediate SOAs). Switching attention from S1 to S2 is considered the main cause of backward masking at intermediate and long SOAs. The assumption that attentional effect is dependent on configural properties of stimuli matches the views of Bachmann and Allik (1976) and Francis (1997). Re-entrant feedback, where the mismatch between the input of the S2 is detected when compared to the first input (S1), is the basis of substitution masking (e.g. Di Lollo, 2000). In **Study IV** we predicted that: 1) the different-face S2 would be the most competive for selective-attentional resources at long SOAs, compared to the noise- and same-face S2; 2) finely quantized different-face and noise S2 would also have strong influence on S1, compared to coarsely quantized S2; 3) there should be no differences between different S2s of same quantization level at intermediate to long SOAs if spatial frequency analysis is expected to be behind the masking effect; 4) we should see that the S2 containing face information has a stronger impact on S1 than the noise S2 if the results are based on attentional object substitution processes; 5) the noise and different-face S2s are expected to have strong masking effect at the short and intermediate SOAs compared to same-face S2 when intra-channel inhibition processes are the cause of the results. The data of the experiment of **Study IV** showed that configural characteristics, rather than the spectral content of the mask, predicted the extent of masking at relatively long stimulus onset asynchronies (SOAs). This poses difficulties for the theory of transient-on-sustained inhibition as the principal mechanism of masking and also for local contour interaction being a decisive factor in pattern masking. The scale of quantization of noise masks had no effect on S1 identification. However, the scale of quantization of different-face masks had a strong effect on the mean responses to S1. Also, the decrease of configural masking with an increase in the coarseness of the quantisation of the mask highlights ambiguities inherent in the re-entrance-based substitution theory of masking: coarse-quantised mask images should include more local spatial uncertainty when matched with target-image segments during the reentrant matching process and thus should lead to stronger masking. The results of the **Study IV** led to the conclusion that any of the causative processes proposed by any of the different masking theories separately, cannot explain the identification processes of the face image in backward masking conditions. The mechanisms proposed separately should be combined, in order to create a complex, yet comprehensible model of visual backward masking.

CONCLUSIONS

My thesis contributes to the knowledge of interactions of object perception and attentional selection. One aspect of the research that is carried out is about object perception in the conditions where the control of attentional selection was manipulated. It was found that “top-down” attentional selection is not effective compared to “bottom-up” enhancement of target object features when distractive stimuli are present and the target is also surrounded and followed by attentionally distractive mask stimulus. The reason could be that only the sensory type of cue is shortening the time to orient attention to the target. Interaction of the target and another stimulus that is located closely (mask) was looked at further in the experiments of another study. We found that different contrast polarities of the target and mask stimuli also improve attentional selection of the target when the target location is hard to detect in the periphery of the visual field and certain processing time has passed. We offered two explanations. First, is related to the fact that luminance processing is taking place in isolated visual ON- and OFF-pathways below the cortical level. Performance might improved in different polarities trials because one of the pathways could be faster. Second, differences in luminance or color could improve formation of separate target and mask representations possibly through grouping or segregation processes. However, when the stimuli are presented in the focus of attention one after another, high contrast of the first stimulus deteriorates the ability to discriminate temporal order of the stimuli when the time between the stimuli is very short (less than about 35 ms). The reason may be some implicit bias enforcing subjects to regard a more contrasted stimulus as the one that appears after the less contrasted stimulus or the processes proposed in perceptual retouch theory (e.g. Bachmann, 1984, 1994). In the latter case, the parameters of the theory-based model have to be substantially changed.

The other aspect that is investigated in this thesis is how the mask stimulus that has limiting effect on target may influence identification processes in time. To achieve this we manipulated different features (e.g. spatial relations of the constituent parts, local contour interactions, spatial frequency) of the mask that appears either briefly before or after the target. When the local contour interaction of the two stimuli was studied, we found that local contours of the mask decrease the mean percentage of target identification when the stimulus onset asynchrony (SOA) between the following target and mask is short (<100ms). The impact of local contour interaction decreases when SOA=100 ms. Attentional selection of the object did not depend on the lower level sensory characteristics of mask. In our studies with face images, we found that to identify a face, in addition to spatial frequency and local features analysis, processing configuration information is crucial and this is probably influenced by attentional selection. Later stage attentional processing of the target was generally not influenced by the manipulations of the lower level factors of the mask unless those manipulations changed the higher level (cognitive) characteristics of the mask.

This thesis should give reader an understanding that contrary to the common belief of the simplicity of vision, the interactions of object perception and attentional selection processes are complex. However, every study that adds a piece of knowledge takes us closer to the discovery of what is attention and what are the principles of its functioning in visual object perception.

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SUMMARY IN ESTONIAN

OBJEKTITAJU JA SELEKTIIVSE TÄHELEPANU PROTSESSIDE INTERAKTSIOON

Töö eesmärkideks on uurida selektiivse tähelepanu ja objektitaju interaktsioonimehhanisme kahest aspektist. Ühelt poolt uurin, kuidas erinevad tähelepanu suunamise viisid mõjutavad eesmärkobjekti selektsiooni segavate objektide hulgast nägemisvälja perfeerias. Teiselt poolt näitan, kuidas selle objekti (maski) tunnused, mida näidatakse samaaegselt või põgusalt enne või pärast eesmärkstiimulit, mõjutavad eesmärkobjekti äratundmist. Varieeritud on selliseid maskeeriva objekti tunnuseid nagu osade kaugus üksteisest ja nende suhteline asetus, kontrast ja ruumilised kontrasti jaotumise sagedussignaalid. Põhiliseks uurimismeetodiks on visuaalne maskeerimine, mis võimaldab limiteerida eesmärkobjekti töötlust ja teadvustamist ajas täpselt ja selektiivselt. Töö koosneb kuuest artiklist, milles on avaldatud järgmised teadmised objektitaju ja tähelepanulise selektisooni interaktsioonimehhanismide kohta:

I artikkel näitab, et "ülalt alla" (sümboolse osundajaga) tähelepanu suunamise viis ei ole sama efektiivne kui "alt üles"(sensoorse lokaalse osundajaga) tähelepanu suunamine tingimustes, kus eesmärkobjekti peab leidma segavate objektide seast ning eesmärkobjekti ümber on tähelepanuresursside eest võistlev objekt ehk mask.

II artikkel on uurimus, mis selgitab, et tähelepanuline maskeerimine ei sõltu maskeeriva objekti tüübist ega objektidevahelisest ajaintervallist juhul, kui intervalli väärtus jõuab umbes 0,1 sekundini. Lokaalsete kontuuride maskeerimisefekt ilmneb lühikestel ajaintervallidel enamkülgnevate kontuuridega maskitüübi kasutamisel.

III artikli tulemuste põhjal väidame, et nägude äratundmise etappidest on kõige olulisem mikrogeneetiline konfiguratsiooni info töötlus, sest eesmärknäole eelnev kvanditud stiimulnägu mõjutab eesmärknäo töötlust vastavalt mikrogeneetilise teooria eeldustele.

IV artiklist ilmneb, et konfiguraalse info manipuleerimine maskis ning samas tagatud madalama taseme tunnuste kontrolli all hoidmine mõjutas eesmärkstiimuli taju kõige rohkem pikema stiimulitevahelise ajaintervalli möödudes, tulemused ei ole kooskõlas ühegi praegu kehtiva maskeerimisteooriaga eraldi, vajalik oleks nende kombineerimine.

V artikkel käsitleb kahe stiimuli ajalise järjekorra taju, kui stiimulid esitatakse ühes ruumipunktis üksteise järel väga lühikese ajaintervalliga. Tulemused näitasid, et kui esimese stiimuli kontrast on tunduvalt suurem kui teise oma, tajutakse esimest stiimulit ajas teisena (ajaintervall kahe stiimuli esitusaja alguse vahel lühem kui 33.4 ms).

VI artikkel kajastab uurimust, kus uuriti eesmärkobjekti ümber ilmuva objekti (maski) interaktsiooni eesmärkobjektiga varieerides eesmärkobjekti ja maski kontrasti polaarsust. Selgus, et maski ja eesmärkobjekti kontrasti polaarsuste erinevus võimaldab paremat eesmärkstiimuli tähelepanulist selektsiooni.

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I

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II

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III

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V

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VI

Luiga, I. & Bachmann, T.
Luminance processing in object substitution masking.
(submitted)

Luminance processing in object substitution masking

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Abstract

It has been shown that metacontrast masking is diminished when a target and a surrounding mask have opposite contrast polarity values. We were interested in how lower level features such as luminance increments and decrements influence relatively higher level, attention dependent substitution masking. Results of two experiments showed that contrast polarity of the target and the mask had an effect on substitution masking. A target was generally identified better when surrounded by an opposite polarity mask compared to a same polarity mask on a gray background. Opposite contrast polarity of mask stimuli decreased an effect of distracters. Therefore, opposite polarity mask that also functioned as a spatial cue influenced the time of directing attention to a target. Also, opposite contrast polarity mask decreased masking with delays longer than 100.2 ms. Therefore, re-entrant processes could be influenced either by isolated processing in ON-OFF pathways that process luminance or by color/ luminance processing that enables faster formation of separate target and mask representations.

Keywords: substitution masking, visual masking, ON-OFF pathways, luminance, contrast polarity

1. Introduction

One way to research perceptual interaction of visual object processing details and attentional processes is to use object substitution masking paradigm. DiLollo, Enns & Rensink, (2000) have described substitution masking that appears to involve relatively high-level attention and object-recognition mechanisms. Substitution masking is said to occur when the emerging representation of the target object comes into conflict with the emerging representation of the mask object at the same visual field location. The necessary preconditions for the masking to occur include delayed attention to target either by location uncertainty or simultaneous presentation of distracters (Enns & Di Lollo, 1997; Di Lollo, Enns & Rensink 2000). Distracters are additional visual objects presented with the target. When distracters are in view, their similarity with the target is important and also target eccentricity (Jiang & Chun, 2001; Di Lollo et al., 2000).

The masking effect can be seen even when the contour masking (Breitmayer, 1984; Francis, 1997) possibility is minimized. Substitution masking occurs when the target stimulus is flanked only by four dots (the mask) corresponding to the corners of an imaginary square surrounding the target and the onset of the mask is simultaneous with the target. If the mask offset is also simultaneous with the target, there is little impairment of target visibility. If the mask offset is delayed relative to the target offset, discrimination performance drops rapidly, with maximum impairment occurring at offset delays of around 100–150 ms (with no recovery at longer delays). The object substitution masking has been shown to be mostly attention dependent because the main source of masking is the time interval needed to direct attention to a target. This time interval depends solely on number of distracters (Di Lollo et al., 2000). The more distracters on display simultaneously with the target, the longer is the time interval for directing attention to the target and therefore, the more pronounced is the masking effect. This is seen in behavioural results as a decrease in the target identification accuracy depending on how long a mask offset is delayed relative to a target offset and the decrease is gradually larger the more there are attention delaying stimuli on the display. Masking effect dependent on low level features and observed in substitution masking conditions (local contour interaction, luminance, color) should be seen within less than 80 ms from stimulus onset (Spencer and Shuntich, 1970; Di Lollo et al., 2000). It is suggested that during this interval the number of distracters on display does not yet affect the strength of masking.

A type of visual masking that is based mostly on lower level features is metacontrast masking. It is known to be a relatively lower-level effect because it occurs with specific stimuli and time between the onsets of the stimuli (Breitmeyer, 1984; Bachmann, 1994). Metacontrast masking mechanism is supposedly based on a contour of the mask ring influencing a luminance “filling-in” or in other words, inward propagation process of the target area. Becker and Anstis (2004) found that when a target and a mask have opposite contrast polarity (e.g. white and black on a gray background), there was no masking. Their results support the idea of isolated ON and OFF pathways that process luminance, if target and mask are processed by the weakly interacting channels, masking is decreased.

Whenever luminance increments and decrements have to be detected, ON and OFF pathways are in work. Luminance increments are detected by ON cells and decrements by OFF cells in retina. These signals remain isolated at least up to primary cortical areas as has been shown by Schiller (1982; 1984; 1992), Bilotta et al (1995) and Dvorak and Morgan (1983). However, works by Bowen (1997; 1995) have shown that those pathways can also work in interaction at the cortical level.

Bowen (1995, 1997) has explained that isolation of ON and OFF pathways can be inferred when a psychophysical threshold of a test stimulus detection is based on the response of a single pathway. Behavioural data would show that when bright stimulus would increase the detection threshold of the brighter following stimulus compared to the detection threshold of the dimmer following stimulus. Interaction means that psychophysical threshold of luminance detection is raised by the responses of the opposite pathway and lowered by the responses of the same pathway. In other words, interaction would occur due to the inhibiting effect of the signals evoked as a response of the following stimulus processed in the opposite pathway. Therefore, interaction was inferred (Bowen, 1995) when on a bright bar of a preceding stimulus, threshold shift was greater for the following decremential than incremental tests, and the opposite was true on a dark bar of the mask.

We became curious about how lower level features such as luminance increments and decrements are processed (in isolation or in interaction) in the substitution masking condition where contour masking is minimal, stimuli are set on simultaneously and attentional orientation is delayed by displaying distracters together with the target.

Two experiments were conducted to study luminance processing in object substitution masking. According to the metacontrast masking study (Becker & Anstis, 2004) a smaller substitution masking effect could be hypothesized when a mask and a target have opposite contrast polarities. Typical substitution masking effect would be expected in the same contrast polarity conditions. In the first experiment we presented same or different contrast polarity stimuli on 45% luminance (mid-gray) background. In the second experiment we presented the stimuli on 65% luminance (light gray) background. Manipulation of the background luminance was important to control for the saliency of the positive polarity stimuli.

2. Experiment 1

2.1. Method

2.1.1. Stimuli and procedure

Landolt stimuli with either negative or positive contrast polarity were shown for 20 ms on 45% luminance (61.2 cd/m², mid-gray) background on a computer monitor. The luminances of the stimuli were following: positive polarity stimuli were 100% luminance enabled by our computer screen (136 cd/m² (white), contrast c=1.2). Negative polarity stimuli were 0% luminance determined by our computer screen values (8.2 cd/m², contrast c= -0.87). The centres of the Landolt rings (1.2º in diameter) were located on an imaginary circle (8.6 º in diameter) that surrounded a fixation cross (0.2º). The cross was visible throughout the experiment. Spacing between neighboring Landolts was 3.6º from center to center. The gap in a Landolt ring was 0.3º, four possible gap directions were up, down, left or right. There were 1 to 8 Landolts on display. When there was maximum number of Landolts on display they were evenly distributed. Less than 8 Landolts on display were randomly distributed between 8 possible locations that were evenly distributed. Location of the Landolts was randomly selected from 8 locations on each trial. A simultaneous four dot mask appeared around a target Landolt. One dot (the dot had a square shape) measured 0.4º times 0.4º and the separation between a target and a mask was 0.4º. Depending on a trial, the mask was either switched off simultaneously with the target or the offset was delayed 100.2, 200.4 or 300.6 ms after the target offset.A participant had to fixate and click a button with a computer mouse. After a button click, all stimuli appeared simultaneously around the fixation cross. The stimuli where Landolts and the target Landolt was surrounded by a four-dot mask. The task of the participant was to identify the direction of the gap in a target Landolt with a mouse click on an appropriate Landolt on the response panel after the stimuli had disappeared. 10 students (3 males, 8 females) voluntarily chose to participate in the first experiment for additional course credit points.

2.2 Results

Data for Experiment 1 are presented in Fig. 1., separately for each contrast polarity condition. Three way repeated measures within subjects ANOVA of mean percentage of correct responses was conducted. Independent factors (4 (contrast polarity: negative, positive, mask negative target positive, mask positive target negative contrast polarity stimuli) * 4 (number of distracters: 0, 1, 3, 7) * 4 (mask delay: 0, 100.2, 200.4, 300.6 ms)) yielded 64 within subject measurements.

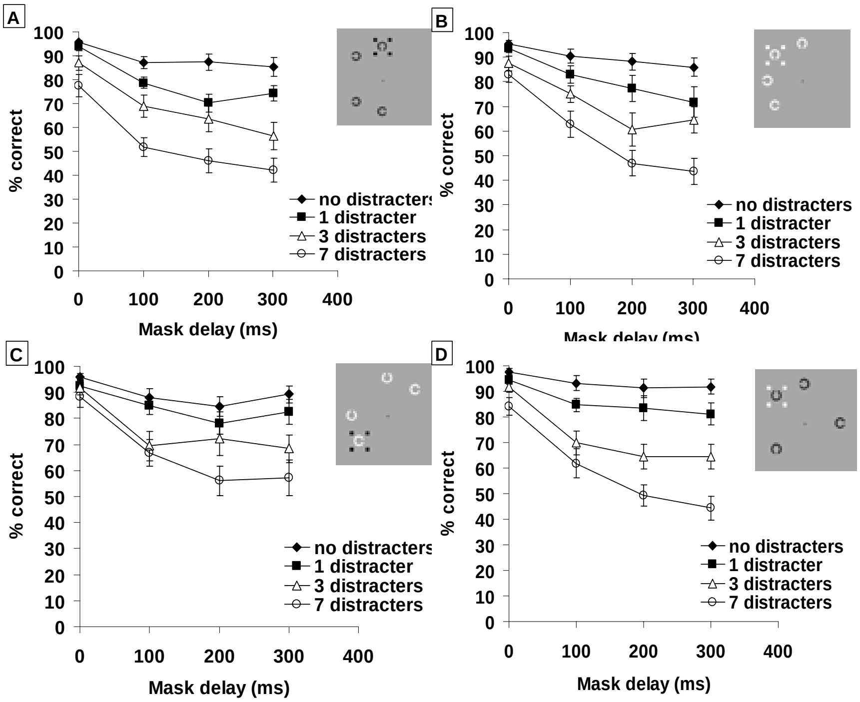

Fig. 1. Mean percentages correct in Experiment 1 (45% luminance background). Four different contrast polarity conditions where mean percentages correct are presented across mask delays as functions of number of distracters. (A) the target and the mask had negative contrast polarity, (B) the target and the mask had positive contrast polarity, (C) the target had positive and the mask had negative contrast polarity, (D) the target had negative and the mask had positive contrast polarity.

Substitution masking effect was replicated in all polarity conditions. Interaction between mask delay and number of stimuli $F(9,81)=16.2$, $p<.0001$ showed a gradual decrease in target identification the more distracters were on display and the longer was a mask offset delay (Fig. 1). Logically, also a main effect of mask delay $F(3,27)=65.2$, $p<.0001$ was found, indicating a decrease in a target identification with longer mask delays. A decrease in mean percentages correct with increasing number of distracters was confirmed by a main effect $F(3, 27)= 133.3$, $p<.0001$. These results are in accordance with Di Lollo et al. (2000), simultaneous four-dot masking effect (decrease in percent correct) reaches its maximum around mask offset delay 150 ms and does not recover.

As we predicted, a main effect of contrast polarity $F(3, 27)=5.1$, $p=.006$ occurred (Fig. 2). Pairwise comparison of all polarity conditions showed that identification was better in the condtions where a mask and a target had opposite contrast polarity compared to the condition where a mask and a target had negative contrast polarity (see Table 1 for post hoc comparisons).

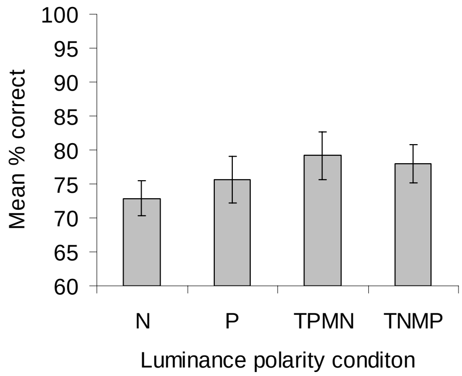

Fig. 2. Mean percentages correct in Experiment 1 (45% luminance background) in four contrast polarity conditions. N – the target and the mask had negative contrast polarity; P- the target and the mask had positive polarity; TPMN- the target had positive and the mask negative polarity; TNMP – the target had negative and the mask positive polarity.

Table 1. Paired samples t-test comparisons of mean percentages correct of all luminance polarity conditions in Experiment 1.

	N vs TPMN t	p value	N vs TNMP t	p value	N vs P t	p value
Main effect of polarity	-4.0	.003**	-3.6	.006**	-1.5	.166
Mask delay 0 ms	-2.6	.031*	-2.1	.070	-.9	.412
Mask delay 100.2 ms	-3.2	.012*	-3.1	.014*	-3.8	.005**
Mask delay 200.4 ms	-3.1	.014*	-2.8	.023*	-1.1	.332
Mask dealy 300.6 ms	-4.6	.002**	-1.5	.184	-.3	.739
No distracters	-.7	.527	-2.8	.020*	-.6	.578
1 distracter	-2.5	.031*	-3.0	.014*	-.7	.504
3 distracters	-2.7	.024*	-2.0	.079	-1.1	.331
7 distracters	-4.3	.002*	-1.8	.107	-2.4	.042*
	P vs TPMN t	p value	P vs TNMP t	p value	TPMN vs TNMP t	p value
Main effect of polarity	-1.5	.179	-1.4	.210	.6	.542
Mask delay 0 ms	-1.4	.190	-1.4	.197	.2	.831
Mask delay 100.2 ms	-.2	.880	.1	.920	.4	.704
Mask delay 200.4 ms	-1.6	.138	-1.4	.199	.8	.469
Mask dealy 300.6 ms	-2.8	.025*	-1.2	.262	1.6	.144
No distracters	.2	.835	-2.8	.021*	-4.7	.001**
1 distracter	-.8	.421	-1.8	.109	-.7	.529
3 distracters	-1.3	.228	-.6	.582	.8	.463
7 distracters	-2.2	.054*	-.2	.816	2.1	.063

Note: N – a target and a mask had negative contrast polarity; P- a target and a mask had positive polarity; TPMN- a target had positive and a mask negative polarity; TNMP – a target had negative and a mask positive polarity; * p<.05; ** p<.01.

Interaction between contrast polarity and mask delay, $F(9,81)=2.1$, $p=.046$ indicates that contrast polarity has an effect on substitution masking. As can be seen from Fig. 3 and the pairwise comparisons from Table 1, a masking effect was the largest in negative contrast polarity target and mask condition across mask delays longer than 0 ms. Beyond 0 ms mask delay statistically significantly higher mean correct percentages occurred in the conditions where a target and a mask had opposite polarities compared to the condition of negative polarity stimuli. Positive polarity stimuli were perceived as opposite polarity stimuli with 100.2 ms mask delay and as negative polarity stimuli with 300.6 ms mask delay.

We also found an interaction between contrast polarity of stimuli and number of distracters $F(9,81)=3.1$, $p=.004$ (Fig. 4). However, when positive polarity dots functioned as a mask of a negative polarity Landolt, weaker masking effect was not seen, contrary to what could be predicted by isolation hypotheses. According to the hypothesis, masking effect should be equally attenuated in both conditions where the target and mask had opposite polarities. This seemed somewhat puzzling because in metacontrast conditions (Becker & Anstis, 2004) the lack of interaction between ON and OFF pathways could be inferred and it did not depend on what was the exact center-surround luminance configuration. Explanation to our results could be that the opposite contrast polarity conditions differed from each other because the contrast of positive and negative stimuli was not equally different from the background (the mask with negative contrast polarity had lower contrast value than the target with positive contrast polarity). Therefore, we conducted an additional experiment where we diminished the saliency of the positive contrast polarity target.

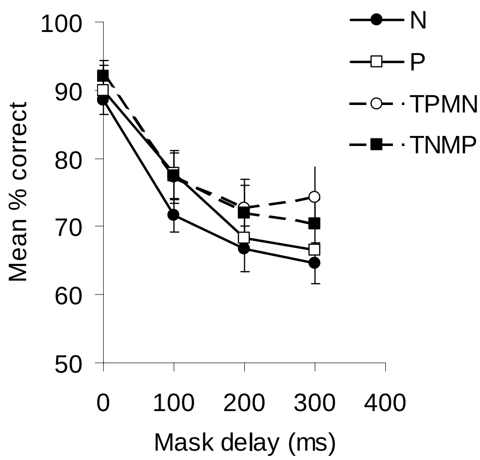

Fig. 3. Mean percentages correct in Experiment 1 (45% luminance background) across mask delays as functions of contrast polarity condition. N – the target and the mask had negative contrast polarity; P- the target and the mask had positive polarity; TPMN- the target had positive and the mask negative polarity; TNMP – the target had negative and the mask positive polarity. The “whiskers” depict standard errors of the means.

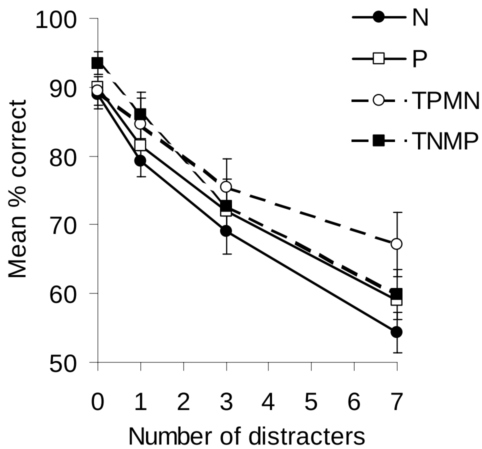

Fig. 4. Mean percentages correct in Experiment 1 (45% luminance background) across number of distracters conditions as functions of contrast polarity condition. N — the target and the mask had negative contrast polarity; P — the target and the mask had positive polarity; TPMN — the target had positive and the mask negative polarity; TNMP — the target had negative and the mask positive polarity. The "whiskers" depict standard errors of the means.

3. Experiment 2

In order to control whether better saliency of a target with positive contrast polarity on 45% luminance background could explain the results of the first experiment we changed luminance background to 65% (88.4 cd/ m²), and therefore the contrast of positive stimuli to c=0.54 (contrast of negative stimuli c=-0.91). Stimuli and procedure were the same as in previous experiment. 10 female students voluntarily chose to participate in the study for additional course credit points.

3.2. Results

Repeated measures within subjects ANOVA of mean percentage of correct responses (4 (contrast polarity: negative, positive, mask negative target positive, mask positive target negative contrast polarity stimuli) * 4 (number of distracters: 0, 1, 3, 7) * 4 (mask delay: 0, 100.2, 200.4, 300.6 ms)) revealed same significant effects as in previous experiment. Mean percentages of correct responses in no distracters conditions were about 10% lower in all conditions where either a target or a mask had positive polarity. This indicates that saliency of the positive polarity stimuli could compensate the contrast polarity effect in the first experiment. Interestingly, means of the negative polarity target and mask condition did not change much in this second experiment although 65% luminance background should have made the negative stimuli more salient.

Interaction between mask offset delay and number of distracters, $F(3,81)= 8.8$, $p<.0001$, confirmed substitution masking effect in all contrast polarity conditions. Main effect of mask delay was $F(3, 27)=49.2$, $p<.0001$, showing gradual decrease in mean percentages correct with increasing mask delays. Main effect of number of distracters was $F(3,27)=104.8$, $p<.0001$, the more distracters on display, the lower mean percentages correct.

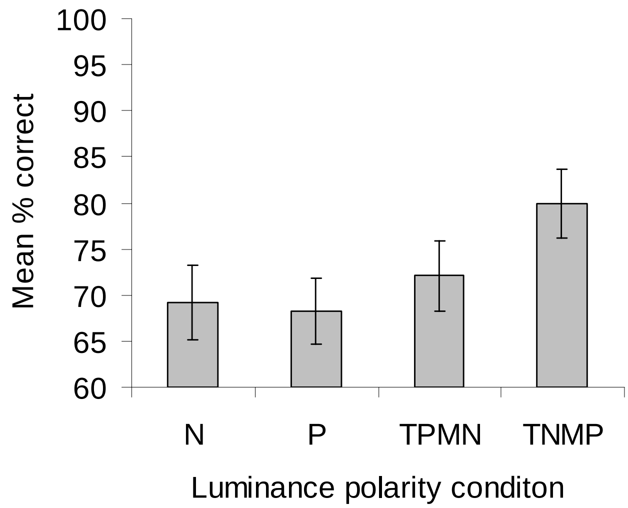

Fig. 5. Mean percentages correct in Experiment 2 (65% luminance background) in four contrast polarity conditions. N – the target and the mask had negative contrast polarity; P - the target and the mask had positive polarity; TPMN - the target had positive and the mask negative polarity; TNMP – the target had negative and the mask positive polarity. The “whiskers” depict standard errors of the means.

The experiment was conducted to find out whether the polarity effect still occurred when the background had higher luminance (a positive luminance target would be less salient). Indeed, the main effect of the stimulus polarity was found again, $F(3,27)=17.1$, $p<.0001$ (Fig. 5). Identification was better when a target and a mask had opposite polarities compared to the conditions where a target and a mask had a same contrast polarity. Least masking occurred in negative polarity target, positive polarity mask condition. Therefore, lighter background decreased the effect of mask to some extent but the effect of decreased masking in positive polarity target, negative polarity mask conditions was also still significant. There was no difference in identification when a target and a mask had the same contrast polarity.

Interaction between mask offset delay and four contrast polarity conditions was F(9,81)=2.7, p=.008 revealing that in opposite polarity target and mask conditions masking was decreased compared to same polarity conditions when mask delay was longer than 100.2 ms. Trials with 0 to 100.2 ms mask delay showed decreased masking only in negative polarity target positive polarity mask condition (Fig. 6).

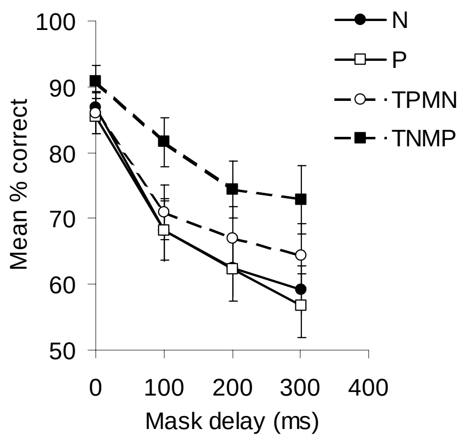

Fig. 6. Mean percentages correct in Experiment 2 (65% luminance background) across mask delays as functions of contrast polarity condition. N – the target and the mask had negative contrast polarity; P - the target and the mask had positive polarity; TPMN - the target had positive and the mask negative polarity; TNMP – the target had negative and the mask positive polarity. The “whiskers” depict standard errors of the means.

Interaction between number of distracters and contrast polarity conditions was F(9,81)=6.5, p<.0001. Fig. 7 and Table 2 revealed that if there were distracters on display then an opposite polarity mask was not as effective as a same polarity mask with more than 1 distracters on display. In the first experiment the mean percentages correct of positive contrast polarity stimuli condition did not differ from the opposite polarity stimuli conditions. Overlapping mean percentages correct for same polarity conditions appeared in this experiment and were significantly lower from opposite contrast polarity conditions. The effect of positive polarity mask on negative polarity target was weak also when there were less than 3 distracters on display. Therefore, luminance processing influence in this experiment comes partly from weakened local interaction of opposite polarity stimuli.

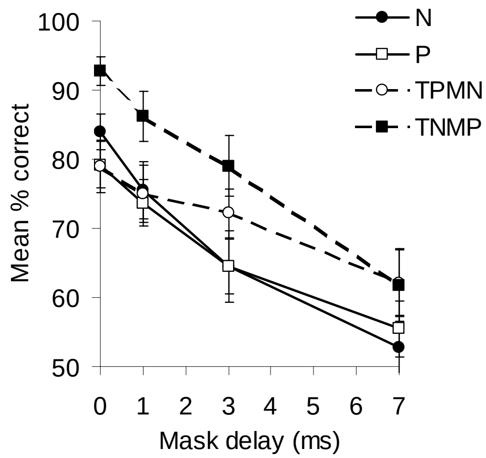

Fig. 7. Mean percentages correct in Experiment 2 (65% luminance background) across number of distracters conditions as functions of contrast polarity condition. N — the target and the mask had negative contrast polarity; P — the target and the mask had positive polarity; TPMN — the target had positive and the mask negative polarity; TNMP — the target had negative and the mask positive polarity. The “whiskers” depict standard errors of the means.

Table 2. Paired samples t-test comparisons of mean percentages correct of all luminance polarity conditions in Experiment 2.

	N vs TPMN t	p value	N vs TNMP t	p value	N vs P t	p value
Main effect of polarity	–2.2	.049*	–5.7	.001**	.4	.675
Mask delay 0 ms	.5	.652	–2.9	.016*	.9	.368
Mask delay 100.2 ms	–1.3	.212	–5.1	.001**	–.3	.746
Mask delay 200.4 ms	–2.2	.054*	–4.7	.001**	–.4	.758
Mask dealy 300.6 ms	–3.5	.007**	–4.8	.001**	1.3	.234
No distracters	2.1	.067	–4.6	.001**	2.3	.041*
1 distracter	.1	.941	–3.1	.014**	.8	.471
3 distracters	–3.8	.004**	–7.1	.001**	–.1	.957
7 distracters	–4.2	.002**	–4.6	.001**	–.5	.629
	P vs TPMN t	**p value**	**P vs TNMP t**	**p value**	**TPMN vs TNMP t**	**p value**
Main effect of polarity	–2.3	.048*	–5.6	.001**	–4.4	.002**
Mask delay 0 ms	–.4	.665	–2.8	.020*	–2.5	.034*
Mask delay 100.2 ms	–.9	.370	–5.5	.001**	–5.8	.001**
Mask delay 200.4 ms	–2.1	.071	–3.6	.006**	–2.4	.041*
Mask dealy 300.6 ms	–2.7	.024*	–5.7	.001**	–2.6	.027*
No distracters	.3	.801	–6.6	.001**	–5.7	.001**
1 distracter	–.5	.605	–5.4	.001**	–3.5	.007**
3 distracters	–3.2	.012**	–5.0	.001**	–3.5	.006**
7 distracters	–2.6	.008**	–2.0	.076	.3	.804

Note: N — a target and a mask had negative contrast polarity; P — a target and a mask had positive polarity; TPMN — a target had positive and a mask negative polarity; TNMP — a target had negative and a mask positive polarity; * p<.05; ** p<.01.

4. General discussion

The aim of the present study was to find out how luminance increments and decrements are processed in substitution masking conditions. Both experiments showed that masking effect was decreased in trials with more than 1 distracter or mask delays longer than 100.2 if opposite contrast polarity conditions were compared with negative polarity conditions. Trials where the target and mask had the same polarity and there were more than 1 distracter, or mask delay longer than 100.2, showed significantly more masking than opposite polarity conditions in the second experiment.

Meta-analyses of the results of the first and second experiment showed that positive polarity stimuli were more salient in the first experiment. This can be seen from decreased mean percentages correct of positive polarity target and mask conditions in the second experiment. Better saliency was probably the reason why positive polarity stimuli conditions gave similar mean percentages of correct identification with opposite polarity conditions in the first experiment. However, the mean percentages of correct identification of negative polarity target and mask conditions were the same in both experiments. This indicates that saliency of negative polarity stimuli was not increased by changing the background luminance to 65%. Therefore, besides the saliency explanation of better detection of the positive polarity stimuli in the first experiment there is another possible way of explanation. It has been shown that ON-pathways are faster than OFF-pathways in mammals (Chichilnisky & Kalmar, 2002; Ueno et al. 2004). In addition, delays in primary visual cortex and in middle temporal (MT) cortex have been shown in processing low-contrast stimuli (Conway et al. 2005). Using high contrast stimuli (Del Viva et al. 2006), when no physical delay is present in the opposite contrast stimulus pair, the visual system introduces a delay of the black relative to the white. Interestingly, in that study lowering the contrast of black dots did not affect the result (illusory motion was perceived) but lowering the contrast of the white dots (as we also did in our second experiment) annulled the illusion. All those findings may explain the difference in results of same polarity conditions with longer than 0 ms mask offset delays in our first experiment. Del Viva et al. (2006) study would explain why decreasing the contrast of positive polarity stimuli decreased masking the most in the target negative, mask positive contrast conditions in our second experiment. No difference in the mean percentage of correct identifications of same polarity stimuli in simultaneous offset conditions in both experiments could be explained by the non-disrupted functioning of the attentional processes.

We found that the target in substitution masking opposite contrast polarity conditions did not completely recover from masking as in Becker & Anstis (2004) metacontrast masking study. Our results are more similar to Breitmeyer (1978) study where metacontrast masking was only slightly reduced in opposite polarity conditions. However, the general decrease in substitution masking when the target and the mask had opposite contrast polarities and mask was delayed more than 100.2 ms favors the view of some isolation of luminance signals in ON and OFF pathways even after reaching visual cortex. It has been shown that at the cortical level those channels interact (Bowen, 1997; 1995) producing results opposite to ours. We believe that the difference in results may be related to using different methodologies. Bowen presented his stimuli one after another; the target and mask in our study were onset simultaneously.

The fact that substitution masking was decreased in conditions with more than 1 distracter directed us to compare these results with polarity and grouping effects in visual search studies. Gilchrist et al. (1997) experimented with a search display of paired dots where distracters where horizontally aligned same or opposite contrast polarity dots and the target searched for was a similar pair of vertically aligned dots. They found that a same polarity target among positive polarity distracters was found faster than a pair of opposite polarity dots among opposite polarity distracters. The authors offered two possible explanations for why search for opposite polarity pair of dots was slower. First, grouping of objects may be based on absolute brightness levels, requiring identical brightness token values representing surface properties of objects (Marr, 1982). Second, grouping between objects may depend on the derivation of low spatial frequency components from the brightness values in the image (e.g. image blurring, Watt & Morgan, 1985). When image-blurring technique proves ineffective (opposite polarity condition), search becomes slow and effortful. Our experiments did not reveal the superiority of a same polarity target and mask “group”. At least in the second experiment it appeared that opposite polarity target and mask were found faster than either positive or negative polarity target-mask object. Therefore, decreased masking in opposite polarity conditions where more than one distracter was displayed supports processing based on brightness values. The task of the subject in our study was to search for a mask-cue and ungroup it from the target efficiently in order to identify a target. This task was easier with opposite luminance polarity stimuli. Perhaps opposite brightness values improve Gestalt grouping based segregation of target and mask.

Similarly, Moore and Llearas (2005) proposed that when the target and the mask are of different colors it should be easier to establish distinct object representations for the two before target offset than when they are of the same color. Therefore, there should be less object substitution masking in the different colors-separated condition than in the not-separated condition. In their study the decrease of masking in different colors-separated conditions occurred when mask was delayed, number of distracters was kept constant (8 distracters). This logic could apply to our results too since opposite polarity conditions look like different colors condition (black and white stimuli on a gray background).

In conclusion we can say that lower level features such as luminance or color may have effect on substitution masking also after 80 ms from stimulus onset and shorten time to contact with the target. When those lower level features enable faster formation of distinct object representation, it could decrease the relative role of attention in object substitution masking.

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2006–2006	Research Fellow and Lecturer, Institute of Law, Faculty of Law, University of Tartu
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- cognitive experimental psychology
- visual masking
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2003–2007	doktoriõpe, psühholoogia osakond, Tartu Ülikool

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2005–2005	Psühholoogia osakonnas õppeülesande täitja, Sotsiaalteaduskond, Tartu Ülikool
2006–2006	Kognitiiv- ja õiguspsühholoogia õppetool; psühholoogia erakorraline teadur ja õppeülesande täitja, Õigusinstituut, Õigusteaduskond, Tartu Ülikool
Alates 2006	Kriminaalõiguse õppetooli psühholoogia erakorraline teadur; Avaliku õiguse instituut, Õigusteaduskond, Tartu Ülikool

Teadustegevus

Teadustöö põhisuunad:
- nägemistaju
- kognitiivne eksperimentaalpsühholoogia
- visuaalne maskeerimine
- visuaalne tähelepanu
- objektitaju

Kuulumine erialastesse organisatsioonidesse:
- Eesti Psühholoogide Liit

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